



# Agent reflexivity in computational models: the case of diffusion of innovations

César García-Díaz

Department of Business Administration  
Pontificia Universidad Javeriana  
Bogotá, Colombia

Central Economics and Mathematics Institute  
Russian Academy of Sciences

February 12, 2021

# About me



- César García-Díaz
- PhD from the University of Groningen (Netherlands)
- Associate Professor, School of Economics & Business, PUJ
- Computational analysis of social and organizational systems
- Interested in the link between micro-level rules, structural interdependence and macro-level outcomes in a variety of settings (e.g., organizational dynamics, industry evolution, competitive spatial location).

# 1o. Motivation and background

- Social systems, unlike natural systems, are **artificial structures designed and transformed by human action.**
- Such systems are collectives characterized by **heterogeneous, purposeful** individuals who are nested through a set of relationships or **interconnections** embedded in a structure, so that, consequently, the systems display **complex behaviors.**

# 1o. Motivation and background

- **Statistical physics** approaches maintain a visible influence on how complex systems theories are applied to study **social systems** (cf. Castellano et al., 2009; Galam, 2012).
- **Emergence** is a fundamental concept in complex systems. However, no proper distinction has been drawn between emergence in **natural** and **social systems** (Goldspink and Kay, 2007). Thus, emergent phenomena can have very different drivers in natural complex systems (**non-reflexive**) vs. social complex systems (**reflexive**) (Goldspink and Kay, 2007).

# 1o. Motivation and background

- Alike natural systems, humans can recognize patterns (i.e., societies, institutions, organizations) and set their behavior according to such patterns. This has been named “**second-order emergence**” (Gilbert, 2002).
- Need to differentiate between **epistemic** (representation of a reality rendered intelligible to an observer) and **ontic** (reality itself) sides in simulation modeling (Hauhs and Trancon y Widemann, 2012).
- Despite acknowledged importance by some few researchers, remains an ethereal concept of no scientific value due to its self-referential, paradoxical nature (Lynch, 2000). Nonetheless, Umpleby (2007) highlights the importance of developing knowledge that chooses “**scope**” over “**form**” (Umpleby, 2007: 515).

## 20. Perspectives on reflexivity

- Umpleby (2007) speaks of reflexivity as “**the relation that exists between the entity and itself**” (Umpleby, 2007: 515):
  - **Heins von Foerster**’s second-order cybernetics (or the inclusion of the observer in the system under study)
  - **George Soros**’ conception of economic and political actors as both actors and observers
- Special issue of the *Journal of Economic Methodology*, Volume 20, Issue 4 (2013)
  - Reflexivity and Economics: George Soros's Theory of Reflexivity and the Methodology of Economic Science

## 2o. Perspectives on reflexivity

- Lynch (2000) reviews a number of interpretations of the concept, among which we highlight the following:
  - **Mechanistic reflexivity** (recursive processes that involve feedback).
  - **Substantive reflexivity** (an essential feature of human communication and interaction).

## 2o. Perspectives on reflexivity

- **Self-fulfilling prophecies** (Ferraro et al., 2005):  
Social science researchers can affect the system they study by shaping practices they try to understand through the diffusion of new language / jargon.



## 2o. Perspectives on reflexivity

- Reflexivity as **second-order behavior** (Goldspink, 2000:2.6): An agent is a “*natural or artificial entity with sufficient behavioural plasticity to persist in its medium by responding to recurrent perturbation within that medium so as to maintain its organisation*”

## 3o. Adding reflexivity to diffusion processes: Diffusion as classification (Etzion, 2014)

- Alternative process: Consideration of “**awareness**” (Etzion, 2014) : the moment at which an agent is capable of distinguishing between adopters and non-adopters
- Population of agents endowed with a perception capability:

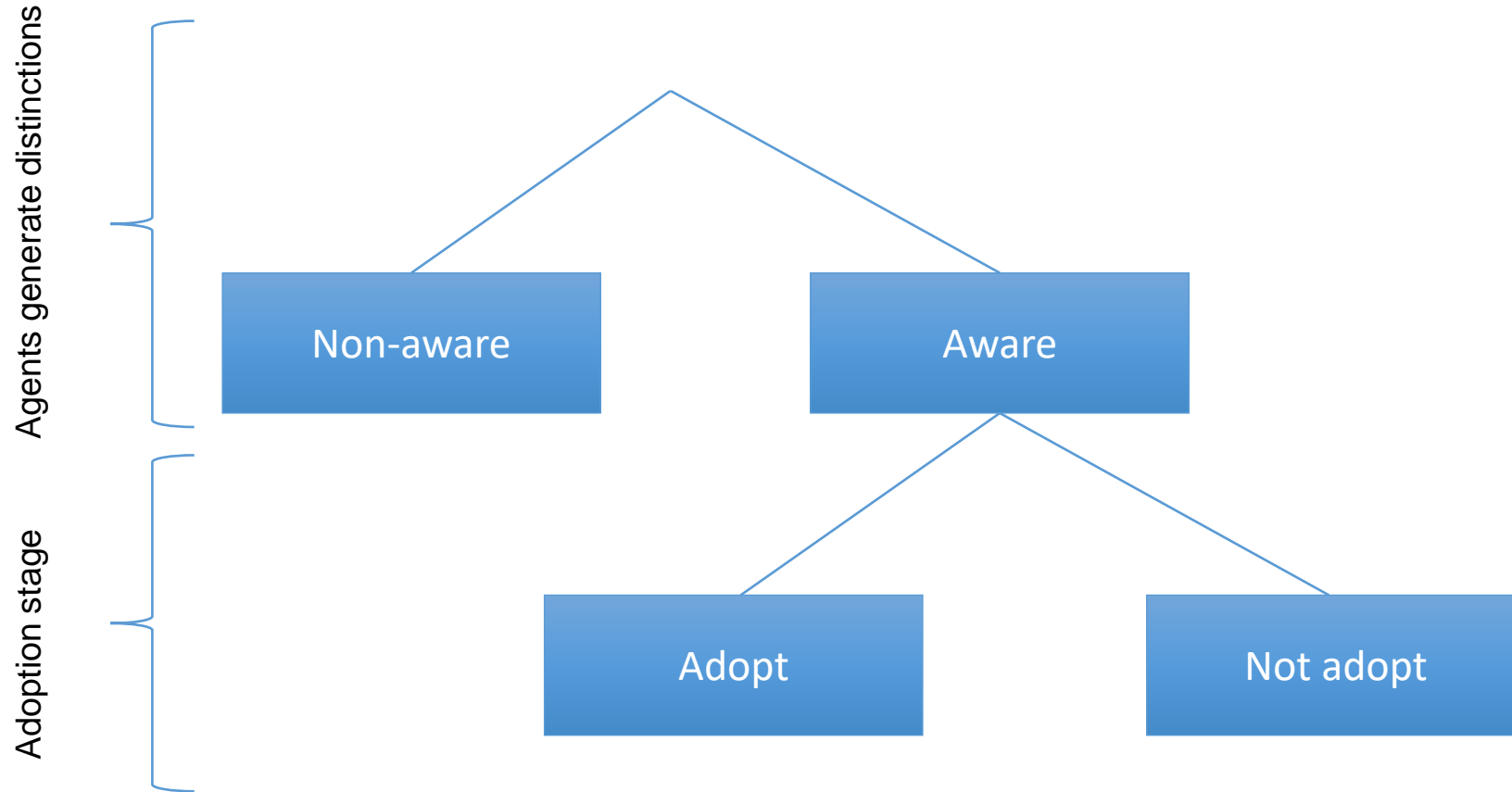
$$p_i \sim N(\bar{p}_i, \sigma^2)$$

- Awareness is defined as follows (Etzion, 2014):

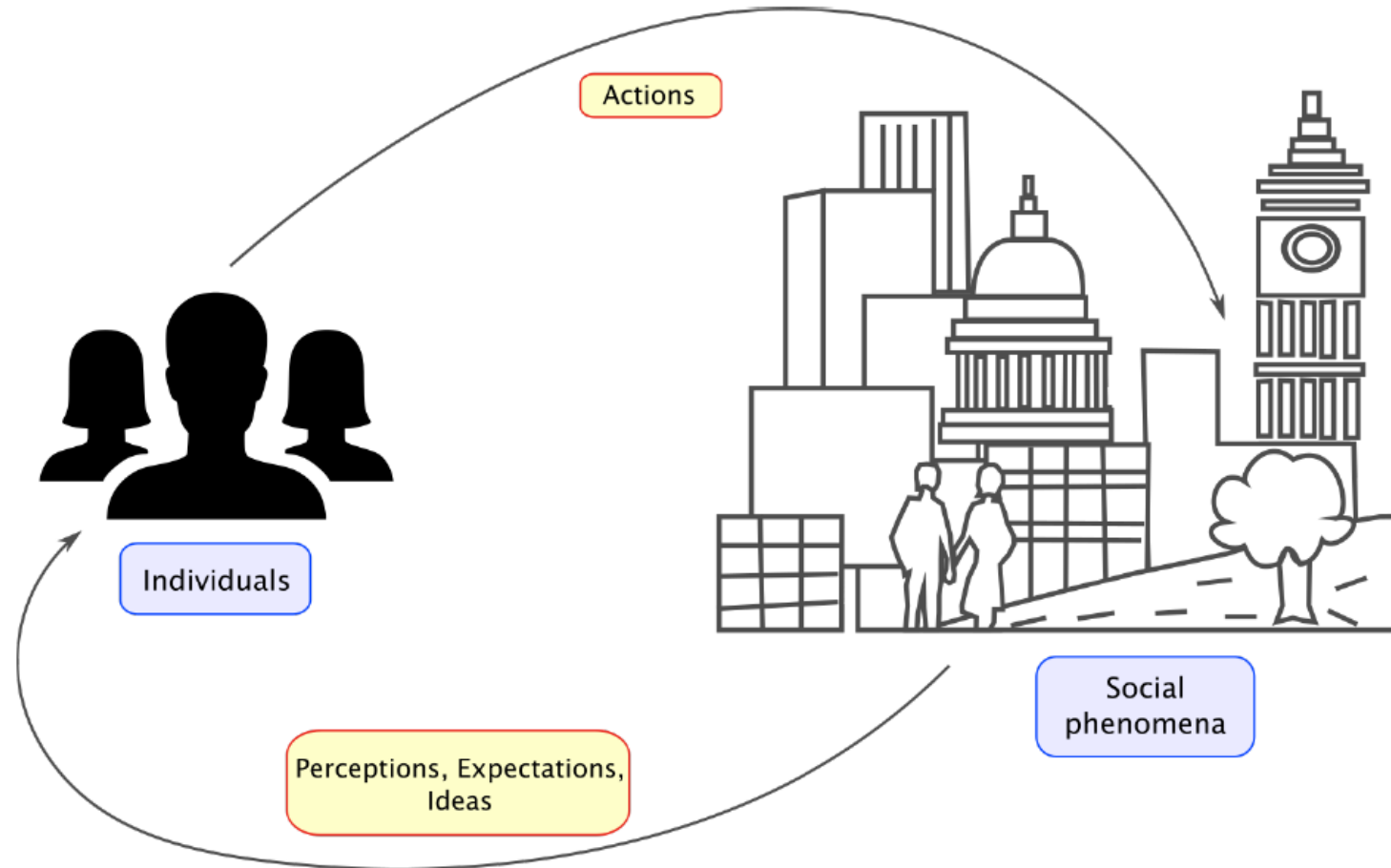
$$a_{i,t} = \begin{cases} 1 & \text{if } p_i + n_{t-1} \geq H \\ 0 & \text{if } p_i + n_{t-1} < H \end{cases}$$

- $H$  corresponds to a threshold, while  $n_t$  represents the population of adopters at time  $t$ .

# 3o. Adding reflexivity to diffusion processes: Diffusion as classification (Etzion, 2014)

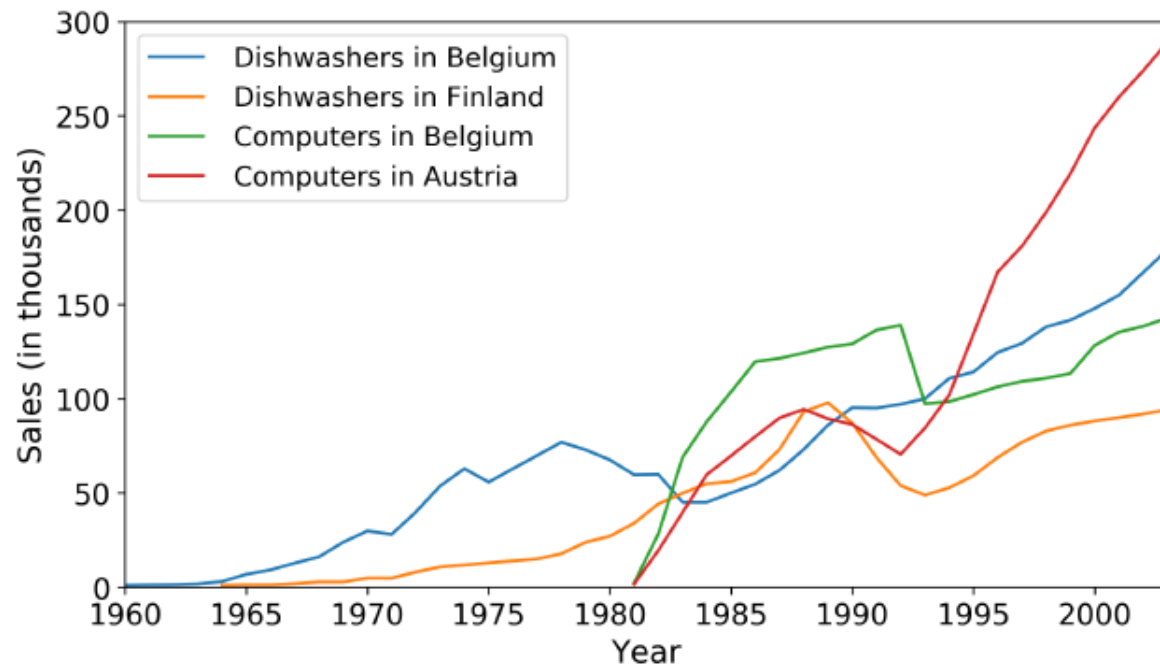


# 3o. Adding reflexivity to diffusion processes: Córdoba and García-Díaz (2020)

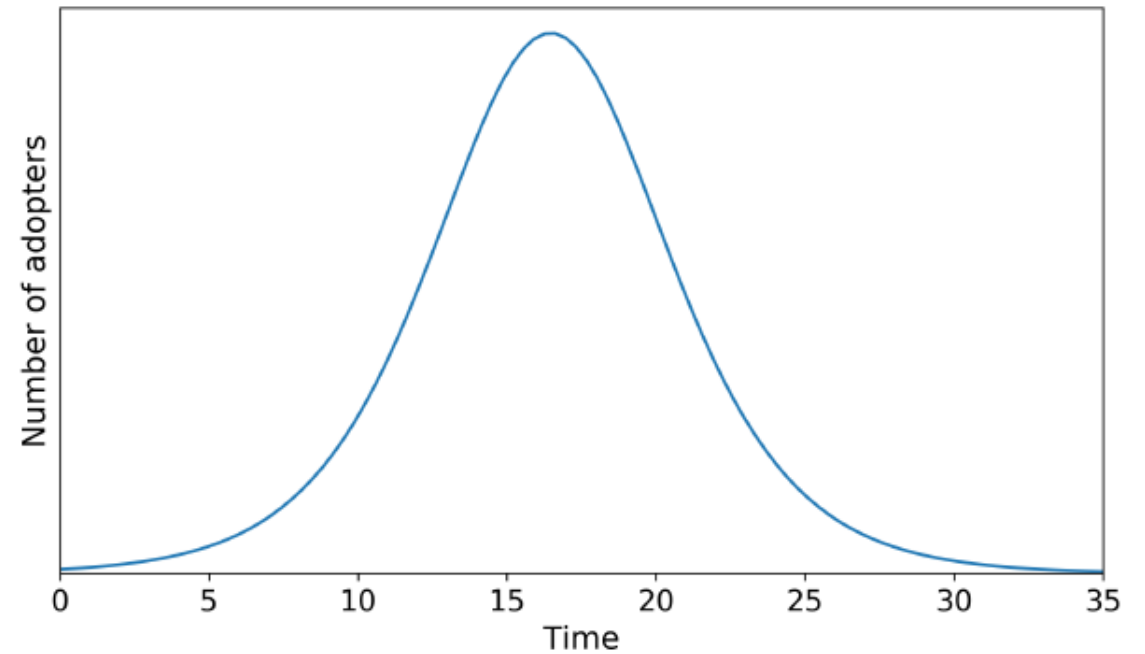


Córdoba, C., & Garcia-Diaz, C. (2020). Reflexivity in a Diffusion of Innovations Model. *Journal of Artificial Societies and Social Simulation*, 23(3), 1-9.

# 3o. Adding reflexivity to diffusion processes: Córdoba and García-Díaz (2020)



(a)



(b)

Córdoba, C., & Garcia-Diaz, C. (2020). Reflexivity in a Diffusion of Innovations Model. *Journal of Artificial Societies and Social Simulation*, 23(3), 1-9.

## 4o. Model

- Agents placed in a social network (e.g., scale-free, small world, random)
- A given number of agents ( $\delta$ ) are initialized as adopters
- Adoption decisions:  $D_i$

$$D_i = \begin{cases} 1, & U_i \geq U_{i,\min} \text{ or } \lambda > s_i \\ 0, & \text{otherwise} \end{cases}$$

- $U_i$  is agent  $i$ 's utility;  $U_{i,\min}$  is a utility threshold for adoption;  $\lambda$  is the marketing effort, and  $s_i$  is agent  $i$ 's marketing susceptibility to adoption
- $U_{i,\min} \sim U(0,1), s_i \sim U(0,1)$

## 4o. Model

- $U_i$  has two components: a local factor ( $U_{Li}$ ) and a global social influence ( $U_G$ )

$$U_{Li} = \beta \cdot x_i + (1 - \beta) \cdot y_i$$

$$x_i = \begin{cases} 1, & A_i \geq h_i \\ 0, & \text{otherwise} \end{cases}$$

$$y_i = \begin{cases} 1, & p_i \leq q \\ 0, & \text{otherwise} \end{cases}$$

- $\beta$  is the **social influence** parameter;  $A_i$  is the fraction of adopters in neighborhood;  $h_i$  is a threshold value;  $p_i$  is the **individual preference**; and  $q$  is **product quality** parameter.  $p_i, h_i \sim U(0,1)$ ,  $\beta, q \in (0,1)$

## 4o. Model

- We also incorporate a **global influence** effect, which leads agents to consider a **category distinction** between adopter and non-adopters
- This is a function on the average size of connected components in the subgraph of adopters

$$U_G = \frac{\bar{C}}{N}$$

$$\bar{C} = \sum_{j=1}^{n_c} \left( \frac{n_j}{N} \right) n_j, \quad n_j > 1$$

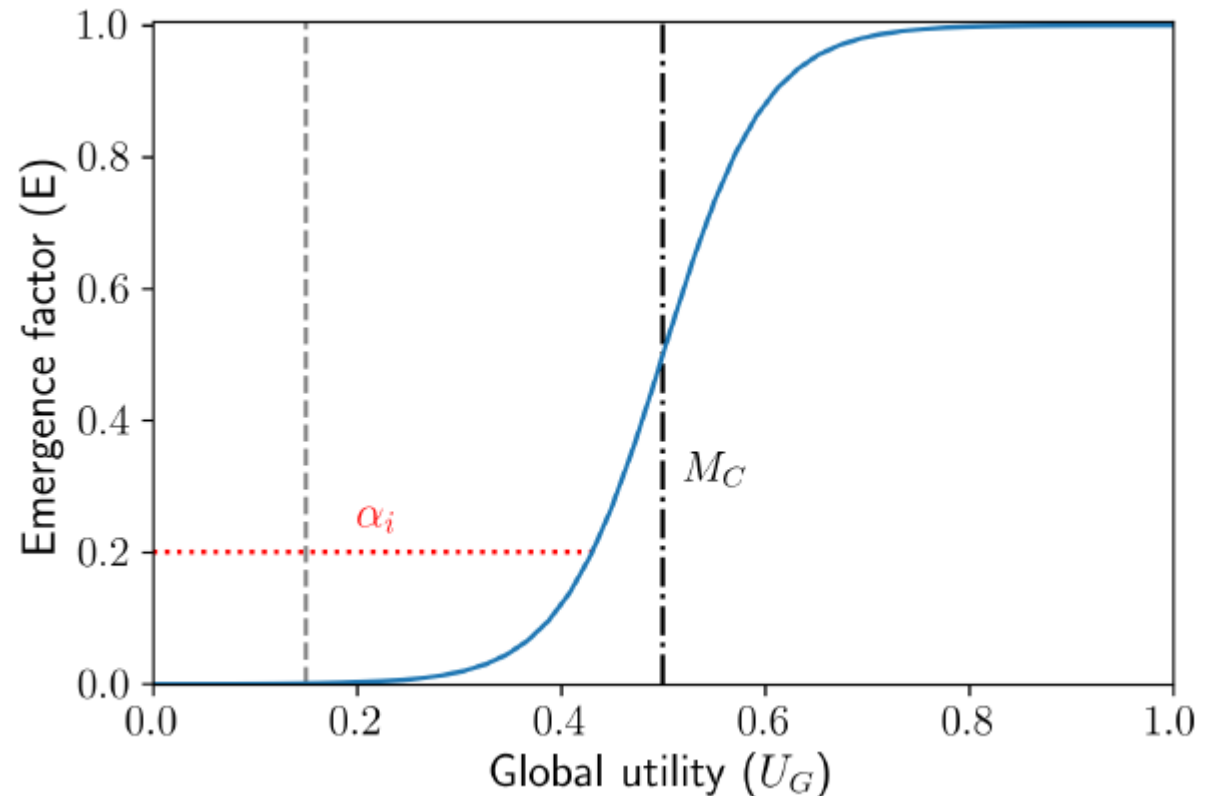
- $N$  is the total number of agents;  $n_j$  is the number of adopter in network component  $j$ ;  $n_c$  is the total number of components. Thus,  $\bar{C}$  is the weighted average size of components of adopters.



# 4o. Model

- Reflexivity index:  $\alpha_i \sim U(0,1)$
- Emergence factor:  $E(U_G)$
- Critical mass:  $M_C$

$$E(U_G) = \frac{1}{1 + e^{-\phi(U_G - M_C)}}$$

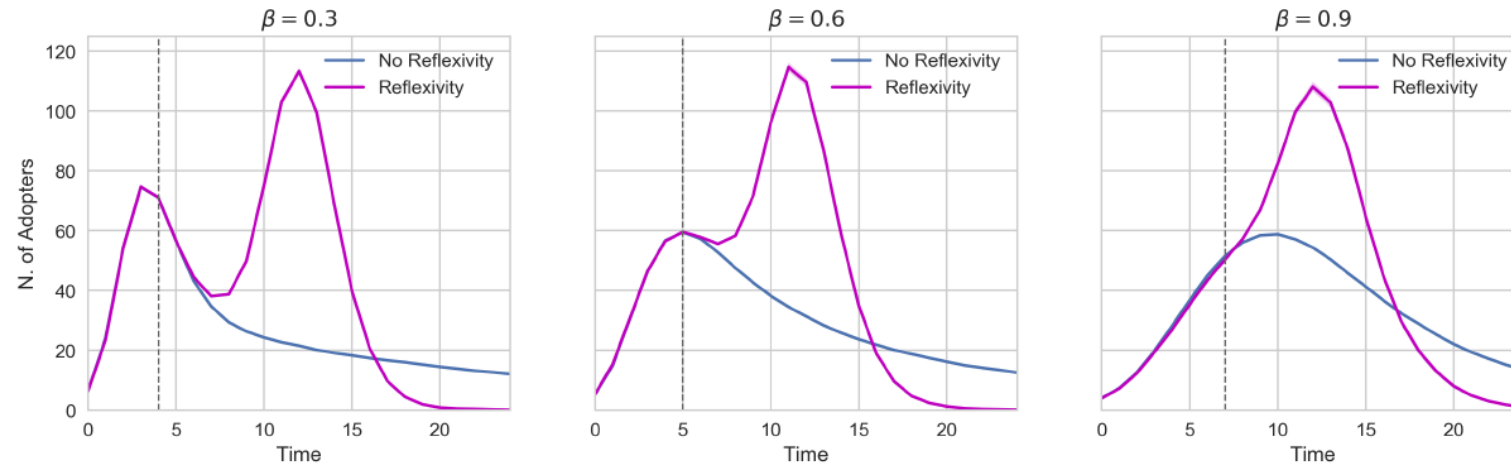


## 4o. Model

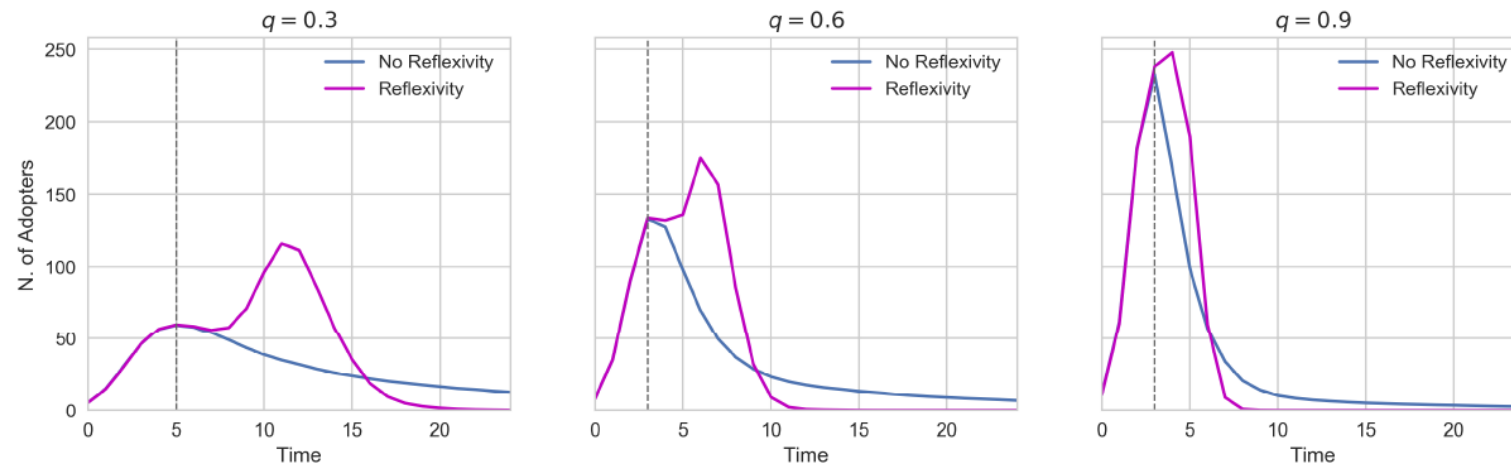
$$U_i = \begin{cases} U_{Li} + U_G - U_{Li} \cdot U_G, & E(U_G) > \alpha_i \text{ and } t_a > d_i \\ U_{Li}, & \text{otherwise} \end{cases}$$

- $t_\alpha$  is the time elapsed since the awareness of the emergence of a critical mass of adopters, and  $d_i$  is the time delay for including this awareness in the utility function.

# 50. Results: without time delays (scale free network)

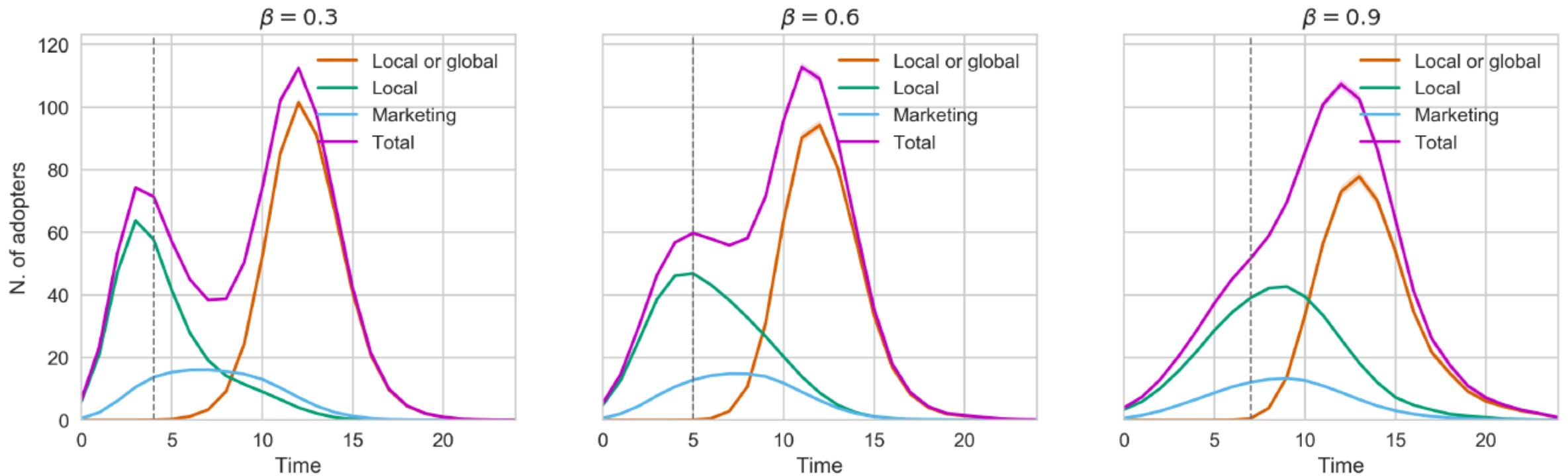


(a) For all curves  $q = 0.3$

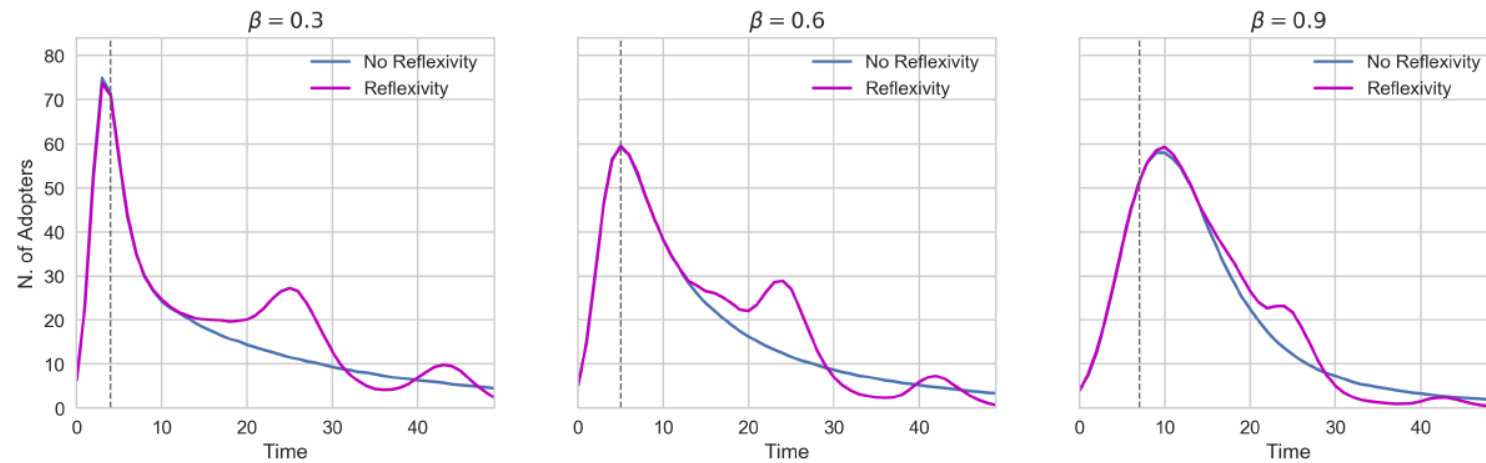


(b) For all curves  $\beta = 0.6$

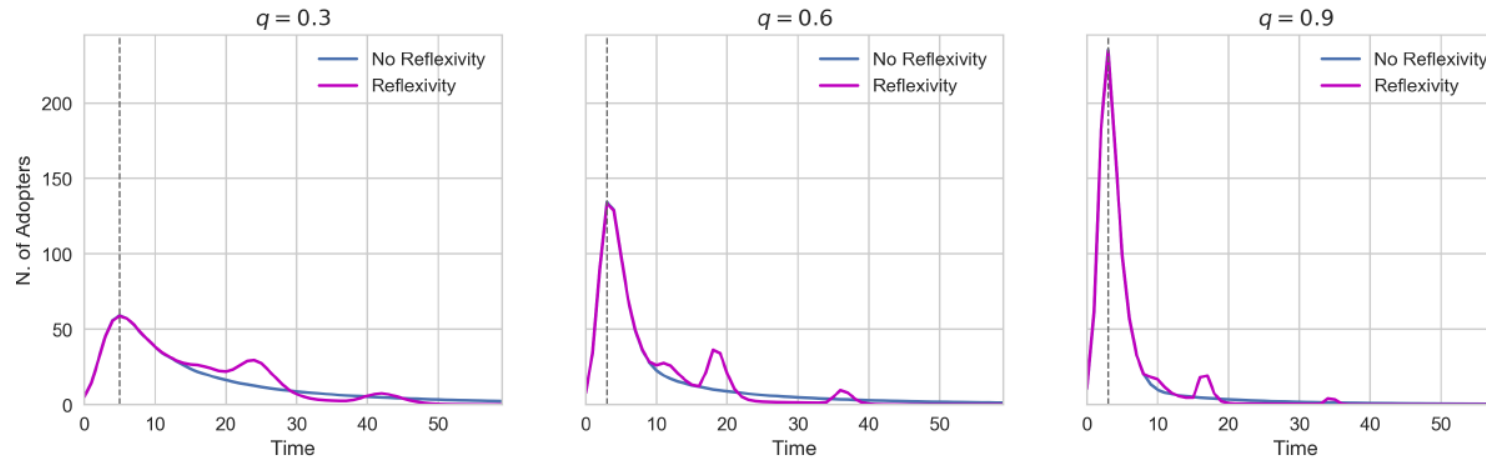
# 50. Results: without time delays (scale free network)



# 50. Results: with time delays (scale free network)

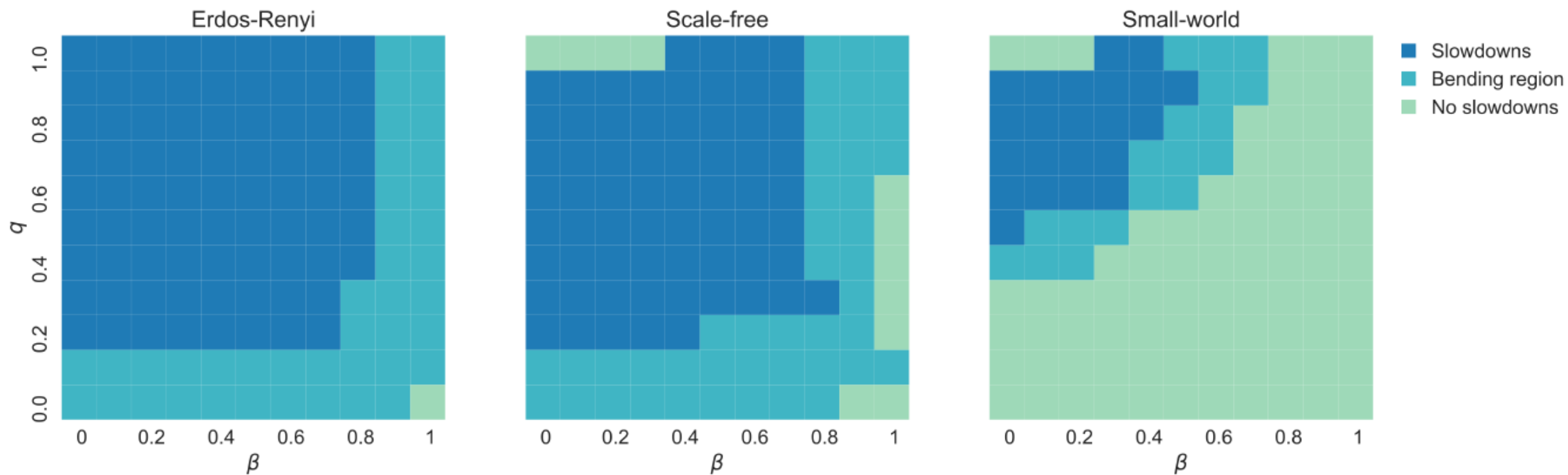


(a) For all curves  $q = 0.3$



(b) For all curves  $\beta = 0.6$

# 50. Results: $\beta q$ space



Link to the full paper:

Córdoba, C., & Garcia-Diaz, C. (2020). Reflexivity in a Diffusion of Innovations Model. *Journal of Artificial Societies and Social Simulation*, 23(3), 1-9.

<http://www.doi.org/10.18564/jasss.4255>

Thank you for your attention  
Any questions?



# References

- Bok, B. (2007). Experiential foresight: Participative simulation enables social reflexivity in a complex world. *Journal of Future Studies*, 12(2): 111-120.
- Castellano, C., Fortunato, S., Loreto, V. (2009) Statistical physics of social dynamics, *Review of Modern Physics*, 81 (591).
- Etzion, D. (2014). Diffusion as classification. *Organization Science* (in press).
- Ferraro, F. Pfeffer, J., Sutton, R. (2005). Economics language and assumptions: how theories can become self-fulfilling, *Academy of Management Review* 30(1): 8–24.
- Galam, S. (2012). *Sociophysics: A Physicist's Modeling of Psycho-political Phenomena (Understanding Complex Systems)*. New York: Springer.
- Córdoba, C., & Garcia-Diaz, C. (2020). Reflexivity in a Diffusion of Innovations Model. *Journal of Artificial Societies and Social Simulation*, 23(3), 1-9.
- Gilbert, N. (2002). Varieties of emergence. Paper presented at the *Social Agents: Ecology, Exchange, and Evolution Conference*, Chicago.
- Golspink, C., (2000). Modeling social systems as complex: Towards a social simulation meta-model, *Journal of Artificial Societies and Social Simulation* 3(2).
- Goldspink, C., Kay, R. (2007). Social emergence: Distinguishing reflexive and non-reflexive modes. *Emergent Agents and Socialities: Social and Organizational Aspects of Intelligence Symposium*, Washington DC.
- Hauhs, M., Trancon y Widemann (2012). A critique of agent-based modeling in ecology. *Proceedings of ECMS'12*, Koblenz (Germany).
- Lynch, M. (2000). Against reflexivity as an academic virtue and source of privileged knowledge, *Theory, Culture & Society*, 17(3): 26–54.
- Umpleby, S (2007). Reflexivity in social systems: The theories of George Soros, *Systems Research and Behavioral Science* 24, 515–522.