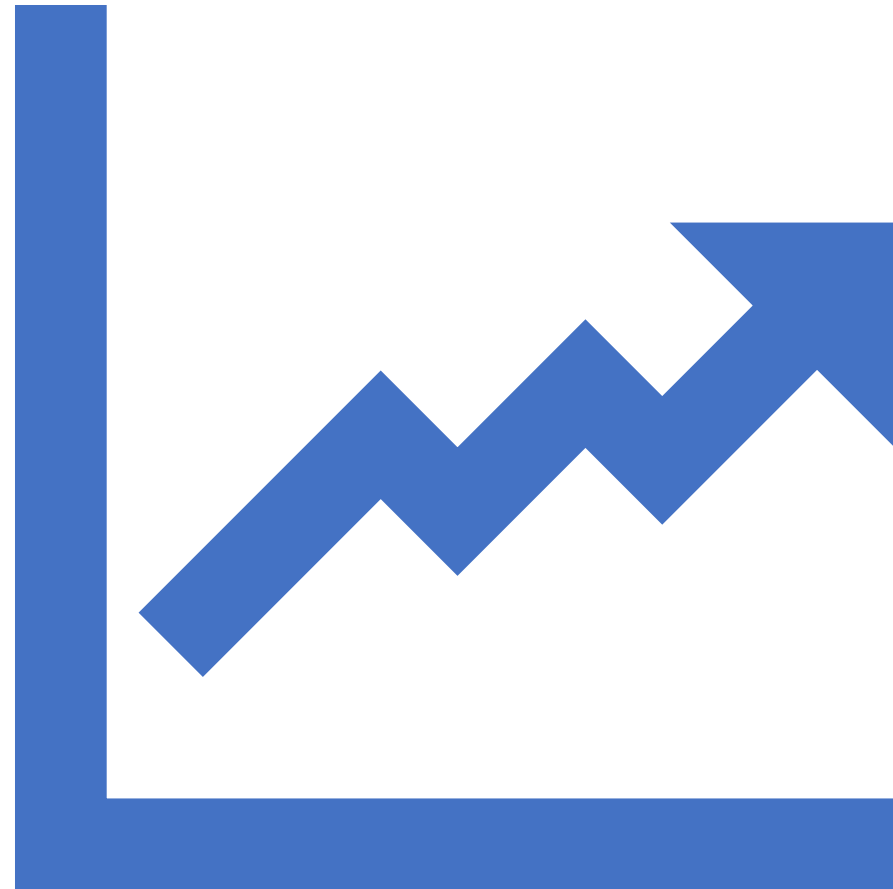


Presentation to the 2<sup>nd</sup> workshop on  
Social Complexity, University of  
Sydney, February 2024

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# Complexity and urban scaling in productivity



# Overview

- The topic is the large spatial inequalities which exist in productivity (and incomes)
- A particular example which raises many of the key points
- The main **general** empirical features of spatial inequalities in productivity and incomes
- These same features are seen in many other contexts – suggesting that a general theoretical model will help understand them
- What economics has to say
- A simple, sparse theoretical model which generates the main empirical features
- Policy implications



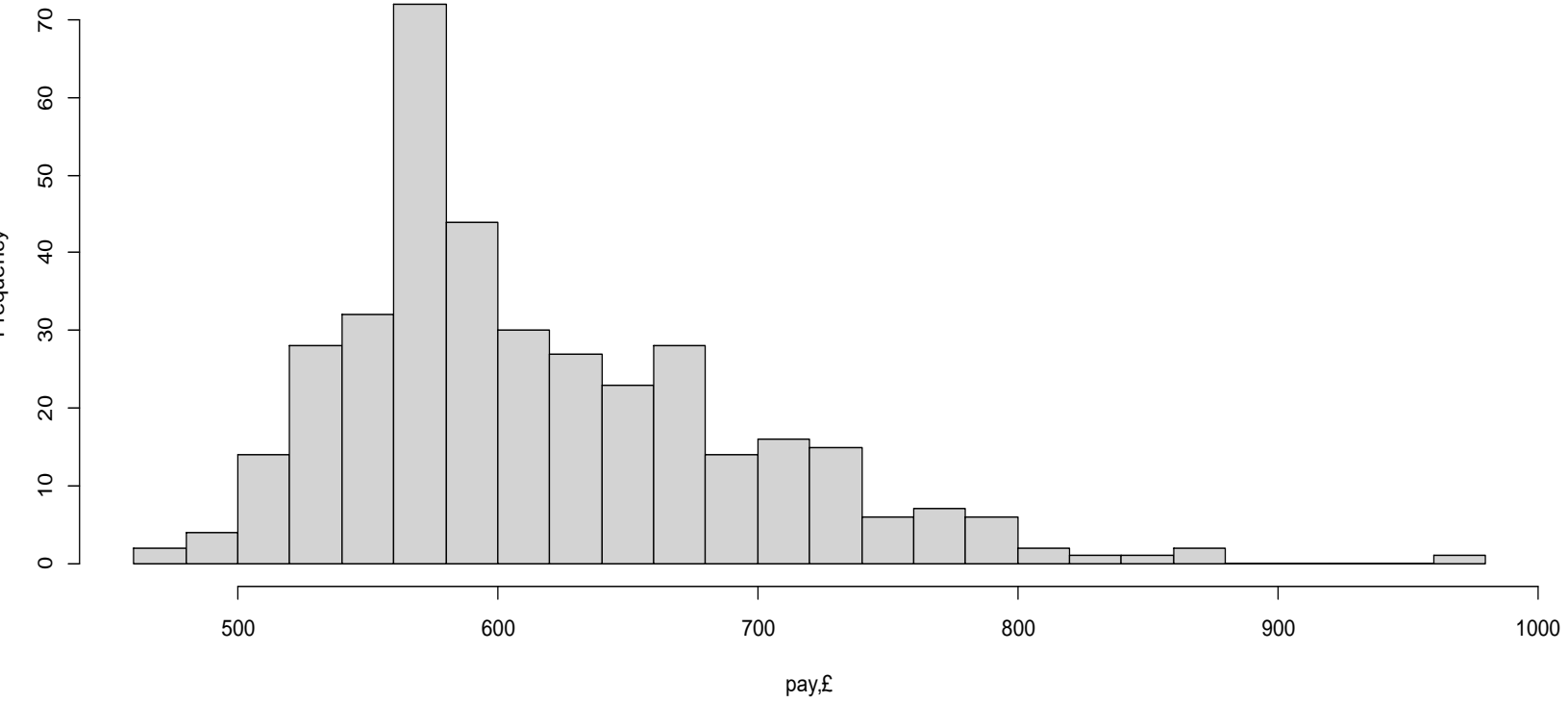
# Key features of the spatial distribution of incomes/productivity

- Persistent over time
- Fat tailed
- Self-similar

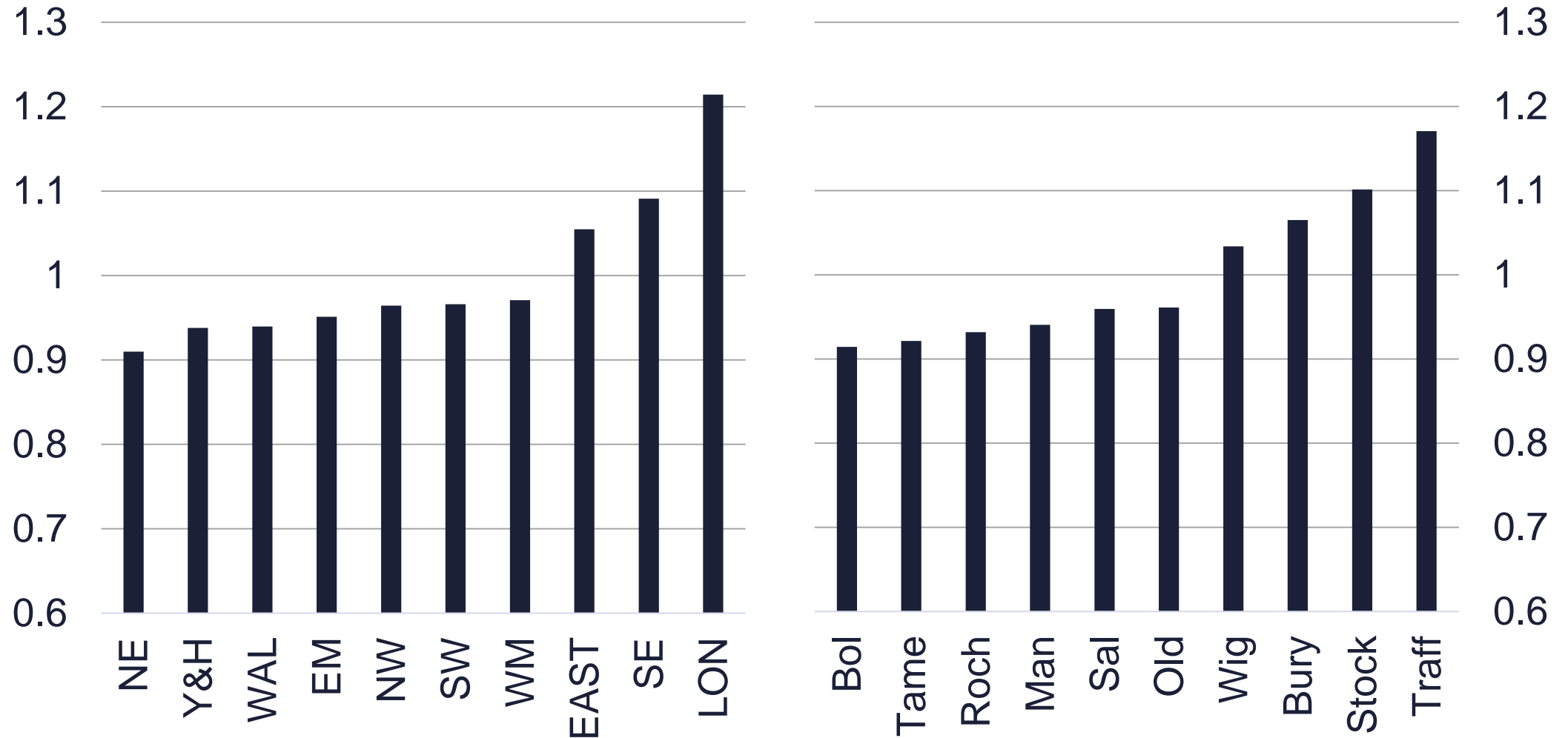
# Persistence

- “Spatial disparities across EU metro areas are profound, persistent, and may be widening”: Ehrlich, M.V. and Overman, H.G., 2020. Place-based policies and spatial disparities across European cities. *Journal of Economic Perspectives*, 34(3), pp.128-149.
- Ranking local authority areas by their unemployment rates, there is very considerable stability in the rankings over time even *within* regions in both the UK and the US
- The correlation between ranks *within* states/regions over a 20-year period is 0.60 for the US and 0.81 for the UK
- Ormerod, P., 2014. The persistence of unemployment at the local area level: evidence from the US and the UK. *Applied Economics Letters*, 21(1), pp.28-30.

Median gross weekly pay by UK local authority  
2021



# Index of median weekly gross pay of residents (2021)



# Implications of the key features

- Fat-tailed, self-similar outcomes are a characteristic footprint of systems whose component parts interact with each other directly (not just indirectly via the price mechanism as in economic theory)
- There is a **self-reinforcing process** in which the more productive tend to become even more productive.
- “Human networking and productivity exhibit heavy-tailed distributions, with some individuals contributing disproportionately to city totals.....agglomeration effects benefit urban elites the most, with the majority of city dwellers partially excluded from the socio-economic benefits of growing cities”. Arvidsson, M., Lovsjö, N. and Keuschnigg, M., 2023. Urban scaling laws arise from within-city inequalities. *Nature Human Behaviour*, pp.1-10.



# Non-Gaussian (fat-tailed) distributions are pervasive

- “It is the purpose of this paper to analyse a class of distribution functions that appears in a wide range of empirical data – particularly data describing sociological, biological and economic phenomena. Its appearance is so frequent, and the phenomena in which it appears so diverse, that one is led to the conjecture **that if these phenomena have any property in common it can only be similarity in the structure of the underlying probability mechanisms**” Simon, H.A., 1955. On a class of skew distribution functions. *Biometrika*, 42(3/4), p.425)
- Simon cites the distribution of word frequency in prose; distribution of scientists by papers published; distributions of cities by populations; distributions of incomes by size: distributions of biological genera by number of species
- Ormerod (2012) gives other examples: viewings on YouTube; film producers’ earnings; the number of sexual partners people have; the size of price changes in financial assets; crowds at soccer matches; firm sizes; the size and length of economic recessions; the frequency of different types of openings in chess; the ratings of American football coaches in *USA Today*; the distribution of £1 million homes across London boroughs; unemployment rates by county in America; deaths in wars; the number of churches per county in William the Conqueror’s Domesday Book survey of England in the late eleventh century

# Economics both old and new recognises self-reinforcement

- Marshall (**1890**) clusters and agglomeration.
- "concentrations of specialized industries in particular localities"
- spatial proximity facilitates the ability to take advantage of increasing returns to scale external to the firm
- knowledge spillovers; a common pool of labour force skills is developed. An implication is that firms become more willing to invest in training their workforce; greater levels of specialisation and increased inter-firm cooperation with extensive activity links and resource ties. This enhanced cooperation reduces the cost of innovation.
- Increasing returns to scale external to the firm is the basis of Nobel Laureate Paul Romer's work in the **1980s** – endogenous growth theory
- "The observed concentration of economic activity within cities cannot be explained by natural advantages alone, but instead requires substantial agglomeration forces" Redding, S.J., **2023**. Quantitative Urban Models. *The Journal of Economic Perspectives*, 37(2), pp.75-98.

## Market forces are relevant but are weak and slow

- 2019 Nobel Laureates in economics, Abhijit Banerjee and Esther Duflo show in *Good Economics for Hard Times* (2019) that in spatial contexts both capital and labour are “sticky”.
- Resources move between places both much more slowly and by less than much economic theory presumes.
- “Economists have traditionally been unwilling to embrace place-based projects....This analysis seems to give too little weight to the facts on the ground” (p.85)

# A parsimonious theoretical model: preferential attachment

- Simon, H.A., 1955. On a class of skew distribution functions. *Biometrika*, 42(3/4), pp.425-440.
- Barabási, A.L. and Albert, R., 1999. Emergence of scaling in random networks. *Science*, 286(5439), pp.509-512.
- There are  $k$  locations, and we initially allocate  $n$  agents to them at random. New agents enter the model and choose amongst the locations with probabilities equal to the proportions of agents which are already on them.
- This is a self-reinforcing process which produces: inequality which is strongly persistent
- But the problem is that after a relatively small number steps in the process, the rankings – certainly at the most popular end – have only a tiny probability of being changed.

# Copying/social learning is effective in complex environments

- Alchian, A.A., 1950. Uncertainty, evolution, and economic theory. *Journal of Political Economy*, 58(3), pp.211-221.
- Rendell, L., Boyd, R., Cownden, D., Enquist, M., Eriksson, K., Feldman, M.W., Fogarty, L., Ghirlanda, S., Lillicrap, T. and Laland, K.N., 2010. Why copy others? Insights from the social learning strategies tournament. *Science*, 328(5975), pp.208-213.
- A computer tournament in which strategies competed in a complex and changing simulation environment. Each agent has 3 options on each round
- *Innovate*: individual learning e.g. trial and error, which always returned accurate information about the payoff; *Observe*: represented any form of social learning or copying through which an agent could acquire a behaviour performed by another individual - this information is noisy; *Exploit*: agents acquire a payoff - pulling one of the bandit's arms
- “The most important outcome of the tournament is the remarkable success of strategies that rely heavily on copying when learning. This outcome was not anticipated by the tournament organizers, nor by the committee of experts established to oversee the tournament”p.212

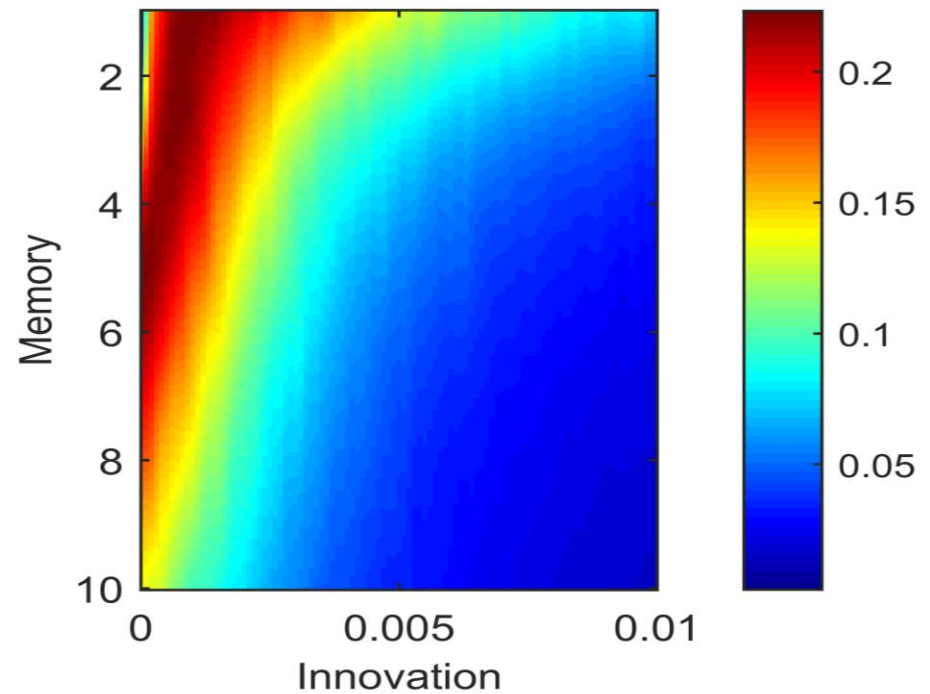
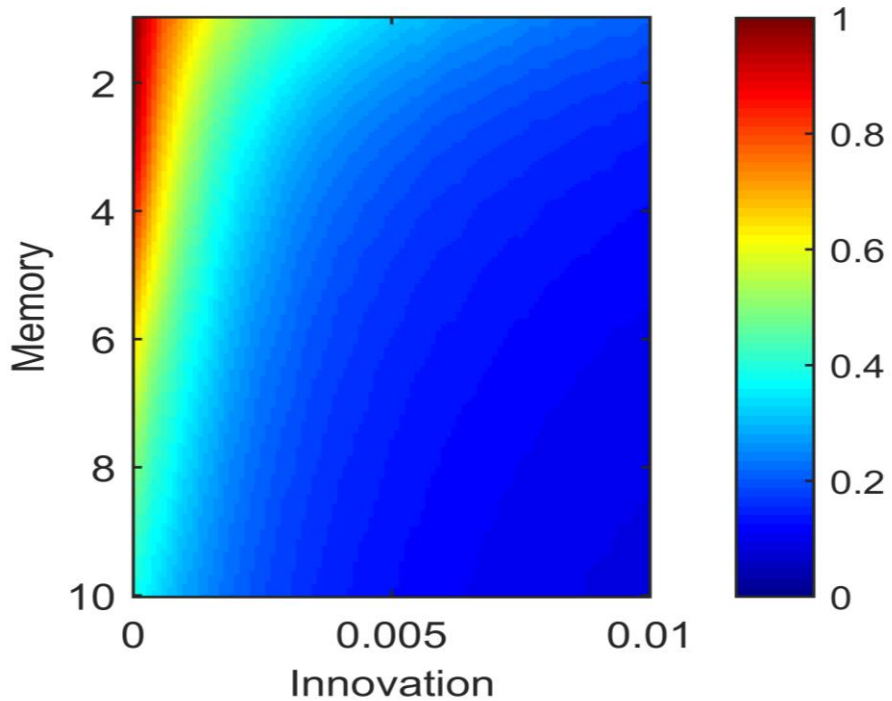
# A generalisation: adding innovation

- It is based on a classic model of genetic evolution Wright, S., 1931. Evolution in Mendelian populations. *Genetics*, 16(2), pp.97-159
- The core principle remains that of preferential attachment (PA). But, when a new agent chooses, with a small probability it chooses from existing locations purely at random
- This “**innovation**” parameter ensures that even the most popular location will eventually lose its number one slot.
- The higher is innovation, the greater the chances of low ranked locations moving up substantially

## More features but still parsimonious

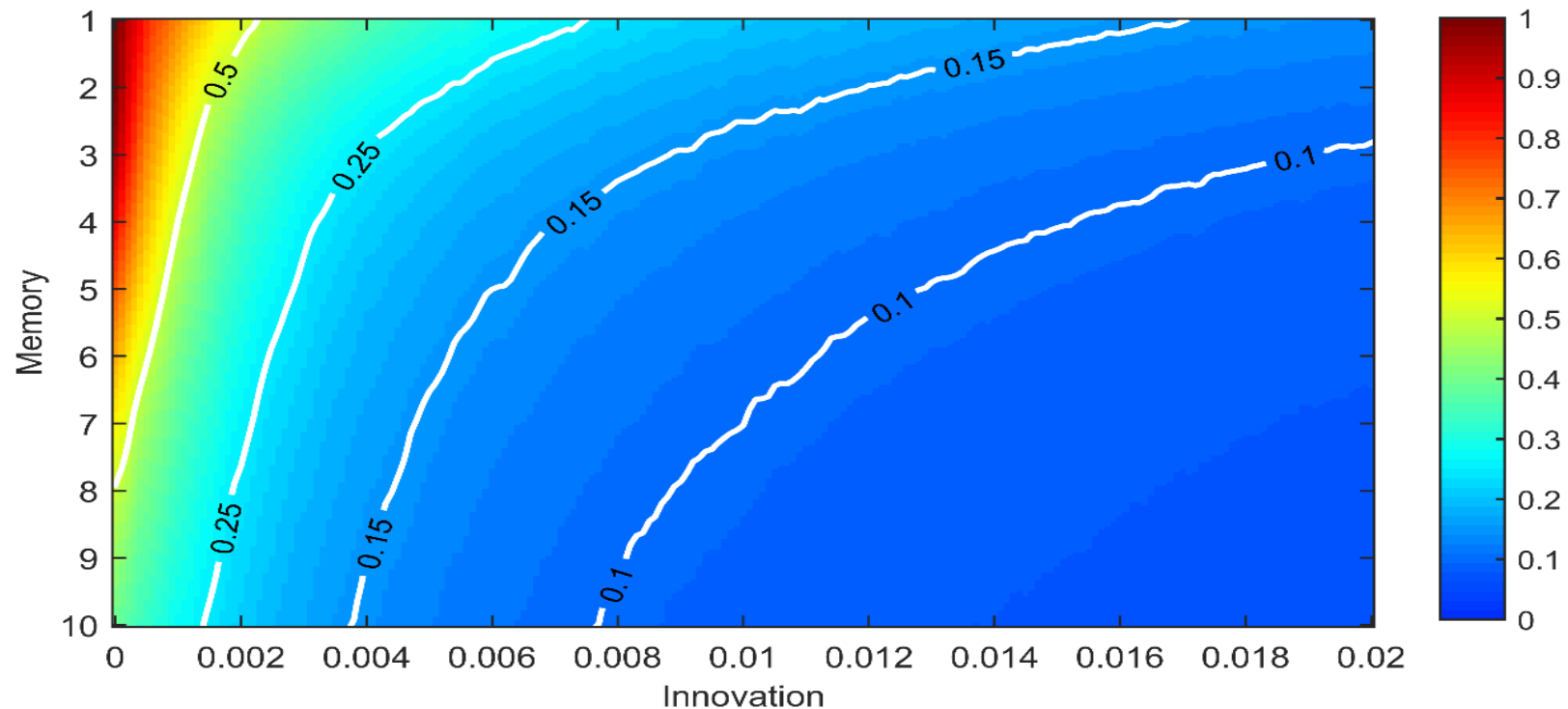
- PA assumes that all previous choices are taken into account when calculating probabilities. Bentley, R.A., Ormerod, P. and Batty, M., 2011. Evolving social influence in large populations. *Behavioral Ecology and Sociobiology*, 65(3), pp.537-546 add a “memory” parameter.
- Bentley, R.A., Caiado, C.C. and Ormerod, P., 2014. Effects of memory on spatial heterogeneity in neutrally transmitted culture. *Evolution and Human Behavior*, 35(4), pp.257-263 add a spatial dimension
- Nyman, R., Ormerod, P. and Bentley, R.A., 2023. A Simple Model of the Rise and Fall of Civilizations. *Entropy*, 25(9), p.1298.

Mean values and standard deviation around the mean of the HH Index obtained across 1,000 separate solutions of the model for each pair of the innovation and memory parameters examined. There are 1010 such combinations, with memory taking integer values from 1 through 10, and innovation measured in steps from 0 to 0.01





Mean values of the HH Index obtained across 1,000 separate solutions of the model for each pair of the innovation and memory parameters examined. There are 2010 such combinations, with memory taking integer values from 1 through 10, and innovation measured in steps from 0 to 0.02. All solutions to the right of the 0.1 contour line have a mean HH Index value of less than 0.1 etc



# Policy implications

- The basic processes implied by clusters/agglomeration/preferential attachment generate unequal spatial outcomes of incomes/productivity.
- There is an inherent tendency of the outcomes to become “locked in” – market forces will have at best a weak effect on lifting up the less productive areas. *Public sector intervention is therefore justified.*
- **The higher the rate of innovation, the greater the chances of the less successful areas being lifted up.**
- “economic complexity that combines data on the geography of exports by product, patents by technology, and scientific publications by field of research shows that countries that score high in all three metrics tend to exhibit lower emission intensities” Stojkoski, V., Koch, P. and Hidalgo, C.A., 2023. Multidimensional economic complexity and inclusive green growth. *Communications Earth & Environment*, 4(1), p.130
- Strong links with the universities and their associated research institutes in the city centre is a key part of the Atom Valley strategy, plus a centre located in Atom Valley to promote diffusion of technology in machines, materials and AI/machine learning, plus courses at FE colleges tailored specifically not just to industry but to individual firm needs – **innovation**