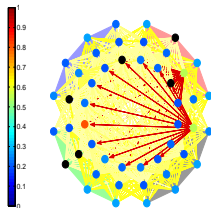


# Effects of Globalization in a Model of Production Networks

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Potential for Complexity Science for Business, Governments and  
Media

Budapest August 5, 2006

# Research Program at SG lab

- Financial Networks
- Foreign Direct Investments Networks
- Supply/Credit Network
- Trust-Based Network and Recommendation Systems
- Self-Organized Robustness in Networks

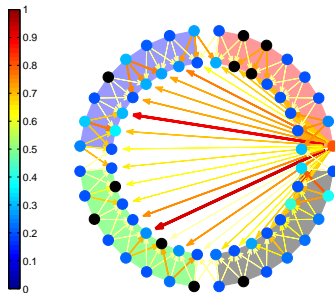
# Outline

- Motivations
- Description of the model
- Results
- Conclusions

# The Benefit of Intertwined Economies

- Since early 900' economies have become more and more intertwined, [Krugman, 2003]
  - ▶ Import-Export of goods
  - ▶ Investments in foreign financial markets
  - ▶ Foreign Direct Investments
- Models of International Economics show that exchange is (almost always) beneficial, [Ricardo], [Samuelson-Jones], [Heckscher-Ohlin]:
  - ▶ Comparative advantage
  - ▶ Economies of scale

## └ Motivations



# The Problems with Intertwined Economies

- Contagion
  - ▶ International Economics: propagation of financial distress via macroeconomic variables (no direct interaction)
- Interdependency, negative feedback loops, intermittency
  - ▶ Systems Theory
- Governments do not follow the prescriptions of International Economics, [Krugman]
- Pro and contra [“Globalisation and its Discontents”, Stiglitz]

# Globalization: Absorbing Shocks or Creating Instabilities?

- What is the impact of globalization on aggregate growth, stability, inequality?
- Is there an optimal level of globalization?

More modestly:

- In terms of bankruptcy propagation, long range connections may have a twofold role:
  - ▶ Attenuate local damage (light shocks can be partially absorbed by other regions)
  - ▶ Spread damage in faraway regions (hence amplifying severe shocks)
- Is there an optimal level of long range connections?

## Networked Economy vs Main Stream Paradigm

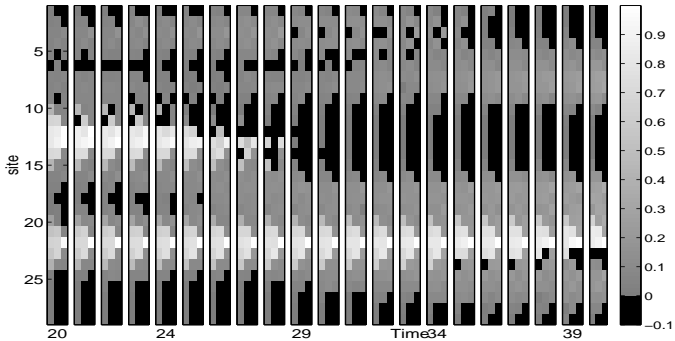
- Paradigm of mainstream economic theory (Arrow-Debreu general equilibrium): individuals make decisions in isolation, using information contained in price.
- Imperfect information and incomplete markets: interaction in space and time cannot be neglected.
- Network of credit among firms and between firms and banks (Stiglitz and Greenwald, 2003).
- Exploring the features of a networked economy in which firms interact directly:
  - ▶ The outputs of some firms are inputs for some other firms and
  - ▶ Some firms extend trade credit to some other firms.

## Starting points and goals

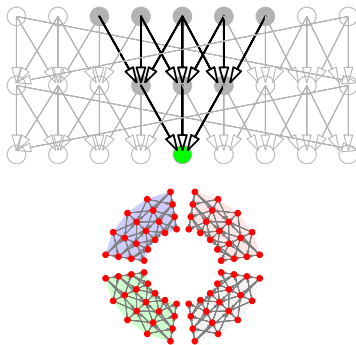
- Extending to multiple networks the framework of the models introduced in
  - ▶ “Credit Chains and Bankruptcy Propagation in Production Networks”... [Battiston, Delli Gatti, Gallegati, Greenwald, Stiglitz, 2006] ( $BDG^3S$ ) under revision for JEDC
  - ▶ “From Production Networks to Regional Economics”, [Weisbuch, Battiston, 2006] ( $WB$ ) under revision for JEBO
- Inspirations:
  - ▶ SOC in production lattice by [Bak et al. 1993]
  - ▶ The CATS model Gallegati, Delli Gatti etc. [ $B^2G^3P$ , 2005]
  - ▶ General Equilibrium Theory of Credit [Stiglitz and Greenwald 2003]

## Previous Results

- Main features
  - ▶ firm-firm interaction
  - ▶ direct propagation of bankruptcy
- Main Results
  - ▶ stylized facts
  - ▶ aggregate output fluctuations
  - ▶ spatio-temporal correlation
  - ▶ local interaction can induce domino effects (in absence of global couplings)
  - ▶ domino effects are amplified by global couplings

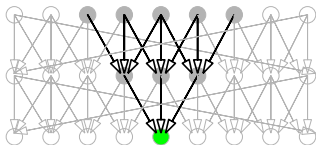


# Outline of the Model



- $N_E$  economies,  $N$  firms,  $M$  production layers
- Firm  $i$  in a layer  $k_i$  is supplied by some firms in layer  $K - 1$
- Firm  $i$  supplies some firms in layer  $K + 1$ .
- Firms are connected to each other through input and payment
- Linear technology

# Timing



At each time step, in each economy, at each layer:

- Determine **desired output**  $Y^{(d,K)}$  and send orders
- Determine **expected output**  $Y^{(e,K)}$  at each layer
- Produce **output**  $Y^{(K)}$  and supply firms in lower layer. No inventory.
- Pay firms in upper layer ( $\sim Y^{(s,K)}$ ).
- **Spontaneous production failures** with small prob.  $q$ .
- Firm go bankrupt if loss is too large. Replaced after  $\tau$  steps.

# Responsiveness of Firms and Strategy for Order Allocation

- In case of spontaneous production failure of supplier  $j$ , firm  $i$ , is not be able to adjust resources (labour and premises) within one period.
- Firm  $i$  places orders proportionally to the production capacity of the suppliers  $l$ :

$$O_{li}^{(K, K+1)}(t) = \frac{A_i(t)}{\sum_{l \in V_i^S} A_l(t)} \quad (1)$$

where  $|V_j^S|$  is the cardinality of the set of suppliers  $l$  of firm  $j$

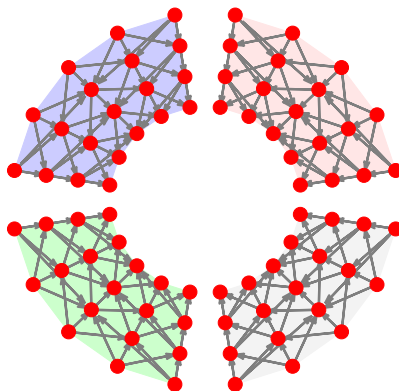
# Scenarios

## Cross-Country Supply Relationships

- Autarchy
- Strong Protectionism
- Protectionism
- Internationalism
- Globalization

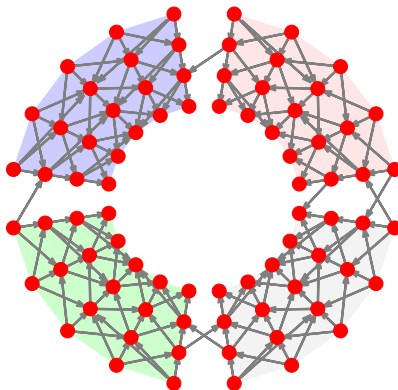
# Autarchy

- No cross-country connections



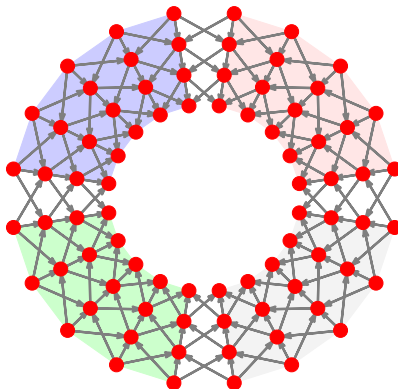
# Strong Protectionism

- Few cross-country connections



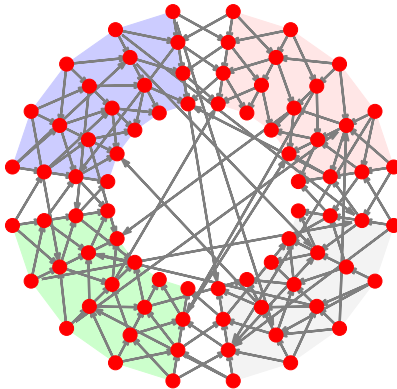
# Protectionism

- Homogeneous local connections



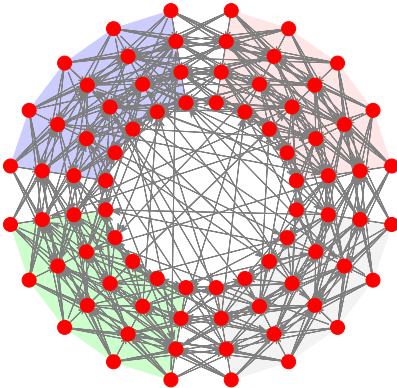
# Internationalism

- Random connections, small degree



# Globalization

- Random connections, high degree



## Analytical Results

- Condition for average positive growth:

$$g_i^{(K)}(t) = \frac{A_i(t+1)^{(K)} - A_i(t)^{(K)}}{A_i(t)^{(K)}} > 0 \rightarrow \rho > c_s + \frac{c_r}{(1-q)}$$

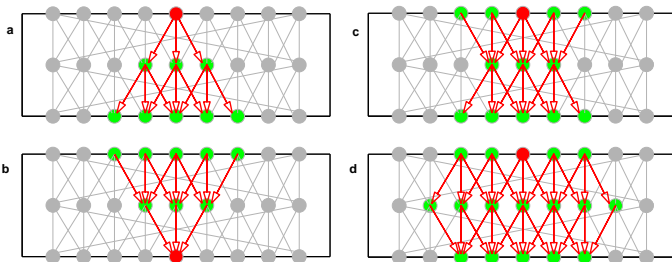
- Condition for bankruptcy:

$$\mathcal{P}_i^B = \int_{1-\delta}^{u_i^*(t)} \mu(u) du \quad (2)$$

$$u_i^*(t) \simeq \frac{-\beta A_i(t) + C_i(t)}{Y_i^s(t)} \simeq \frac{(c_r - \beta/\theta) Y_i^e(t) + c_s Y_i(t)}{Y_i^s(t)}$$

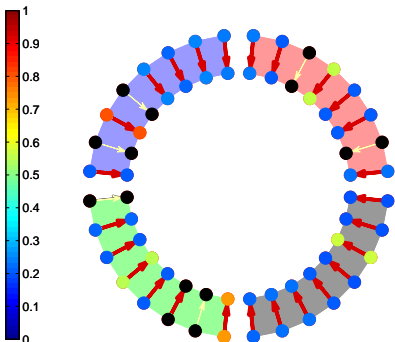
# Avalanches

Bankruptcies can propagate **downward** OR/**AND** **upward** (in the direction of production or/and opposite to it)

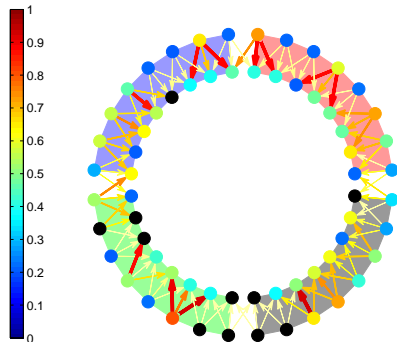


If failures can propagate only downward/upward, they stop at bottom/top layer.

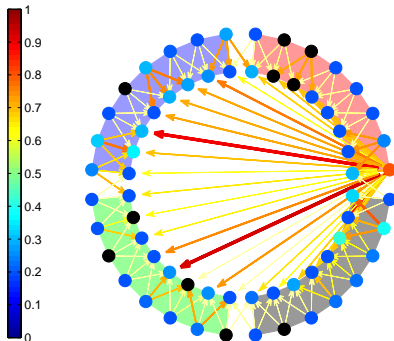
$$k_{out} = 1, E(L) \sim 2Mq$$



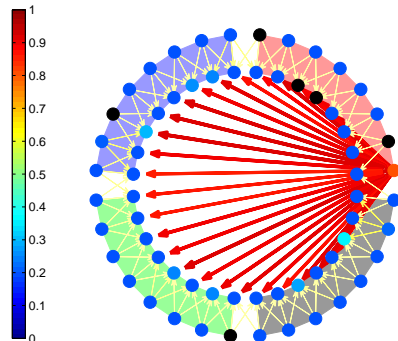
$$k_{out} = 3, E(L) \sim M(q + q^2)$$



$$k_{out} = 3 + \text{hub}$$

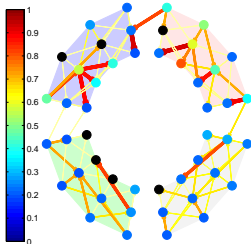


$$k_{out} = 3 + \text{hub}, E(L) \sim 2Mq$$



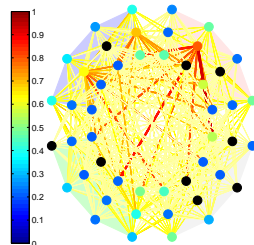
# Output Patterns

## Strong Protectionism



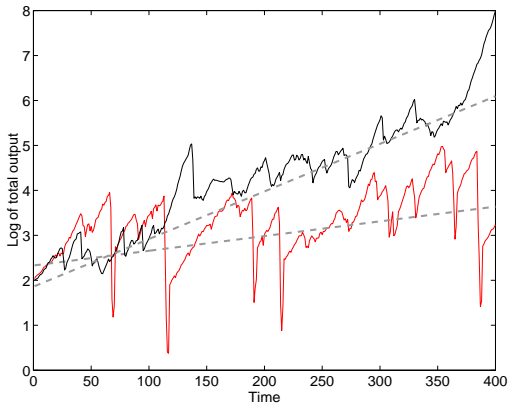
video

## Full Globalization



video

## Aggregate Output



- Exponential growth over time + fluctuations in all cases
- Growth is enhanced by long range connections for small conn. degree.
- Instability is enhanced by long range connections for high conn. degree.

# Overview

- The role of long range connections:
  - ▶ at small degree  $k_i^{out}$  absorb and increase stability
  - ▶ at high degree  $k_i^{out}$  distribute distress and decrease stability

## Conclusions

- We have applied the framework of  $BDG^3S$  to investigate role of long range connections in a set of several production networks.
- The aim is to gain some insight on the role of non-local links in the propagation of financial distress in connected economies.
- We have explored some basic scenarios: from “autarchy” to “full globalization”.
- We can characterize the output of the global economy with respect to patterns, trend, stability and distribution.
- We found that random long range connections
  - ▶ at small degree  $k_i^{out}$  absorb and increase stability
  - ▶ at high degree  $k_i^{out}$  distribute distress and decrease stability

## Further Work

- Results are still preliminary
- To be done:
  - ▶ Systematic study of the density of long range connections and connectivity degree
  - ▶ Monitor impact on other economic variables
  - ▶ Gain some analytical insight
- Comments

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- Stiglitz J.E. and Greenwald B. 2003, "Towards a New Paradigm in Monetary Economics", Cambridge (UK), Cambridge Univ. Press

# Main Quantities I

- Profit:

$$\pi_i^{(K)}(t) = P^{(K)} u_j(t) Y_i^{(s,K)}(t) - C_i^{(K)}(t)$$

- Cost:

$$C_i^{(s,K)}(t) = c_s \sum_{j \in V_i^S} Q_{ij}^{(K,K-1)} P^{(K-1)} u_j(t) Y_j^{(K-1)} \quad (3)$$

$$C_i^{(r,K)}(t) = c_r Y_i^{(e,K)} = c_r \sum_{j \in V_i^S} Q_{ij}^{(K,K-1)}(t) Y_j^{(e,K-1)}(t)$$

## Main Quantities II

In real terms (dividing by the level of prices in each layer):

- Profit:

$$\pi_i^{(K)}(t) = u_j(t) Y_i^{(s,K)}(t) - C_i^{(K)}(t)$$

- Cost:

$$C_i^{(s,K)}(t) = c_s \sum_{j \in V_i^S} Q_{ij}^{(K,K-1)} u_j(t) Y_j^{(K-1)} \quad (4)$$

$$C_i^{(r,K)}(t) = c_r Y_i^{(e,K)} = c_r \sum_{j \in V_i^S} Q_{ij}^{(K,K-1)}(t) Y_j^{(e,K-1)}(t)$$

## Main Quantities III

- Net Worth of layer K:

$$A^{(K)}(t+1) = A^{(K)}(t) + \pi(t)$$

- Desired Output:

$$Y^{(d,K)} = \min\{\theta A^{(K)}, O^{(K,K+1)} Y^{(d,K+1)}\}$$

- Expected Output:

$$Y^{(e,K)}(t) = Q^{(K,K-1)}(t) Y^{(e,K-1)}(t) = Q^{(K,K-1)}(t) \cdot \dots \cdot Q^{(2,1)}(t) Y^{(e,1)}$$

- Effective Output:

$$Y_i^{(K)}(t) = Y_i^{(e,K)}(t) S_i(t)$$

where  $S_i(t) = 0$  with probability  $q$ .

## Estimation of Growth Condition

- Mean field + small  $q$

$$C_i^{(s,K)}(t) = c_s \sum_{j \in V_i^S} Q_{ij}^{(K,K-1)}(t) Y_j(t)^{(K-1)} = c_s Y_i(t)^{(K)}$$

$$C_i^{(r,K)}(t) = \frac{c_r}{(1-q)} Y_i^{(K-1)}$$

- supply equals demand  $\rightarrow Y_i^{(K)}(t) = \theta A_i(t)^{(K)}$

$$A_i(t+1)^{(K)} = \rho A_i(t)^{(K)} + \pi_i(t)^{(K)} = \left( \rho + 1 - c_s + \frac{c_r}{(1-q)} \right) A_i(t)^{(K)}$$

- condition for average positive growth:

$$g_i^{(K)}(t) = \frac{A_i(t+1)^{(K)} - A_i(t)^{(K)}}{A_i(t)^{(K)}} > 0 \rightarrow \rho > c_s + \frac{c_r}{(1-q)}$$

- But the model produce heterogeneous firm size!

## Bankruptcy Condition

- Price is a s.v. with pdf  $\mu(u)$ , the probability  $\mathcal{P}_i^B$  of bankruptcy for firm  $i$  is:

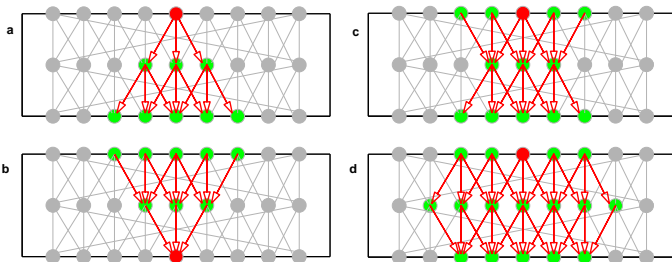
$$\mathcal{P}_i^B = \mathcal{P}\{\pi_i(t) < -\beta A_i(t)\} = \int_{1-\delta}^{u_i^*(t)} \mu(u) du \quad (5)$$

$$u_i^*(t) \simeq \frac{-\beta A_i(t) + C_i(t)}{Y_i^s(t)} \simeq \frac{(c_r - \beta/\theta) Y_i^e(t) + c_s Y_i(t)}{Y_i^s(t)}$$

- Delayed payments AND slow adaptation implies sensitivity of firms to bankruptcies of both customers AND suppliers.

# Avalanches

Bankruptcies can propagate **downward** OR/AND **upward** (in the direction of production or/and opposite to it)



If failures can propagate only downward/upward, they stop at bottom/top layer.