Threshold Models of Technological Transitions

Utrecht University

Summerschool Innovation Systems

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Introduction

- A large part of complexity research deals with conditions under which autonomous particles or agents suddenly show coordinated behaviour leading to the emergence of macroscopic patterns.
- In the social sciences this is an old question as human agents are in principle driven by personal contexts, yet sometimes show remarkable coordinated behaviour. Think of social unrest, social norms, fashions, media hypes, etc.
- Threshold models are models that derive the minimum number of agents already adopting a certain behaviour, such that other agents follow suit.
- Threshold models are very suited as theoretical models of scientific, technological an societal transitions.
- The take away message holds that there are many different but related ways to explain sudden transitions, which means that empirical research really has to go to the micro level to understand mechanism or mechanisms.
- Similarly, policy will only work well if the exact process underlying technology adoption is well understood.

Structure

- I will discuss:
  - The classic lock-in model of competing technologies
  - The modified lock-in model of transitions
  - Informational cascades
  - The NK-model
  - Percolation model

- Background literature:

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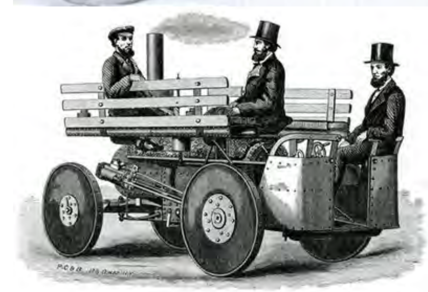
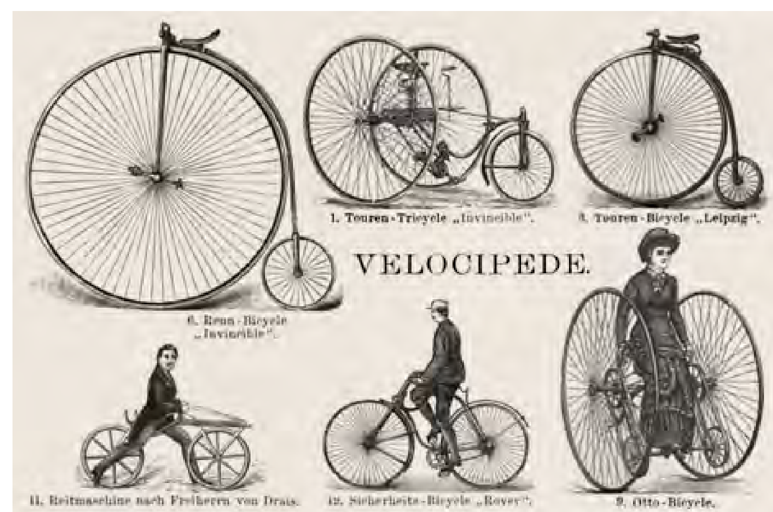
Thresholds models of technological transitions

CrossMark

Paolo Zeppini[a,b,*], Koen Frenken[a], Roland Kupers[c]

The example of cars, bikes and planes





And the dominant designs that followed

A more recent example …

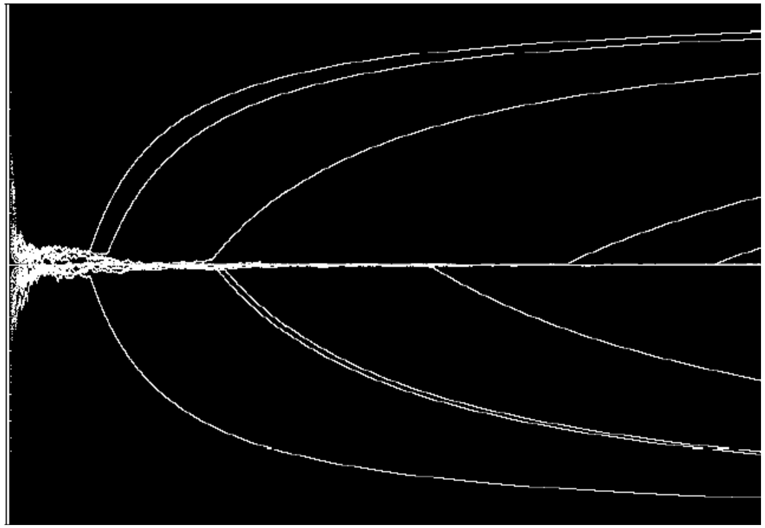
Dominant design

Lock-in

	Technology *A*	Technology *B*
R-agent	$a_R + rn_A$	$b_R + rn_B$
S-agent	$a_S + sn_A$	$b_S + sn_B$

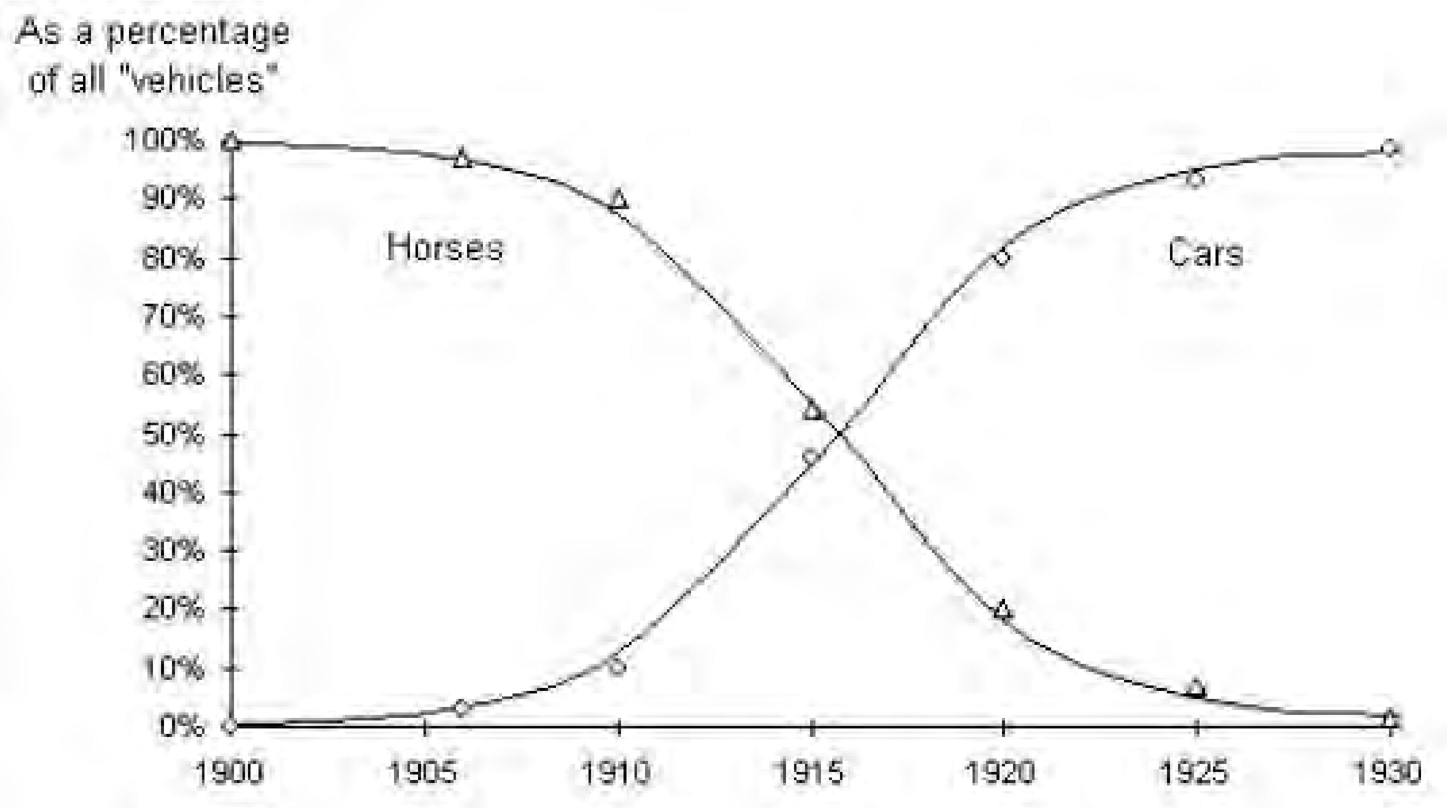
Table 1. *Returns to adopting A or B, given n_A and n_B previous adopters of A and B. (The model assumes that $a_R > b_R$ and that $b_S > a_S$. Both r and s are positive.)*

- *Population consists of 50-50 distribution of R-agents and S-agents*
- *Sequential decision-making*



- *Path dependence*
- *Irreversibility*
- *Multiple equilibria*
- *Unpredictability*

Modified lock-in model of technological transitions



Modified lock-in model

Table 2
Modified Arthur-model of technological transitions.

	Technology 1	Technology 2
any agent	$a+rN_1$	$b+rN_2$

$b > a$, $r > 0$.

Lock-in model

Table 2
Modified Arthur-model of technological transitions.

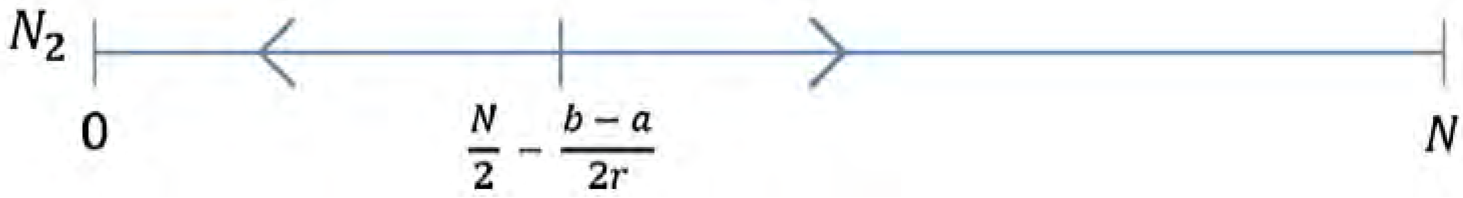
	Technology 1	Technology 2
any agent	$a+rN_1$	$b+rN_2$

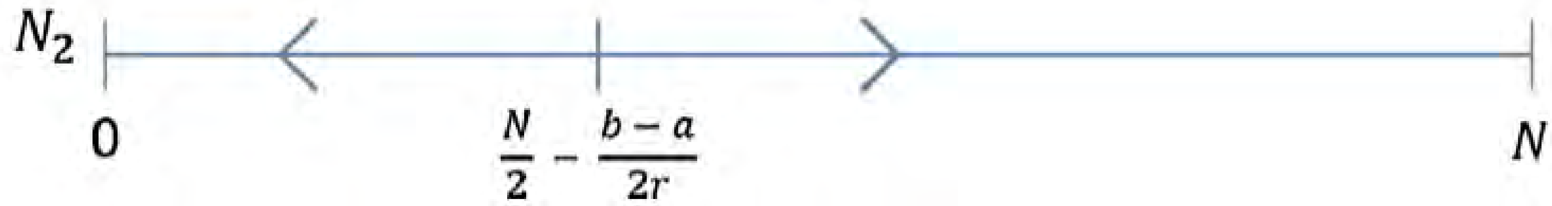
$b>a, r>0.$

There are N agents in the population. We can now consider the question of technological transition as the question under what conditions agents using technology 1 all switch to technology 2. Hence, the starting point in the analysis of a technological transition is the state $N_1=N$. The question becomes how many agents have to switch simultaneously from technology 1 to 2 such that all remaining agents using technology 1 will follow suit, and also switch to technology 2. This will happen once the payoff of using technology 2 will be greater than the payoff of using technology 1, that is, when $b+rN_2 > a+rN_1$. Given that $N_1 = N - N_2$, we get, as tipping point:

$$N_2 > \frac{N}{2} - \left(\frac{b-a}{2r}\right)$$

and the phase diagram becomes:

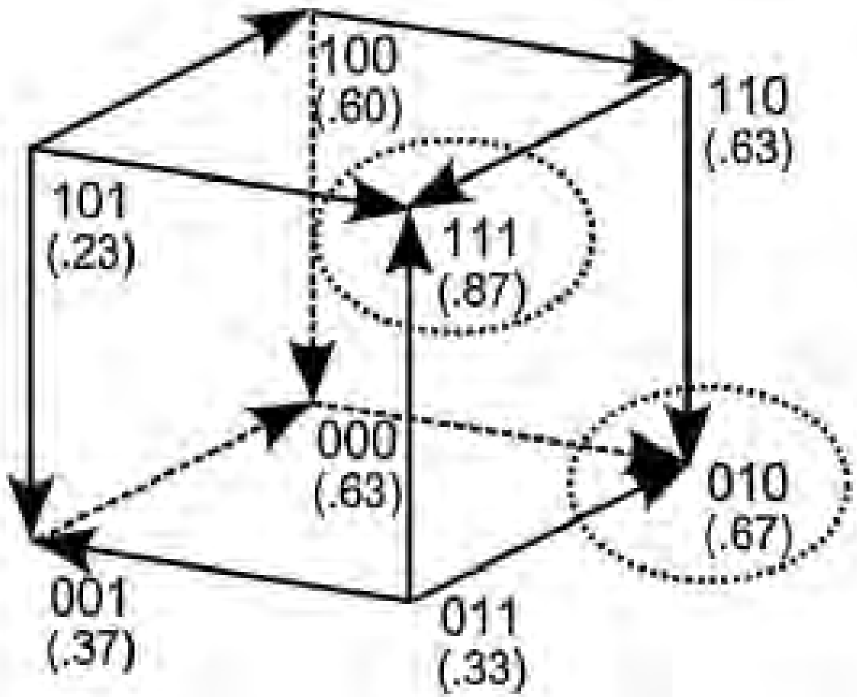




The tipping point specifies the critical mass of users of the new technology 2, which is required to cause a full technological transition. Once this critical mass of users is achieved, all other users will follow suit. We can derive a number of properties of the tipping point:

1. If $(b-a)$ is infinitesimally small, half of the agents must switch from 1 to 2 for a full transition to occur
2. If the sensitivity for increasing returns (r) is very large, half of the agents must switch from 1 to 2 for a full transition to occur
3. The more the quality of the new technology 2 exceeds the quality of the old technology 1, the fewer agents needed to switch from 1 to 2 for a full transition to occur
4. For "an entrepreneur", that is a single agent, to cause a transition, she must introduce a new technology b with sufficiently high quality such that one agent is already sufficient as a critical mass. The threshold is given by: $b > a + r(N-2)$.

NK-model



Centralised search

	w_1	w_2	w_3	W
111	0.9	0.8	0.9	0.87
110	0.7	0.4	0.8	0.63
101	0.2	0.1	0.4	0.23
100	0.3	0.8	0.7	0.60
011	0.1	0.3	0.6	0.33
010	0.6	0.7	0.7	0.67
001	0.3	0.6	0.2	0.37
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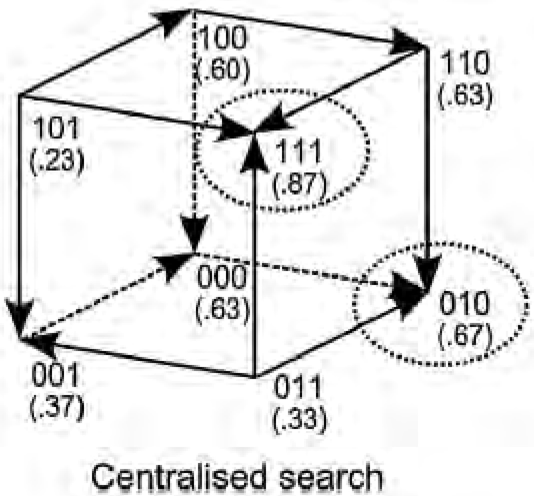
NK-model



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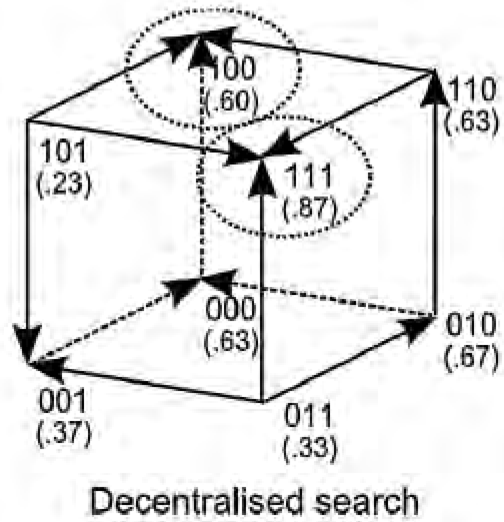
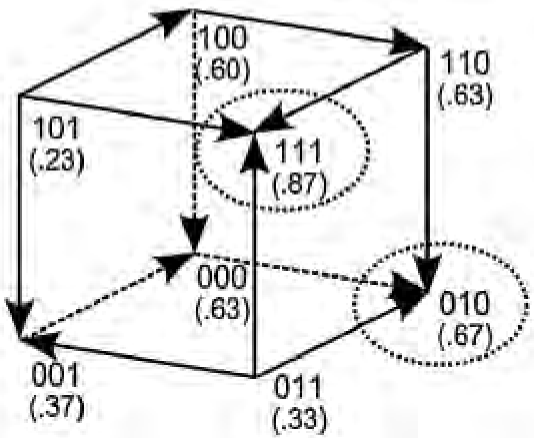


Fig. 1. Simulation of a fitness landscape of a $N = 3$ system with $K = 2$.

NK-model



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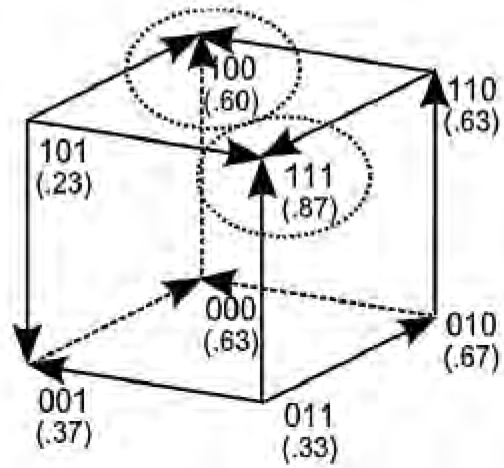
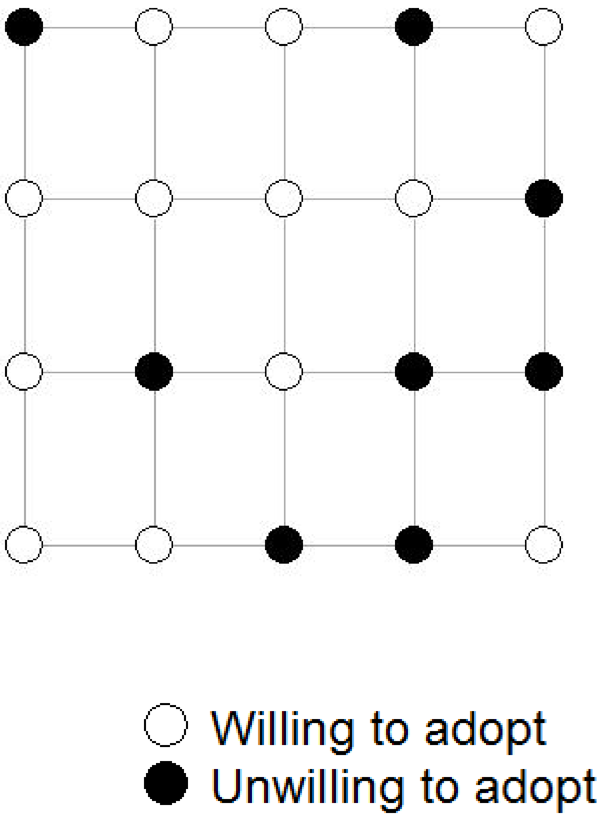


Decentralised search

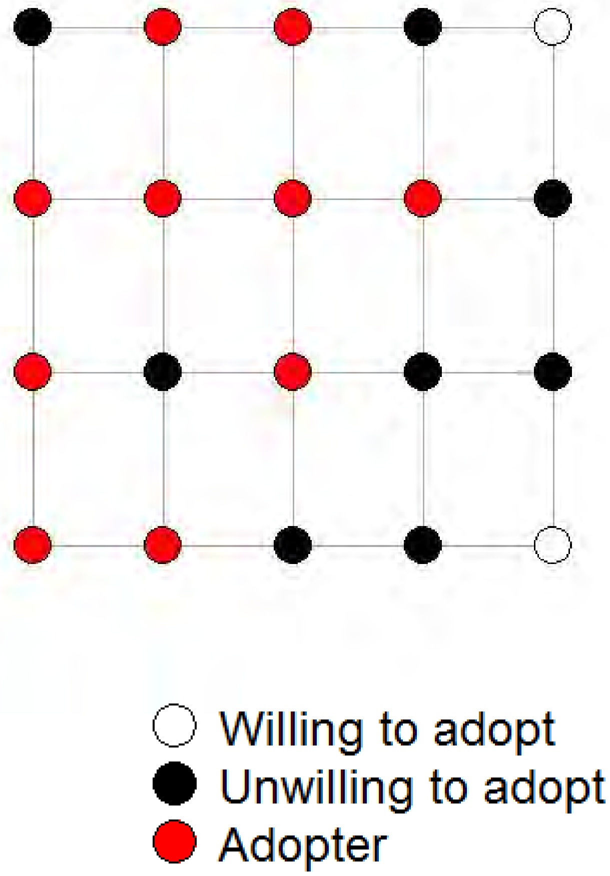
Fig. 1. Simulation of a fitness landscape of a $N = 3$ system with $K = 2$.

As a model of technological transition – that is a move from one local optimum to a better local optimum – the fitness landscape model highlights that to 'unlock' a technological system, a change in governance may by itself already be sufficient. Consider a centralised governance system (*left*) currently locked into in the suboptimal state 010. Changing the governance into a decentralised system (*right*) would mean that the superior technology 111 suddenly becomes accessible via 110. However, success is not warranted, since any other transition path leads to the sub-optimum 100. Reversely, if a decentralised system is locked into the sub-optimum 100, changing the governance system into centralised search would open up a transition path to 111 via 110. Again, success is not warranted as other paths lead to the sub-optimum 010.

Percolation in a social network



Percolation in a social network



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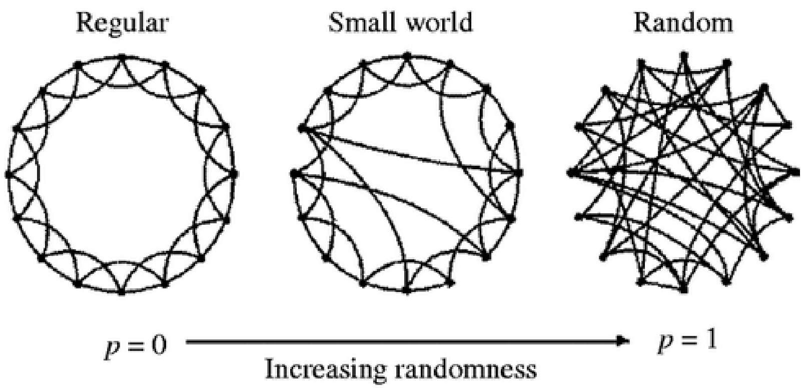
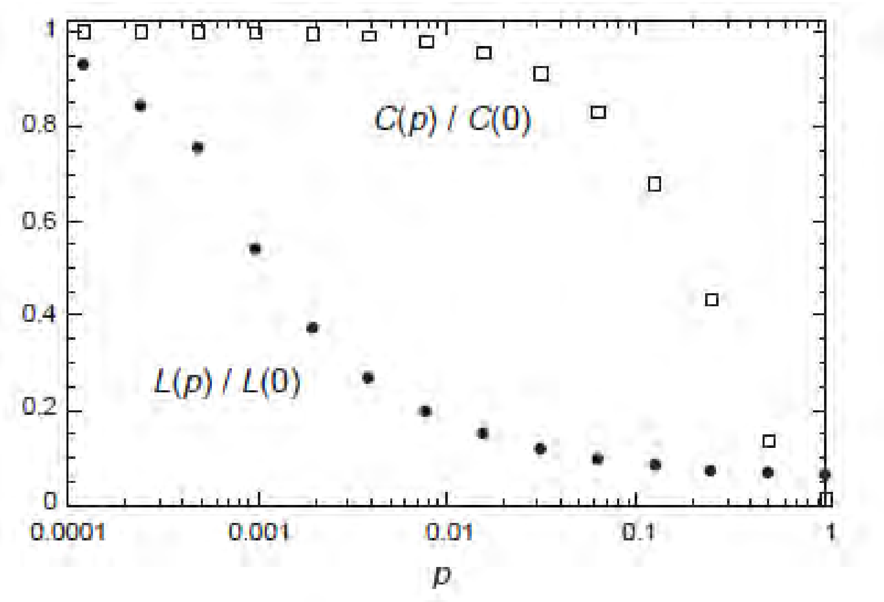
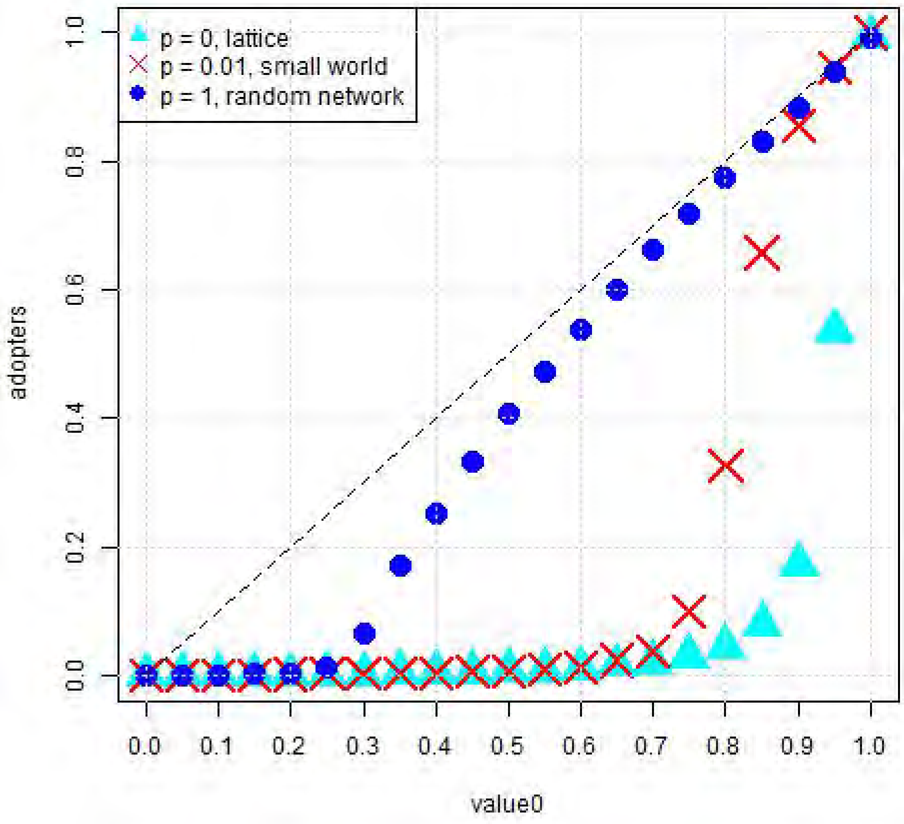
Different network structures





Thresholds depend on network structrures



- Upper bound to diffusion: 45º line (perfect information)
- Phase changes: from a non-diffusion to a diffusion regime
- Regular and Small world networks very inefficient

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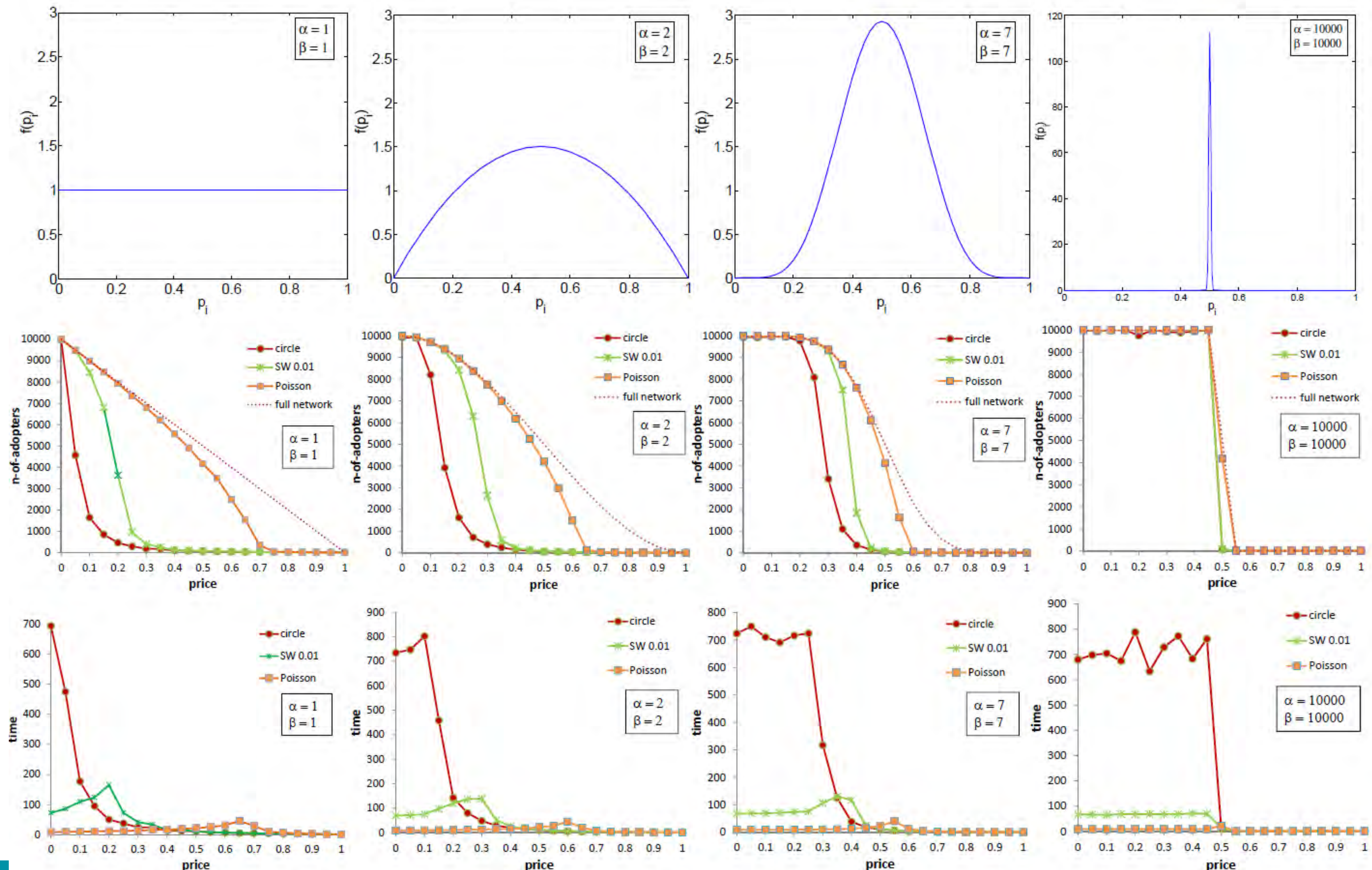
Thresholds also depend on preference/income structrures



Conclusion

- The take away message holds that there are many different but related ways to explain sudden transitions, which means that empirical research really has to go to the micro level to understand mechanism or mechanisms.

- Similarly, policy will only work well if the exact process underlying technology adoption is well understood.

- Threshold models are still rather limited. Possible future extensions include:
  - More than 2 technologies
  - Geography
  - More heterogeneity in demand
  - Policy experiments