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POSITIVE FEEDBACK AND COMPLEXITY

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Abstract: A nonlinear stochastic process combined with the positive feedback feature display increasing returns. A dynamic process with increasing returns may result in lock-in, path dependence and self-organizing behavior with multiple equilibria and possible inefficiency. Small changes in the system may lead to disproportionate and unpredictable effects. These are major properties of complexities and also part of the differences between complex economics and neoclassical economics.

Keywords: positive feedback, increasing returns, nonlinear process

1. INTRODUCTION

A complex system is typically modeled as a collection of interacting agents, representing components as diverse as people, cells or molecules. Complex systems are often characterized by a high degree of interconnectedness, where elements or components are dynamically interdependent and influence each other. The interaction structures of individual elements determined behavior and characteristics of the overall system. Changes in one part of the system have effects throughout the entire system. Small changes in one part of the system can lead to disproportionately large and unpredictable effects in other parts.

This non-linear interaction can make it challenging to predict or control the behavior of complex systems. Furthermore, positive feedback loops play a significant role in complex systems. Positive feedbacks cumulate advantage which can influence the system's stability and behavior. The existence of positive feedbacks amplifies small differences in past and lead to lock-in effects which leads to the property of historical path dependence. In addition, complex systems can spontaneously arrange themselves into structured patterns or states without external intervention. Local interactions eventually produce global coordination and synergy. This self-organization property is often seen in biological systems, such as flocking behavior in birds or the formation of ant colonies.

The nonlinear dynamic processes with random events and positive feedbacks characterized as increasing returns make the system unpredictable and uncontrollable. These features that exhibit diverse patterns and unpredictable outcomes in time and space are called complexity. Complexity exists in nature and society, such as urban evolution, population growth, ecosystems, financial markets, social networks, transportation systems, and atmospheric and climate systems. The agents in different systems representing different system units such as cities, individuals, cells or molecules; the self-organized structure in the system can often be constructed in the form of a network functioning as links connecting the agents. Such complex, self-organized networks typically exhibit the properties of clustering, being scale-free, and forming a small world.

2. POSITIVE FEEDBACK AND LOCK-IN

In complex network systems, the value of the system increases as more components join. Take social media as an example: as more users join a platform, the value of the platform increases for each user, as there are more people to interact with, share content, and connect to. This leads to a self-reinforcing cycle of growth. Complex systems often involve numerous components that are interconnected. In a networked environment, each node is connected to other nodes. The more complex the network, the more connections there are between nodes. This interconnectedness enhances the potential for network effects because each new connection can add value to the overall network, benefiting all participants.

Complex systems tend to offer diverse functionalities or features. As the complexity of a system increases, its ability to address a wide range of user needs also grows. This diversification contributes to the value proposition of the system, attracting more users and thereby strengthening network effects. The mixture of complexity and network effects also lead to sustained growth, where the benefits of the network continue to expand over time. This can make it challenging for competitors to replicate the network effects, as they would need to recreate the complexity and user base. As systems become more complex, participants gain knowledge and experience, leading to greater efficiencies and improved processes. This can result in increased productivity and better resource utilization, contributing to increasing returns. As more users join the network, the system becomes more complex, offering more value. This, in turn, attracts even more users, leading to a cycle of increasing complexity and network effects called positive feedback.

Positive feedback is a process where a change in a system leads to further changes that reinforce the initial change. It can amplify the effects of historical choices or events. When an initial decision or event sets a system on a particular path, positive feedback can make it increasingly difficult to deviate from that path. This is because the initial choice accumulates advantages and momentum, reinforcing the direction initially taken.

Small events or choices made in the past have a disproportionate impact on the current state of the system. As positive feedback reinforces the chosen path, the system becomes increasingly dependent on the historical factors that set it in motion.

Lock-in often arises from historical decisions that become deeply embedded in a system. These decisions may be based on factors such as technology adoption, infrastructure investments, or regulatory frameworks. As the system becomes more locked in, it is increasingly dependent on the past decisions and technologies that led to its current state. It can be challenging to change to a different state. This can lead to a form of complexity known as path dependence, where the current state of the system is heavily influenced by its past.

Positive feedback and path dependence can create reinforcing feedback loops. The initial historical choices or events set the system on a path, and positive feedback amplifies the effects of those choices, making it more difficult to deviate from that path. This feedback loop can result in entrenched lock-in. In complex systems with strong network effects, users might become "locked in" to the platform due to the value derived from the network. Switching to an alternative platform can be challenging due to the loss of network benefits and switching coast involved in transitioning to a new system.

In some cases, the early adoption of a particular technology or standard can create a situation where the system becomes increasingly difficult to switch away from. This can lead to a snowball effect where the system's complexity is reinforced, and the benefits of switching to a different approach become less tempting. Lock-in effects, also known as path dependence, occur when the choices made early in the development of a system create a situation where it becomes increasingly difficult or costly to switch to an alternative. Switching to an alternative solution or system can be costly and time-consuming due to the intricacies of the system. These costs can include retraining personnel, migrating data, reconfiguring processes, and adapting to new interfaces. This effect leads to a self-reinforcing cycle where the more a system is adopted and invested in, the harder it becomes to switch away from it.[1]

Increasing Returns

The property of increasing returns appears in many fields: such as knowledge economy, space economy and international trade. A technology markets with dynamic and increasing-return nature can lead to the systems gradually locked into suboptimal, unpredictable outcomes (Arthur, 1989). Applying the property of increasing returns to the field of economic geography can explain the phenomenon of manufacture agglomeration; and the existence of cities is the result of increasing returns (Krugman, 1991). Accumulation processes under increasing returns lead to regions of varying degrees of development (Krugman, 1992). In trade theory, different mechanisms of increasing returns can lead to various equilibrium outcomes (Krugman, 1985). The determination of industrial location is not necessarily the only result of equilibrium in a spatial economy.

The resources-based economy such as agriculture and mining are constrained by limited fertile land or mineral deposits presenting diminishing returns. Knowledge-based economy has larger proportion of fixed costs than variable costs. Consequently, the average cost is diminishing with the increase of output; the marginal cost mostly is very small. There are economies of scale, and it shows the phenomenon of increasing returns. It has the characteristics of complexity: the result is unpredictable multiple equilibrium or non-equilibrium, and the result is not necessarily efficient. Small random influences in the process may change the subsequent results, that is, the locking effect; different processes and trajectories will have different results, that is, path dependence.

An economy with diminishing returns tends to one predictable equilibrium; the development process and sequence will not determine the final result. A static analysis method can obtain a unique equilibrium outcome. If economic activities have positive feedback, that is, have the characteristics of increasing returns, the result is not approaching the only solution, but there are multiple possible equilibrium or non-equilibrium solutions. It is impossible to resolve a unique efficient optimal solution. Different paths with random events in the process, or different sequences, may lead to different outcomes presenting locked choices. An economy with increasing returns is better analyzed by a nonlinear dynamic analysis including stochastic events and positive feedback mechanisms rather than a static optimal analysis.

3. NONLINEAR RANDOM PROCESSES

A small difference in the initial phase may cause subsequent large-scale structural changes, and because of this, the results are difficult to predict. Therefore, the evolution process of the economy dominated by the mechanism of increasing returns is modeled by a nonlinear dynamic stochastic process. Although there may be many possible results, the system is unpredictable, but the possible dynamic behavior of the system can be analyzed with the nonlinear probability theory.

Nonlinear random processes can lead to the emergence of complex behaviors and patterns that are not immediately apparent from the individual components or initial conditions. These emergent behaviors can be complex and difficult to predict due to the nonlinear interactions involved. It can also show sensitivity to initial conditions, which means that even small changes can lead to significantly different outcomes. This sensitivity can contribute to unpredictable and complex behaviors that arise from slight variations.

In addition, chaotic behavior is a character of many nonlinear systems. Chaotic systems are highly sensitive to initial conditions, and they can exhibit intricate, seemingly random behaviors. These behaviors can resemble complexity, as they can create patterns that are difficult to decipher. Furthermore, nonlinear processes often involve feedback loops and self-organizing behavior. These processes can give rise to complex structures and patterns that emerge from the interactions between elements. The interactions between different nonlinear processes or elements can lead to nonlinear interaction effects that create new emergent behaviors. These interactions can lead to further complexity in the system.

Polya Process

A model of nonlinear Polya process is applied to generate path dependence processes.[2] Assume residents decide on locating in one of *N* possible sites. Let $s_{i,t}(i=1,\ldots,N)$ describe the population of city *i* at time *t*; and $x_{i,t}(i=1,\ldots,N)$ describes the proportion of population of city *i* in the region at time *t*. Assume there is agglomeration benefit for resident in cities. The probability that the next resident prefers site *i* over all other sites is: $q_{i,t}(x_{i,t})$ which is a function of current city population proportion. The change of size at city *i* follows the dynamic process:

$$s_{i,t+1}=s_{i,t}+\beta_{i,t}(x_{i,t}),$$

where

$$\beta_{i,t}=\begin{cases}1 & \text{with probability } q_{i,t}(x_{i,t})\\ 0 & \text{with probability } 1-q_{i,t}(x_{i,t})\end{cases}$$

The evolution of the relative city size at city *i* is:

$$x_{i,t+1}=x_{i,t}+\frac{1}{(z+t)}\left[q_{i,t}(x_{i,t})-x_{i,t}\right],$$

where *z* is the total population initially.

The form of the probability function that the resident choosing city,, determining the dynamic process is convergence or divergence. In figure 1a, the

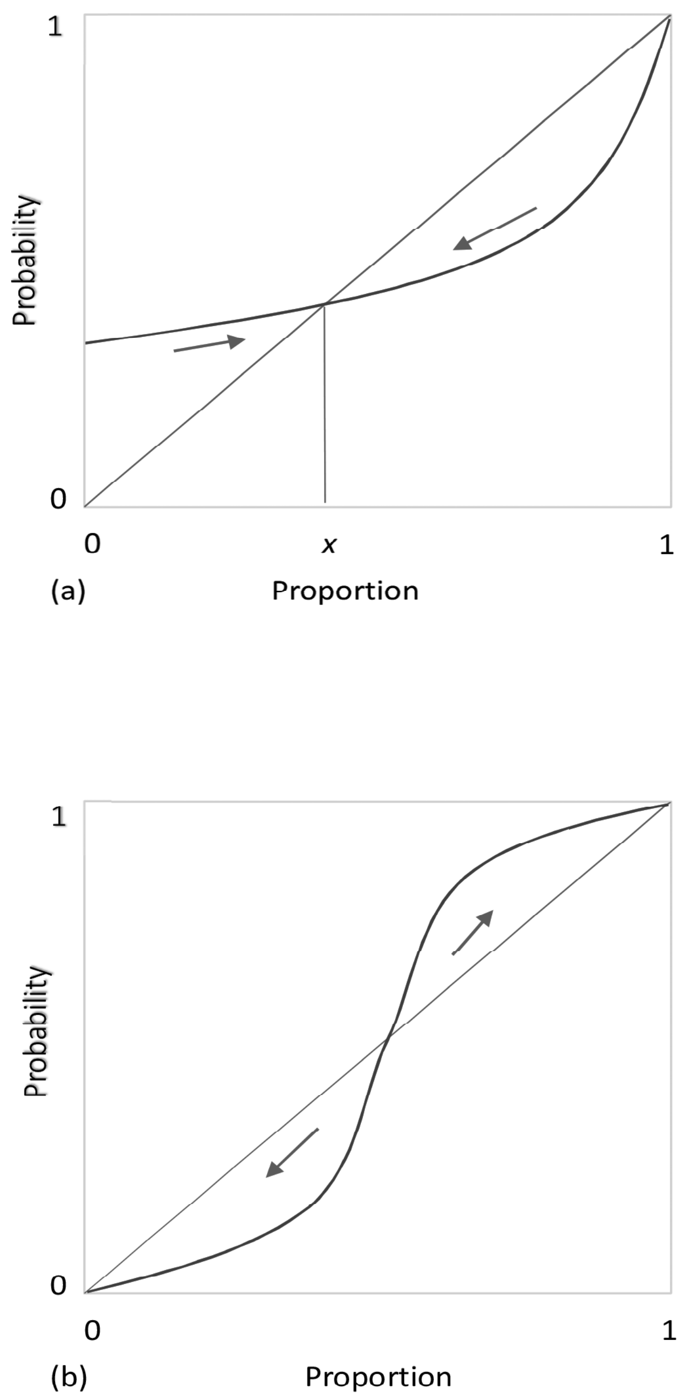
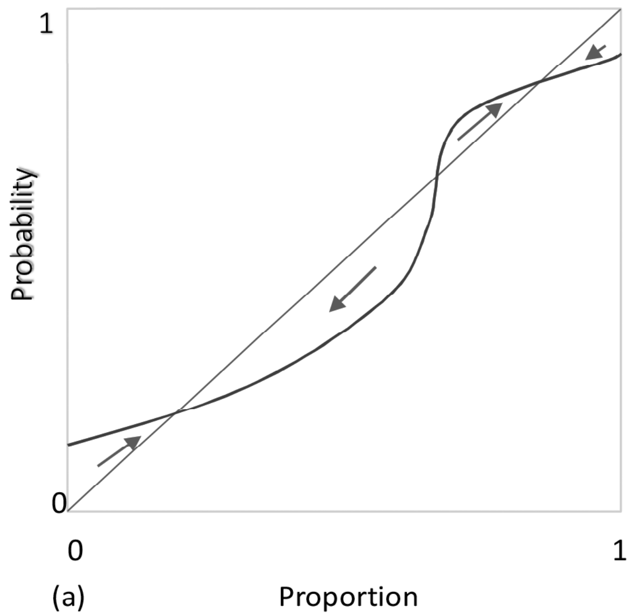


Figure 1: Nonlinear probability function assumed in the Polya process.



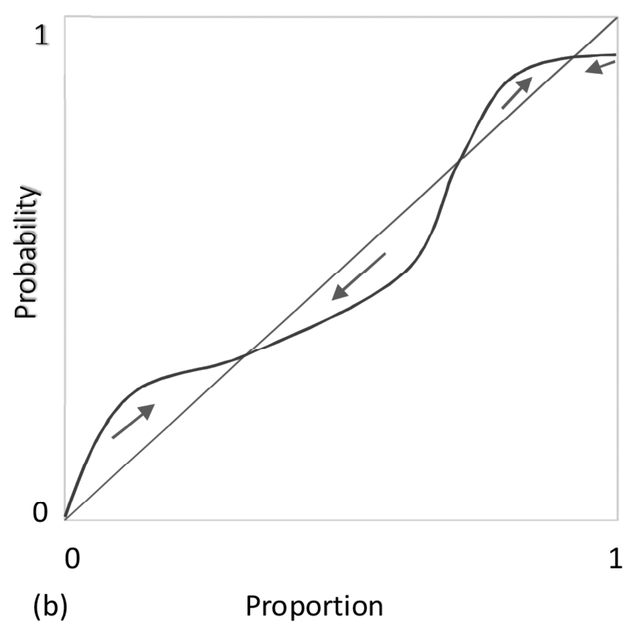


Figure 2 (a)(b): Nonlinear probability function assumed in the Polya process.

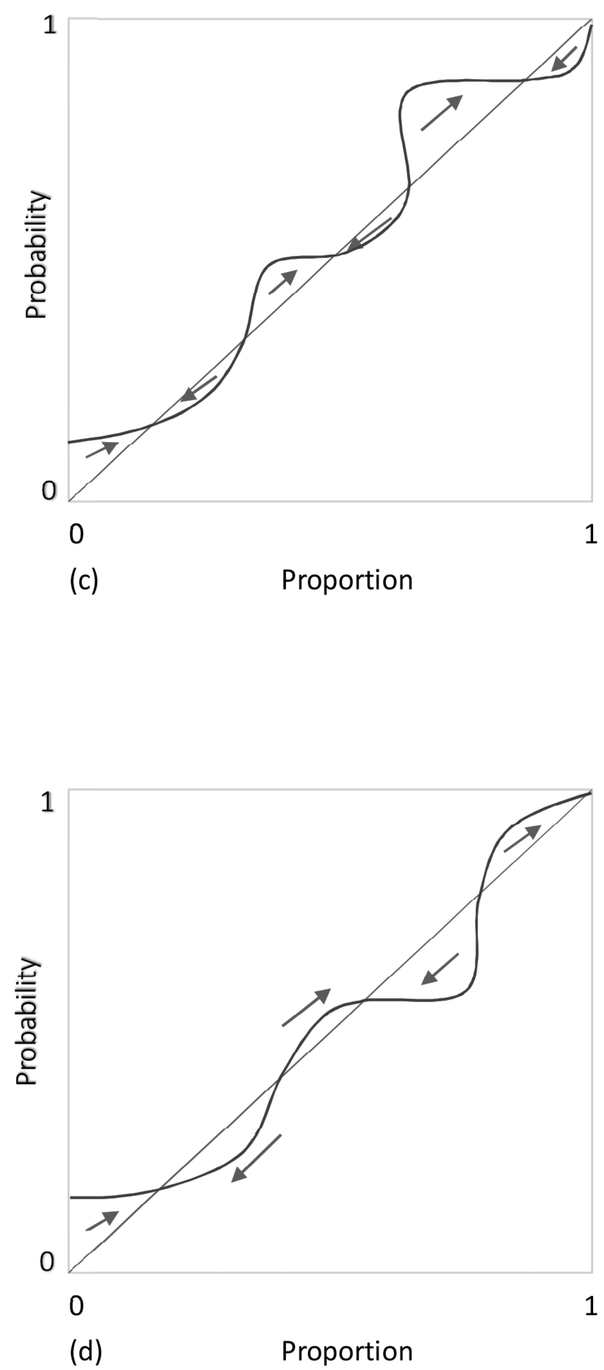


Figure 2 (c)(d): Nonlinear probability function assumed in the Polya process.

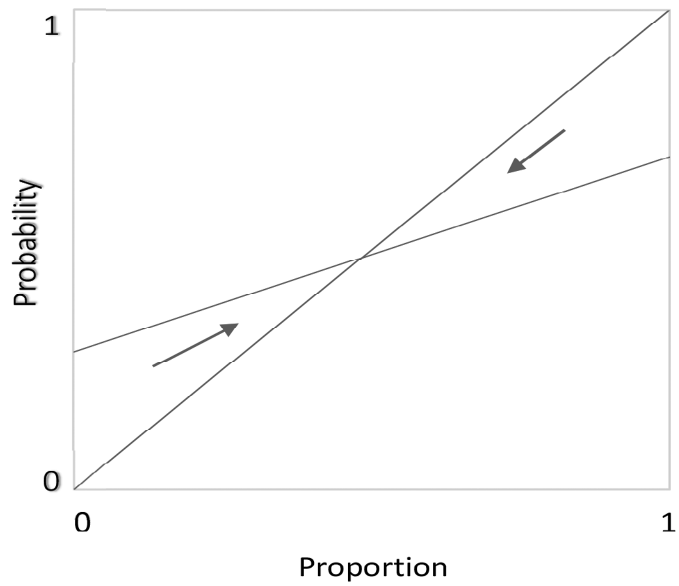


Figure 3: Linear probability function assumed in the Polya process.

function shows a tendency toward a fixed point x. In figure 1b, the function shows a tendency toward 0 or 1. Figure 2 shows various complicated nonlinear functions all with attractions toward several fixed points. Figure 3 is a linear probability function displaying a tendency toward a fixed point. This simple model shows that if the probability function is a linear function of city population share, the limiting population is converging to a certain stable proportion. However, if the probability function is nonlinear with positive feedback, the limiting population shares become uncertain and unpredictable; the result may be multiple stable or unstable equilibrium. This simple nonlinear Polya process generates path-dependence processes and lock-in features which results in the uncertainty and possible multiple equilibriums. These are the properties of complexities. All these features mainly result from the positive feedback and dynamic nonlinear random process of the model.

4. CONCLUDING REMARKS

A nonlinear dynamic stochastic process, combined with the positive feedback characteristics, can show the phenomenon of increasing returns. In a dynamic process of increasing returns, its self-reinforcement mechanism generates four characteristics: multiple equilibria, possible inefficiency, lock-in and path dependence. Small changes in the system may lead to disproportionate and unpredictable effects. This is the so-called path dependence caused by lock-in characteristics. These characteristics caused by increasing returns are also part of the differences between complex economics and neoclassical economics.

NOTES

1. Antonelli (2011), Niosi (2011)
2. Authur (1994), Page, (2006)

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