# BUSINESS NETWORK TOPOLOGY AND RIGIDITIES IN PRODUCTION

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## ABSTRACT

An agent-based model is built with the aim of explaining the effect that organizational architecture has on the performance (network size and stability) of a business group. An artificial network is grown where each node (firm) is subject to random income shocks while the degree of flexibility of the productive system (labor marker rigidity and technology's capita-labor ratio) is assumed exogenously. Two variants of network topology are considered: (i) decentralized management where each node makes local decisions and behaves opportunistically with a positive probability when a troubled partner needs to be rescued, and (ii) centralized management where financial transfers from other firm are made with certainty as long as it has available funds, although, the functioning of this topology entails some monitoring cost.

**Keywords**: Business groups, network topology, economic volatility, labor rigidities

## INTRODUCTION

This paper attempts to understand why business networks may transform their topology or organizational architecture when the productive systems becomes less flexible, either because there is an increase in the rigidity of the labor market or because the participation of the firm's fixed costs increases due to an industrialization process based on capital-intensive production. The hypothesis to be theoretically validated here with an agent-based model (ABM) asserts that these rigidities make more cumbersome the operation of a decentralized network where decision-making is entirely local and, thus, entrepreneurs have the incentive to transform the network adopting a centralized architecture.

Decentralization is less problematic in an environment with minor rigidities since a firm (node) can respond by itself to a negative shock in demand by adjusting its variable costs which are a relatively large component of the cost structure. The adjustment in variable costs is mandatory when the financial system exhibits deficiencies that inhibit cash flow smoothness through credit borrowing. On the contrary, a centralized network fosters the use of financial transfers among firms facing uncertain shocks when cost rigidities preclude a solution to the cash flow problem at the level of individual nodes. In spite of the higher monitoring costs, the centralization of a network is advantageous in this economic setting since it can overcome to a large extent the opportunistic behavior that go with decentralization. These costs are paid to keep a stringent control in the allocation of the subsidiaries' cash flow surpluses and in the nodes' management.

The ABM presented in this paper is built having in mind some features of the Mexican experience in the XIX and XX centuries (Castañeda and Chavarín 2007), and the artificial facts generated with it are contrasted with such experience. However, it can be argued that the model is also adequate to explain the transformation of managerial practices and business alliances in any other country that undertook an industrialization process characterized by a steady increase in the rigidity of the productive system and the prevalence of institutional drawbacks that hampered the functioning of financial markets (Leff 1978, Weinstein and Yafeh 1995, Kali 2003, Khanna and Yafeh 2005, Feenstra, Hamilton and Lim 2002).

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## AN AGENT-BASED MODEL

When 'growing' a business network in the sense of Epstein (2006) it is possible to observe tick by tick how rapid the spin-offs expand and how the network responds to increased labor rigidities and higher volatility. In other words, the ABM allows the observer to discover the performance of a business network that changes from a decentralized status to a centralized one after the fixed costs have increased in the economy. Moreover, the simulation of the model with variations in critical parameters make possible to establish precise conditions that are required to validate the hypothesis theoretically.

### Methodology

Artificial business groups are grown assuming two different network topologies: (i) a decentralized management where each node can fail to meet its commitment to transfer resources to firms facing financial difficulties, and (ii) a centralized management where an implicit holding structure precludes opportunistic behavior by network members. The performance or macroscopic pattern can be measured in terms of the mean network size, its standard deviation and the time span for the network to collapse.

The model is very simple to avoid excessive parameters that can confuse the understanding on how the aggregate outcomes emerge; therefore, the heuristic rule for surplus nodes in the decentralized network is to rescue troubled firms with a probability $p < 1$ (where $1-p$ is the probability of opportunistic behavior); likewise, the remaining cash flow is used to form a new spin-off that is connected to its parent firm, irrespectively of the amount earned in the previous tick. On the contrary, for centralized management there are monitoring costs that reduce earnings in each of the nodes, and the probability of being opportunistic is equal to zero since surplus firms are required by corporate offices to rescue member firms with a deficit, yet the new spin-offs are also attached to their parent firms.

*Income Shocks Due to Changes in Firms' Demands*

Starting with a central point in the grid of a torus, in each tick income fluctuates for the existing nodes according to a uniform distribution U[a, b]. Since fixed costs (k) are such that $a < k < b$ it is likely that a firm can experience a liquidity problem through its life span, when the opposite happens the node creates a spin-off that becomes a member of the network. Nodes can be differentiated in terms of income volatility; for instance, those firms whose lower-bound income is zero have a higher probability of facing financial difficulties than those nodes where $a > 0$.

*Market Congestion and Diseconomies of Scale*

Firms' earnings are reduced because of market congestion, that is, with more network members the market has to be split and this precludes the network to grow without bound. Since competition between different networks is not implemented in the model, market congestion can be interpreted as the cannibalization of the clients between subsidiaries, branches or franchises that belong to the same business group. This constrain of network size can also be interpreted as diseconomies of scale that appear in large conglomerates. In the case of a centralized topology, firms' earnings in each tick are also reduced through a monitoring cost that is proportional to firm's income ($0 < m < 1$); presumably, more economic activity in a subsidiary requires more stringent controls by corporate headquarters.

*Financial Rescuing of Troubled Firms*

The procedure for the rescue operation is as follows: (a) with decentralized management the troubled firm can ask for support to autonomous surplus firms, each of them provide it with probability $p < 1$, thus if there are three surplus firms the probability of not getting any financial support is given by (1-p)(1-p)(1-p) since each node acts locally; (b) with centralized management surplus firms with enough funds have a mandate to help deficit firms that ask for it and hence $p = 1$. Three types of matching between surplus and deficit firms are considered in the model: power-matching, random-matching and accumulated matching. With power-matching the troubled nodes with more ties coming out are rescued first, and surplus nodes with more ties coming out are asked last. This heuristic rule implies that powerful firms (those with more spin-offs) influence network's decisions on who is initially rescued and whose funds are used. However, with random-matching deficit and surplus firms are sorted randomly and, thus, the order of the rescue operation does not depend on any specific feature of the firms or hierarchical consideration.

Because these two types of matching are applied in the centralized and decentralized architectures, the only differences between these topologies have to do with the value of p and whether monitoring costs are relevant or not. In contrast, accumulated-matching is only used by networks with centralized management. Under this heuristic all funds of surplus firms are accumulated in the network's treasury and then used to rescue deficit firms sorted hierarchically, so that firms with more ties coming out are rescued first; therefore, when a centralized architecture adopts an accumulated-matching procedure its performance is compared with a decentralized topology with power-matching. Furthermore, the remaining funds after the rescue operation are used by the contributing firms to create spin-offs regardless of architecture and matching procedure.

*Endogeneity of Opportunistic Behavior*

In the case of decentralized management the probability of opportunistic behavior is endogenized. Since in each tick there can be a fracture in the network when a node vanishes due to liquidity problems and partners that are not capable or willing to provide financing, the out-coming nodes split from the rest of the group and give birth to different sub-networks. Therefore, the value of 1-p increases with the number of sub-networks to reflect the fact that under this new structure opportunistic behavior is more predominant. This artifact can be interpreted as increased fissures in the business group that make reciprocal funding less likely, the denial of funding can be understood as a decomposition in the social fabric of entrepreneurs involved in a decentralized network.

## The Model's Pseudo-Code

A better understanding of the algorithm can be grasped by means of the diagrammatic pseudo-code presented in Figure 1. Notice that the exogenous parameters and procedures (identified with ovals and dashed arrows) that can be modified by the observer are the following: maximum income and degree of volatility that affect the nature of the random shocks; fixed costs and the selection of network topology that influence net earnings in each firm as a consequence of the socioeconomic environment and by making monitoring costs relevant, respectively; this latter selection, the possibility of making endogenous the probability of opportunistic behavior in decentralized networks and the sorting criteria for matching resources affect the rescue operation. The effect of market congestion is another exogenous parameter that is pre-specified in the program yet it is not relevant for the inferences of the model under a wide range of values.

Once the limits of the uniform distribution are specified by the observer, income shocks are seeded randomly in new and old nodes in each tick and, then, the proliferation of nodes determine the level of market congestion and net earnings for each firm. After the production process takes place with the given fixed costs and sales are defined in terms of market congestion, the financial situation of each firm is analyzed. Afterwards, resource matching takes place in terms of the sorting criteria defined by the observer, and in terms of the probability of opportunistic behavior.

Nodes that are rescued stay alive in the network while troubled ones that do not receive support die; under the latter scenario the probability of opportunism increases as a function of the number of sub-networks that the dying nodes generate. Firms with available cash flow net of financial transfers create new spin-offs that depart from the parent node and a new iteration in the program ensues. Finally, when the financial fragility of the nodes is generalized the network collapses and the program stops.

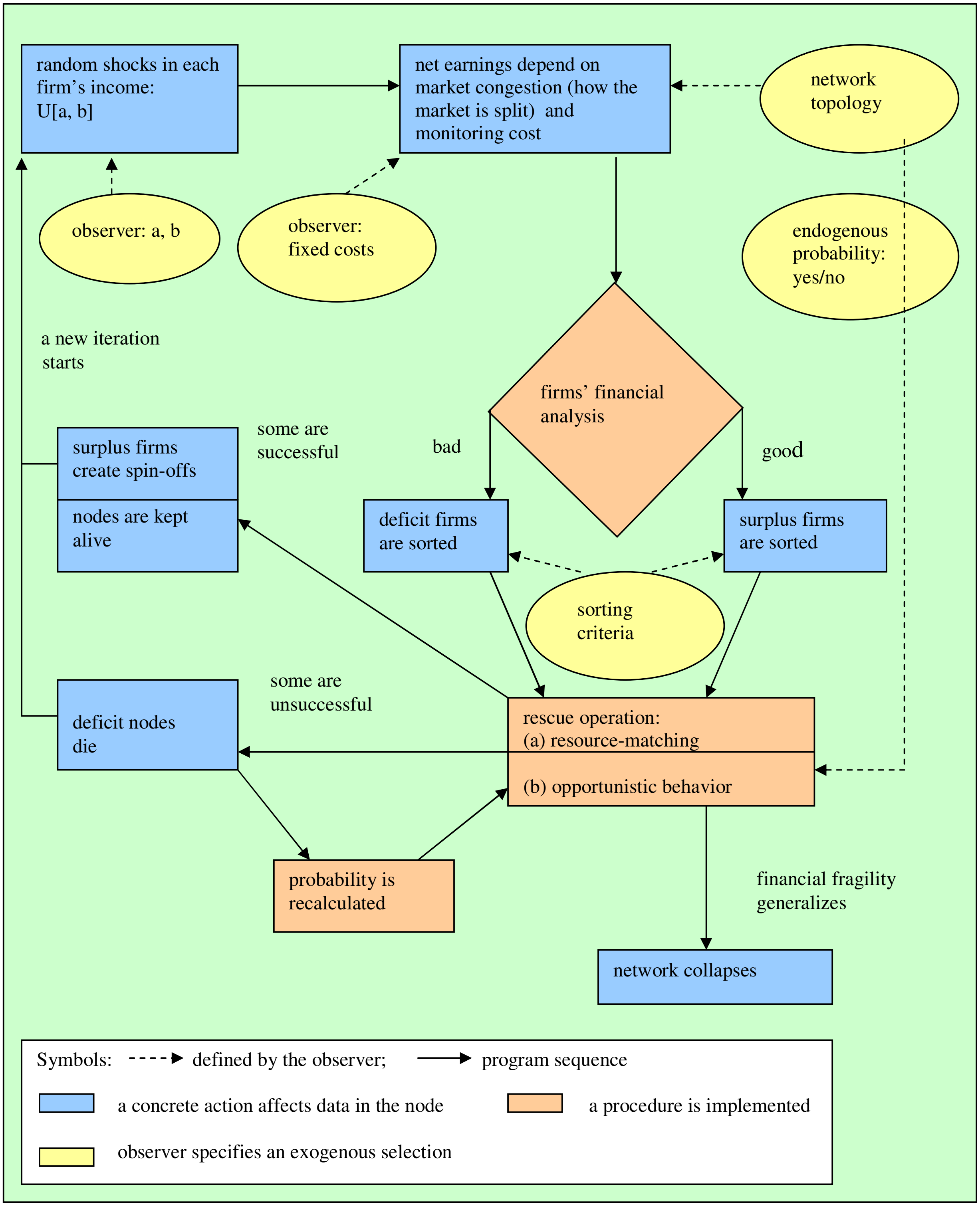


**Figure 1** Diagrammatic Pseudo-code

## SOME SIMULATIONS

### The Main Hypothesis and Variations in Monitoring Costs

This hypothesis asserts that a centralized architecture has a better performance in a post-revolutionary setting (high fixed cost and high income variability) than the decentralized variant, while the opposite holds in a pre-revolutionary environment.[1] Accordingly, for this hypothesis to be theoretically valid the two statements have to be met simultaneously for a range of the monitoring costs in the centralized topology. Figures 2 and 3 present the mean network size, estimated with ten runs, and its confidence intervals for the pre-revolutionary and post-revolutionary settings, respectively. For the point estimates of mean values the decentralized topology performs better in the pre-revolutionary period in the range [0.08, 0.25] while the centralized one has a better performance in the post-revolutionary period in the range [0.05, 0.2]; that is, taken these two intervals jointly it can be argued that the hypothesis holds for the intersection [0.08, 0.2]. Although, the range is shortened to [0.1, 0.15] when considering non-overlapped intervals with 95% of confidence.

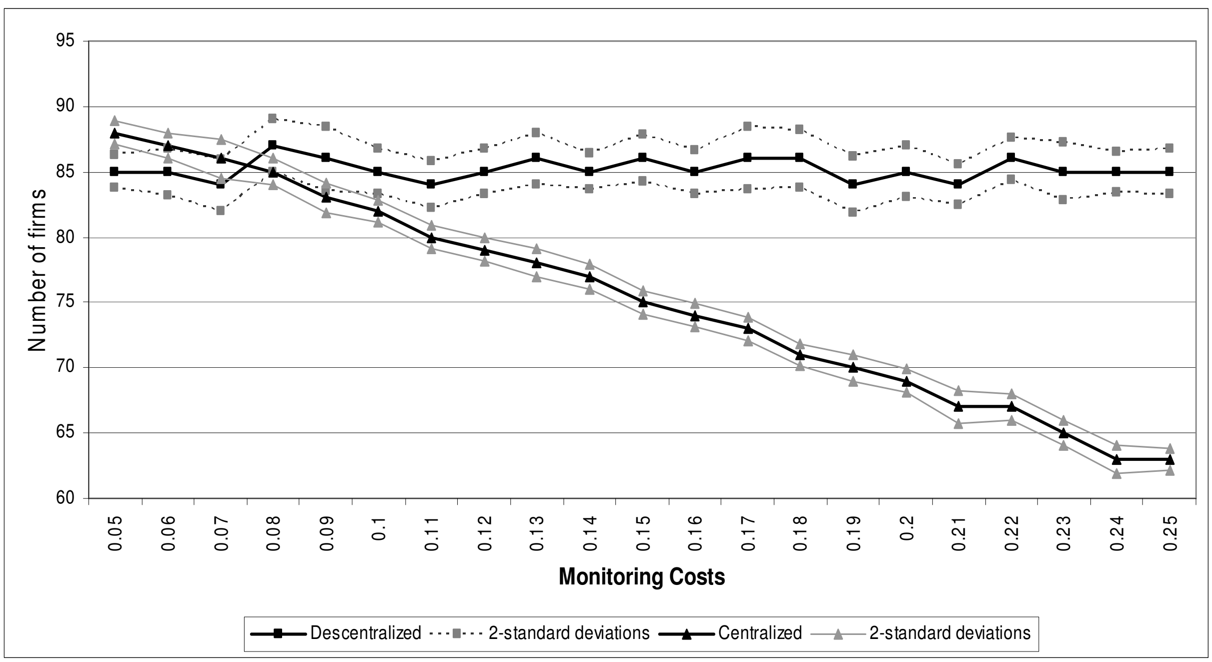


**Figure 2** Mean network size for the two topologies in a pre-revolutionary context

Notes: (a) Each simulation is produced with three stages of 50 ticks each. The aim of the first stage is to let the network grow until it stabilizes due to market congestion. The first two stages are run with a decentralized topology and the third stage with a centralized topology, which is the historical sequence of events. (b) A partial mean size for each topology is calculated using the arithmetic means of the last 10 ticks of stages two and three for the series of moving averages with 30 values of the number of firms; then, the final mean size is obtained averaging the partial means of ten repetitions. (c) The intervals of confidence for the average number of firms are calculated with the mean plus-minus two standard deviations. (d) A pre-revolutionary setting is characterized by the following parameters: low fixed costs (k = 3), low volatility (a = 3, i.e. ratio-of-volatility = 1 in the *NetLogo* interface). (e) For the rescue operation firms were sorted using power-matching. (f) The probability of opportunistic behavior is endogenous and starting at 1-p=0.7.

In terms of the second indicator of performance (stability), results not shown in the paper indicate that the coefficients of variation of network size are higher with the decentralized topology

[1] The pre-revolutionary and post-revolutionary terms are chosen in reference to stylized fact of the Mexican history.

in both environments, irrespectively of monitoring costs; nonetheless, the gap between this indicator for the two topologies is much smaller in the pre-revolutionary setting (e.g. approximately 3 times lower). Therefore, in a pre-revolutionary environment network size seems to be a more important issue given the fact that the economy is less volatile and, hence, when this condition changes in the post-revolutionary environment a centralized architecture offers a better performance in terms of both indicators.

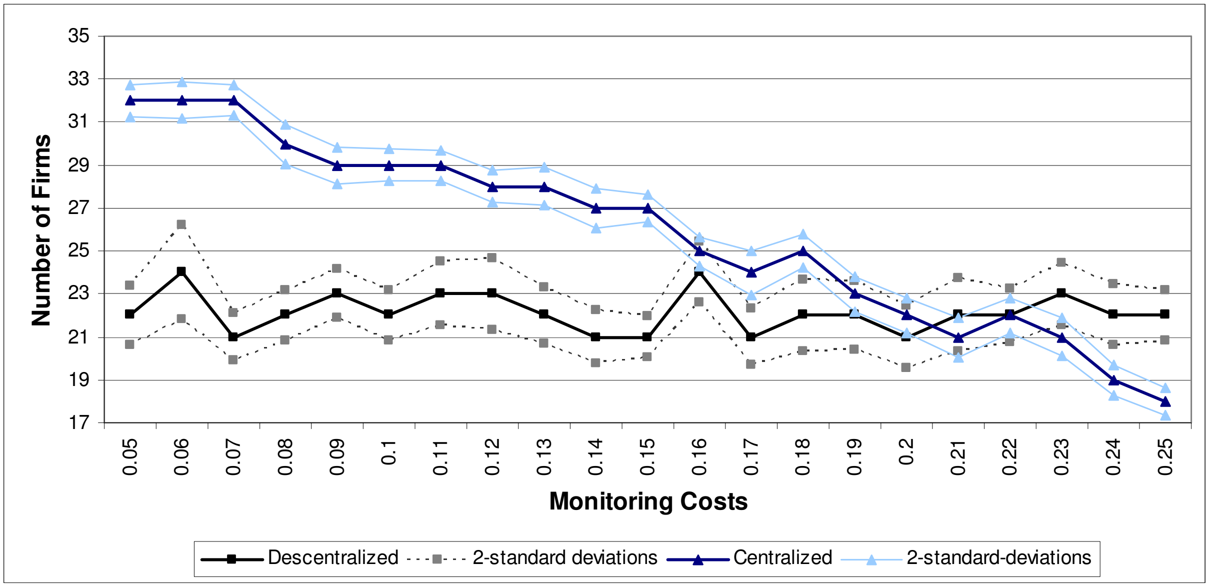


**Figure 3** Mean network size for the two topologies in a post-revolutionary context

Notes: (a) A post-revolutionary setting is characterized by the following parameters: high fixed costs (k = 5), high volatility (a = 0, i.e. ratio-of-volatility = 0 in the *NetLogo* interface).

**Stability of the Network and Counterfactual Exercise**

In the following analysis the stability of each topology is tested in a volatile environment (a = 0) with high rigidities in the productive system (k = 6). The simulations are generated for a value of monitoring costs in the centralized topology which is within the range that validates the hypothesis (m = 0.13), and for an endogenous probability of opportunistic behavior starting at (1-p) = 0.7 in the case of a decentralized variant. An upper limit of 500 is set for the number of ticks and 25 simulations are run for each topology, 11 of them reach this limit when networks are organized with the centralized architecture and none with the decentralized topology. Likewise, the median number of ticks until the network collapses is 239 for the centralized topology and 55 for the decentralized one. The minimum and maximum ticks for these topologies are [13, 202] in the decentralized case and [16, 500] in the centralized case. Accordingly, these results indicate that the centralized architecture becomes critical for the survival of the network in a post-revolutionary environment characterized by important rigidities in the labor market and capital intensive production.

Next, history is re-played by growing a network in a socioeconomic environment that moves from the pre-revolutionary to the post-revolutionary setting in five stages described by the following parameter values [(a=3, k=3), (a=3, k=4), (a=3, k=5), (a=0, k=5) and (a=0, k=5)], each of them lasting 50 ticks. In the first four stages the decentralized architecture operates (with endogenous probability and 1-p=0.7) and, thus, 20 repetitions produce an average network size of

86, 53, 34 and 23,[2] while in the fifth stage the firms transform to a centralized system (with m=0.13) as the stylized facts of history indicate for a an average network size of 27. In contrast, the average size remains in 23 firms when in the fifth stage a counter-factual exercise is simulated with firms sticking to the decentralized topology; therefore, the adoption of a centralized architecture has economic sense in a volatile and rigid environment.

**Phase Transition in the Opportunistic Behavior Space**

The probability of opportunistic behavior in the decentralized topology (1-p) is modified within the range [0.5, 0.9] to calculate the average number of firms in the pre-revolutionary setting (k=3, a=3). Figure 4 describes the mean network size and its interval of 95% confidence calculated with 10 repetitions for each starting probability value. There is an initial plateau of the average number of firms for the starting values of 0.5 and 0.6, but network sizes drops sharply for a probability of 0.7 and, then, another plateau at a lower level is established for the values of 0.8 and 0.9.

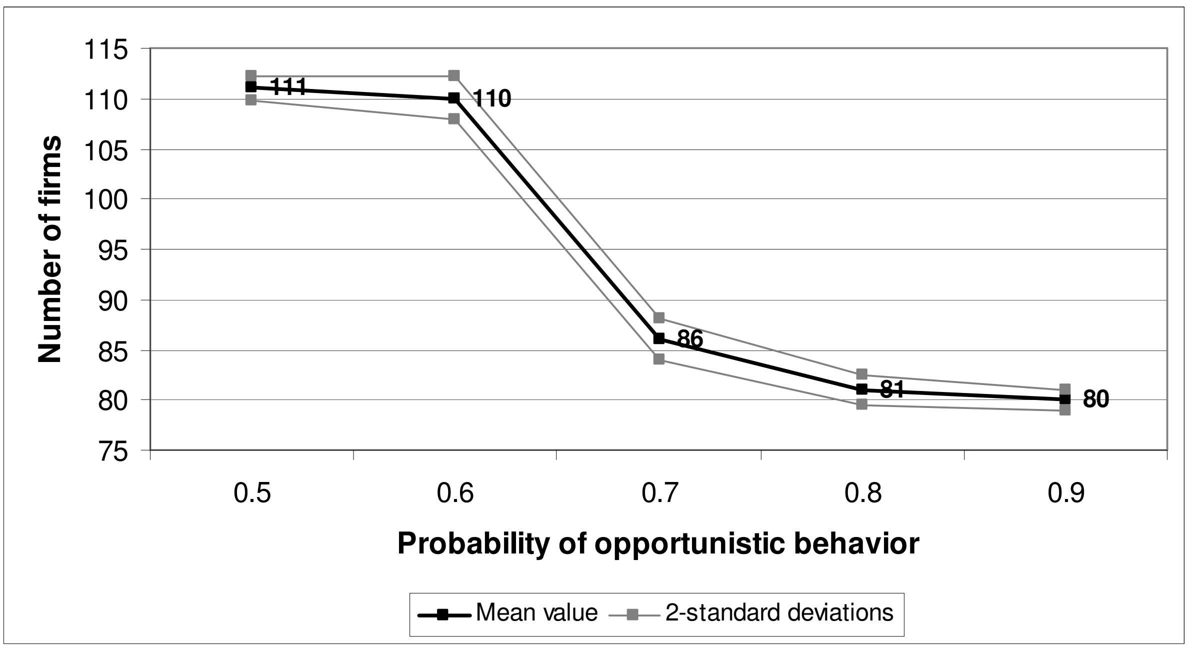


**Figure 4** Mean network size for different opportunistic behaviors in a pre-revolutionary setting
Notes: (a) Arithmetic averages are calculated with the last 10 ticks of stages with 50 ticks. (b) The first stage in the simulations considers (1-p) = 0.5, and this probability is increased one decimal points in each of the subsequent four stages. (c) Ten simulations are run and, hence, mean network size for each parameter value is calculated with the mean of the arithmetic average estimated in each stage of the simulation. (d) In the pre-revolutionary setting: k = 3, a = 3.

There is a phase transition when the opportunistic conduct in the rescue operation starts at 0.7 since the emerging patterns in the dynamic system change drastically when crossing this threshold. The modification in the outcome of the model at this critical value is observed by running 10 more simulations in the post-revolutionary environment (a=0, k=5) for each of the two topologies. While for (1-p)=0.6 the average number of firms is 32 for the decentralized topology, this number is 29 for the centralized variant with monitoring cost of 0.13; means that are statistically different. This is the inverse result to the outcome obtained for (1-p) = 0.7 where the corresponding average sizes are 22

[2] First a partial mean size is calculated using the arithmetic mean of the last 10 ticks of the stage for the series of moving averages with 30 values of the number of firms; then, the final mean size is obtained averaging the partial mean size of the different repetitions.

and 28 (also statistically different), respectively. Accordingly, the hypothesis stated in this paper is theoretically validated only when the probability of opportunistic behavior in a decentralized architecture is relatively high, that is, for starting values of 0.7 or more.

**Different Types of Matching in the Rescue Operation**

Now the robustness of the hypothesis is checked with regard to the type of matching used to rescue troubled firms. Two more alternatives are considered: (i) random-matching where surplus firms rescue deficit firms sorted randomly, and (ii) accumulated-matching where all surplus funds are accumulated in the network's treasury and deficit firms are rescued in terms of their hierarchy (number of ties coming out) until there are no more resources available. In terms of network size the results obtained for power and random matching are practically identical for an scenario with m=0.13 and starting (1-p)=0.7 (see rows 3-6, Table 1). Again network stability is always better with the centralized topology and especially in the post-revolutionary context (see rows 9-12, Table 1).

Furthermore, with accumulated-matching the simulation results validate the hypothesis fairly well for both indicators of performance, network size and stability, in a scenario with m=0.13 and initial (1-p)=0.7. While in the pre-revolutionary environment the decentralized topology outperforms the centralized one with regard to stability (see rows 7 and 8, Table 1), in the post-revolutionary setting the centralized architecture is more stable and also generates larger networks. Notice, however, that the number of firms is statistically identical for both topologies in the pre-revolutionary setting (see rows 1 and 2, Table 1). Statistical results not presented here indicate that using accumulated-matching the hypothesis holds in the intersection interval [0.11, 0.23] for both criteria (network size and stability).

**Table1** Network performance (size and stability) for different types of matching

| | | | **Pre-revolutionary** | **Pre-revolutionary** | **Post-revolutionary** | **Post-revolutionary** |
|---|---|---|---|---|---|---|
| | Type of matching | Type of topology | Average number of firms | Interval of 95% confidence | Average number of firms | Interval of 95% confidence |
| **1** | **accumulated** | Decentralized | 85 | (87.23, 82.77) | 23 | (24.36, 21.64) |
| **2** | | Centralized | 86 | (88.13, 83.87) | 32 | (33.00, 31.00) |
| **3** | **power** | Decentralized | 86 | (87.94, 84.06) | 22 | (23.32, 20.68) |
| **4** | | Centralized | 78 | (79.08, 76.92) | 28 | (28.88, 27.12) |
| **5** | **random** | Decentralized | 86 | (87.55, 84.45) | 23 | (24.30, 21.70) |
| **6** | | Centralized | 78 | (78.78, 77.22) | 28 | (28.49, 27.51) |
| | | | | | | |
| | | | Coefficients of variation | Standard deviation | Coefficient of variation | Standard deviation |
| **7** | **accumulated** | Decentralized | 0.17 | 0.008 | 0.33 | 0.022 |
| **8** | | Centralized | 0.37 | 0.012 | 0.26 | 0.013 |
| **9** | **power** | Decentralized | 0.16 | 0.009 | 0.34 | 0.023 |
| **10** | | Centralized | 0.12 | 0.004 | 0.18 | 0.008 |
| **11** | **random** | Decentralized | 0.17 | 0.006 | 0.34 | 0.018 |
| **12** | | Centralized | 0.11 | 0.004 | 0.19 | 0.010 |

Notes: (a) The coefficient of variation is measured as the ratio of the standard deviation to the mean. A partial estimation is calculated with an arithmetic mean of the coefficients of variation for the last 10 ticks in the corresponding stage using moving means and moving standard deviations of the last 30 numbers of firms, then, a final estimation is calculated with the average of the partial estimations for 10 repetitions. (b) The probability of opportunistic behavior is endogenous and starting at 1-p=0.7. (c) Monitoring cost in the centralized topology is such that m = 0.13.

## CONCLUSIONS

This paper shows that once labor market became very rigid and the industrialization took place in Mexico during the 30's-60's of the XX century there were valid reasons to establish a centralized topology. The high fixed cost and the volatile economic environment made the monitoring costs prevailing in this topology less relevant and, thus, entrepreneurs designed a mechanism to solve automatically the liquidity problems experienced by each node of the network. This situation contrasted with the stylized facts of the 1870-1910 period, where the labor market was flexible and fixed cost relatively small. Under this socioeconomic setting prevailed a decentralized topology where each firm decided independently whether to rescue or not the troubled firms in the group. These facts are consistent with the Monte Carlo simulations produced with an ABM of network formation, at least for some range of monitoring costs and opportunistic behavior.

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