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Future of Networked Information Society: A Deeply Interconnected "Primitive Society"

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ABSTRACT

Human society is evolving toward the future network information society. In this paper, we identify the interconnected level as the key factor driving the evolution of human society and incorporate it into our proposed evolutionary model of social formation. We show the entire process of social formation evolution at the interconnected level through theoretical analysis and simulation. Our result is consistent with what human beings have gone through. By contrast, the result presents the following four characteristics of the future network information society: the personalization of goods or services, the downsizing of enterprises or organizations, the decentralization of production or life, and the sharing of production or living tools. We regard the future network information society as a deeply interconnected "primitive society".

KEYWORDS

network information society; interconnected level; social formation; evolution trends

The functioning of society is based on interconnection and cooperation among human beings[1–3]. The way how economic activities are conducted, including the production, exchange, and consumption of goods or services, can be exploited to distinguish different social forms. These social forms correspond to different characteristics, such as the production of goods or services and the way people live, which are shown in Table 1.

1 Related Work

Since the industrial society, a series of highly-centralized phenomena have emerged with the continuous enrichment of our living foundations in industrial society, such as megacities, mega communities, and mega factories[4–7]. These phenomena have introduced various problems, such as climate change[8,9], environmental pollution[10–12], resource depletion[13,14], traffic congestion[15], the spread of diseases[16], and the imbalance of urban and rural development[17]. To make matters worse, the status quo is still deteriorating. The ways of industrialization are challenging the sustainable development of human society.

A new round of technological revolution has been emerging since the 21st century. Various technologies, such as cloud computing, Internet of things, big data, blockchain, and artificial intelligence, deepen the interconnection of everything in human society, thereby bringing human beings into the networked information society. How will the future of networked information society change the characteristics of goods or services, the scale of production organizations, the distribution of production and life, and the acquisition and usage mode of production and living tools? Is there some enlightenment for exploring the sustainable development model of human society?

Looking back in history, human beings are in a state of highly fragmented tribal life in hunter–gatherer societies. The contact between different ethnic groups is minimal due to the lack of roads and communication tools. Considering the production and consumption of goods or services, self-sufficiency was the mainstream mode, and no exchange behavior was observed yet. At that time, the scale of production organizations was small, goods or services were highly personalized, and production and the sharing of living tools were prevalent[18].

After entering the agricultural society, the contact between different ethnic groups increased due to the appearance of roads. With the formation of villages, towns, and city-states of varying sizes, the highly dispersed state of production and life in hunter–gatherer societies evolved toward a centralized direction. Although the self-sufficient small farmer economy is still the mainstream, small-scale and face-to-face exchanges of personalized agricultural products began to appear, which gradually developed toward a large-scale and standardized direction afterward. Purchases became increasingly common despite self-made production and living tools.

Table 1 Review of the evolution of human society.

Characteristics of human society	Hunter–gatherer society	Agricultural society	Industrial society
Products or services	Personalized	Partly standardized	Standardized
Scale of production organizations	Very small	Small	Large
Distribution of production and life	Extremely dispersed	Dispersed	Concentrated
Acquisition and usage mode of production and living tools	Self-made, public-owned	Self-made or purchased, private-owned	Purchased or partly rented, privately owned

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With the establishment of transportation networks, such as highways, railways, and aviation, together with the invention of communication technologies, such as telegraph and telephone, the closeness of human social connection and communication has been significantly promoted in industrial society. Consequently, the production, exchange, and consumption of products or services have begun to evolve in a standardized, large-scale, and centralized manner.

The previous discussion revealed that the closeness of the connections and communications between people, people and organizations, and organizations and other behavioral subjects in a society is one of the essential reasons for the evolution of the human social form.

We refer to the closeness degree of the connections and communications between various behavioral subjects in society as the interconnected level. This level is positively related to the development of transportation, communication, and other infrastructures in society. The main factors affecting the interconnected level can be summarized as the dimensions of space and time. Among them, the space factor reflects the coverage of the connection, determining the breadth of interconnections. An extensive coverage indicates the potential connection of additional objects. The time factor reflects the efficiency of connection, determining the depth of interconnections. A high efficiency leads to additional connections or interactive information per unit time.

If we use S and T to represent the space and time factors, respectively, then the interconnected level (ICL) k is a function of S and T, and k is positively proportional to S and T.

$$k = f(S, T), k \in [0,1], k \propto S, k \propto T \quad (1)$$

Based on the previous discussion, we measured the interconnected level for China according to the historical data of total railway mileage, total highway mileage, total aviation mileage, network coverage, and network speed from 1884 to 2020 and provided the predicted interconnected level until 2050, as shown in Fig. 1.

2 Method

The time fitting function of the interconnected level is shown in Eq. (1). Herein, t' is the normalized value of the year variable t from 1894 to 2049, that is, $t' = \frac{t - 1894}{2049 - 1894}$.

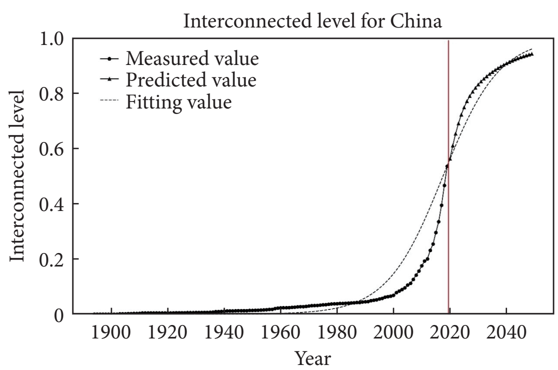

Fig. 1 Measurement and prediction of the interconnected level for China. The black solid circles and connecting lines on the left side of the red vertical line (2020) are the measured interconnected levels in history, and the black solid triangles and connecting lines on the right are the predictions of the interconnected levels based on logistic function fitting. The black dashed line is the fitting logistic function (Eq. (1)) based on the measured and predicted values of the interconnected level.

Figure 1 shows that the interconnected level for China conforms to the logistic growth model (the interconnected level in other regions should also conform to the logistic growth model). The interconnected level for China increased remarkably slowly from 1894 to 2000 in Fig. 1. The growth rate of the interconnected level after 2000 rapidly accelerated (the main reason is the application and popularization of Internet-based technologies). If the development trend of the interconnected level remains unchanged, then it will reach 0.83, 0.91, and 0.94 in 2030, 2040, and 2050, respectively, whose current value is 0.55 in 2020.

Human beings are gradually stepping into the networked information society with an increasingly interconnected level. The future of networked information society will evolve toward the personalization of goods or services, the downsizing of enterprises or organizations, the decentralization of production or life, and the sharing of production or living tools. The theoretical discussion is as follows.

From the perspective of demand, the American psychologist Maslow summarized human needs from low to high into five levels, namely physiological, safety, social, respect, and self-realization needs[19]. A high level of demand requires increased personalization. The level of demand will gradually increase with the improvement of people’s living standards. In other words, human needs will develop toward a personalized direction. From the perspective of supply, with the gradual increase in interconnected level and the development of the economy and society, the specialized division of labor, the collaboration degree, and the diversity of products in society will become increasingly higher, and the cost of producing or providing personalized products or services will become lower. Thus, the ability to meet the individual needs of people will increase. Supply and demand will promote each other and jointly push the development of products or services toward a personalized direction.

The scale of an enterprise or an organization refers to its physical size, which is represented by the number of employees. Small-scale family or manual workshop was the main mode of production organization in the early stage of primitive hunter–gatherer and agricultural societies. Enterprises are born with the development of industry and commerce. Coase[20] thinks that the best scale or boundary for an enterprise lies at the point where the transaction cost of the internal organization (including management cost) is equal to that of the market organization. In industrial society, the transaction cost of market organizations is quite high due to the interconnected level; thus, the average scale of enterprises is relatively large. Large-scale centralized production organizations were quite common during that time. With the increase in the interconnected level, the transaction cost of market organizations will decrease, and the boundary of enterprises will gradually shrink inward, leading to the downsizing of enterprises. By contrast, with the rise in the interconnected level, enterprises are becoming increasingly inclined to outsource labor or sign order-type labor contracts with employees. As a competitive way to obtain human resources, contracted employment will gradually become the conventional way of employment[21], thus accelerating the downsizing process of enterprises or organizations. Simultaneously, the advantages of small and medium enterprises in innovation[22] and the reduction of the income gap with large companies[23] are also boosting the downsizing process due to the rapid development of information technology and Internet technology.

Pursuing a beautiful, comfortable, and low-cost living environment is natural for human beings. In industrial society, people gathered in large cities to pursue a convenient and comfortable living environment and seek additional and satisfactory job opportunities[24]. With the increase in the interconnected level, obtaining means of living, services, job opportunities, and telecommuting is possible through the Internet. People will then spread to places with improved natural environments and choose areas with satisfactory ecological environments to live and work. Simultaneously, enterprises will gradually decentralize the layout of production sites to comply with the decentralization of life; that is, the decentralization of life will, in turn, promote the decentralization of production.

Production and living tools will present a sharing state with the gradually increasing interconnected level due to the following. (1) With the production and life tools becoming increasingly complex and intelligent, the cost of owning and maintaining these tools is also becoming increasingly high. (2) The gradual improvement of various digital and intelligent infrastructures has markedly reduced the cost of discovering and using production and living tools. The habit of not asking for everything but only using it is emerging. As a new way to conduct economic activities, the sharing economy currently provides a new idea for human beings to build a resource-saving and environment-friendly society[25], such as the booming car and housing sharing.

2.1 Interconnected level

We measure the ICL in China from spatial and temporal perspectives. Considering spatial factors, we use road, rail, air, and network coverage to reflect the coverage of connectivity. Meanwhile, considering temporal factors, we use the average rate of roads, rail, air, and networks to reflect the response and transmission rates of the connection. The formula of ICL can be expressed as follows:

$$k = w_S \sum_{j=1}^{4} w_{S_j} cr_j + w_T \sum_{j=1}^{4} w_{T_j} rt_j$$

where w_S and w_T are the weights of spatial and temporal factors, respectively ($w_S + w_T = 1$); w_{S_j} and w_{T_j} are the weights of road, rail, air, and network within the spatial and temporal factors $\left(\sum_{j=1}^{4} w_{S_j} = 1, \sum_{j=1}^{4} w_{T_j} = 1\right)$; cr_j and rt_j are the scoring values of each indicator; cr_j is the coverage rate; rt_j is the respense and transmission rate; $cr_j, rt_j \in [0,1]$.

First, we conducted a principal component analysis on the annual data of the five indicators for China for the past 20 years to obtain the weights of each indicator. The coefficients of each indicator in the first principal component are used as the weights of each indicator. Then, we fit the historical data of each indicator due to the availability of records (as early as 1884) with a logistic regression function to predict the development trend and limit the state of each indicator. Finally, we combined the weights with the scores of each indicator (normalized to the 0 and 1 interval) to measure the current ICL in China and give predicted values.

We performed a series of simulation experiments to verify the evolution history of human society, considering the production, exchange, and consumption characteristics of products and services based on our theoretical analysis results and predict the basic characteristics of the future networked information society.

The basic assumptions of the simulation experiment are presented as follows. (1) Enterprise and individuals in an enterprise are producers and consumers of products and services, respectively. (2) A specialized economic effect exists in enterprise production. (3) The per capita management cost in enterprises increases with the expansion of the scale; that is, a large-scale enterprise indicates a high per capita management cost.

2.2 Decision-making model

As the basic decision-making unit, the firm in our evolutionary model autonomously decides on the number of personnel inputs on several products, the pattern and volume of product exchanges with other firms, and the location where production is performed. We observe the evolutionary behavior of many firms considering product production and exchange when the external environment (i.e., the ICL) changes.

2.2.1 Production

The production strategy of firm i is denoted as $M_i = (m_{i,1}, m_{i,2}, \ldots, m_{i,n-1}, m_{i,n})$, $m_{i,j} \geqslant 0, \sum_{j=1}^{n} m_{i,j} \leqslant Z$, where $m_{i,j}$ is the number of workers producing the j-th product in firm i. S is the maximum size of the firm: when the total number of people in the firm is Z, the labor time of all people is spent on management. Each worker has 1 unit of labor time. A management cost, which increases with firm size, exists within the firm. The management cost of firm i is $c_i = \left(\frac{\sum_{j=1}^{n} m_{i,j}}{Z}\right)^{(1-k)\cdot\gamma}$, where γ is the management cost coefficient and $\gamma > 0$. Therefore, c_i obtains a maximum value of 1 when $\sum_{j=1}^{n} m_{i,j} = Z$. A large γ indicates the rapid increase of c_i with the firm size of the enterprise, and a large k indicates a small management cost. For firm i, the labor time of each worker is $l_i = 1 - c_i$. An economic effect of specialization is also observed in product production.

The production function of the j-th product of firm i is $p_{i,j} = L_{i,j}^{\alpha_j}$, where $p_{i,j}$ is the output of product j and $L_{i,j}$ is the amount of labor time invested in production. $L_{i,j} = m_{i,j} \cdot l_i$, α_j is the technicality factor of the production, and $\alpha_j > 1$, which indicates that productivity rises with increasing inputs. For simplicity, $\alpha_1 = \alpha_2 = \cdots = \alpha_j = \alpha$. The firm can obtain high productivity by focusing on a few product categories, which is denoted as $p_{i,j} = L_{i,j}^{\alpha+\beta\cdot n_i}$. β is the specialization factor of the production function, $\beta > 0$, and n_i is the degree of focus of the firm's production mode, $n_i = \sum_{j=1}^{n} I_{i,j}(m_{i,j})$. When $m_{i,j} = 0$, $I_{i,j}(m_{i,j}) = 1$; otherwise, $I_{i,j}(m_{i,j}) = 0$. Overall, the production volume of the j-th product of firm i is expressed as follows:

$$p_{i,j} = [m_{i,j} \cdot (1 - c_i)]^{\alpha+\beta\cdot n_i},$$

where $c_i = \left(\frac{\sum_{j=1}^{n} m_{i,j}}{S}\right)^{(1-k)\cdot\gamma}$ and $n_i = \sum_{j=1}^{n} I_{i,j}(m_{i,j})$.

2.2.2 Product exchange

Driven by the per capita fitness evaluation function $F_i = \delta(r_i) \frac{\prod_{j=1}^{n} p_{i,j}}{\sum_{j=1}^{n} m_{i,j}}$, $p_{i,j}$ is the quantity of the j-th product held by firm i. Firm i must exchange products with other firms to improve its per capita fitness. $\prod_{j=1}^{n} p_{i,j}$ in the fitness evaluation function indicates that increasing the holdings of one or a few products does not lead to an increase in fitness provided that the total number of holdings remains constant. Firms seek a balance of holdings among all product categories; thus, product exchange is necessary.

When exchanging products with others, firms have two optional exchange modes for each product: the buy–sell and rent modes. The product exchange mode for firm i is denoted as $E_i = [e_{i,1}, e_{i,2}, \ldots, e_{i,n}]$, where $e_{i,j} = 0$ indicates that the exchange mode of enterprise i on the j-th product is the buy–sell mode, and $e_{i,j} = 1$ for the rent mode.

In the buy–sell mode, the firm exchanges out or obtains ownership of a certain type of product with a certain amount. Meanwhile, in the rent mode, the firm offers or obtains the right to use a certain type of product with a certain amount. The contribution of the product's ownership and use is the same during the evaluation of the firm's fitness. However, a product with the right to use would be unavailable for subsequent product exchanges.

The use of durable products (including end-use consumer goods and manufacturing and processing equipment) introduces wear and tear. The durability factor d assumes the depreciation rate of the product for one use. The remaining amount of the product with a total amount of m after being used once is $u(1-d)$, and the product usage amount obtained by the renter is u.

Product exchange follows the principle of maximum variety and minimum quantity. That is, when two firms match supply and demand, these firms exchange all products that can be matched, and the exchange amount is equal to the minimum supply of these products. Suppose that the exchange demand of firms i and j on the n_1 and n_2 products is matched, firm i exchanges product n_1 to obtain product n_2 and vice versa, and the amount of exchanged products is m. Owing to the interconnection costs between firms ($k < 1$), the actual gain between two firms after the production exchange is affected by the k, and the remaining amount of products with a total amount of v after the exchange is vk. For simplicity, we assume that the product exchange cost introduced by the ICL is fully supported by the demand side (the assumption of exchange costs does not affect the simulation results of this paper).

2.2.3 Site selection for production and life

We constructed a two-dimensional map and divided it into several regions based on the topographical environment and natural resource distribution in northern China. For each region (denoted as $s_i = (x_i, y_i)$), we evaluate the possession of high-quality resources (denoted as r_i) considering the geographical environment and natural resources required for production and living, which reflects the livability of the region. Specifically, livability includes a total of four indicators: average regional elevation, average annual temperature, freshwater resource retention, and vegetation cover※. The site selection strategy of firm i is denoted as $l_i = (x_i, y_i)$. The fitness function $F_i = \delta(l_i)\dfrac{\prod_{j=1}^{n} p_{i,j}}{\sum_{j=1}^{n} m_{i,j}}$ evaluates the competitiveness of the firm from the perspective of per capita revenue, where $p_{i,j}$ is the occupancy of firm i on the j-th product, $\sum_{j=1}^{n} m_{i,j}$ is the total number of people in firm i, $\delta(l_i) = \dfrac{r_i}{n_i}$ is the per capita share of quality resources in enterprise i, n_i is the total number of people in the region where firm i is located, and r_i is the possession of high-quality resources in the i-th region. k changes with the distance of the two firms. k at which firms i and j exchange products is $k_{l_i,l_j} = \min\left(\max\left(k + g\cdot\left(1-2\dfrac{d_{l_i,l_j}}{L}\right), 0\right), 1\right)$, where d_{l_i,l_j} is the Euclidean distance between areas l_i and l_j, L is half of the side length of the two-dimensional plane, and g represents the degree to which k is affected by the distance. Thus, the average k between each firm and all regions is k. However, k is high when the connected firm is close to itself.

※Data are available from the corresponding author upon reasonable request.

2.2.4 Simulation

Each company i randomly generates a product production strategy M_i, a product exchange strategy E_i, and a location strategy O_i before the simulation. Firms are distributed on a two-dimensional plane in northern China according to a siting strategy, after which they produce products and hold different numbers of product combinations. When exchanging products, company i will match the supply and demand of products with other companies according to the principle of distance priority and then exchange products due to the high interconnection level of product exchange with companies close to the distance. The matching is completed until firm i has successfully exchanged products for a certain number of times or the matches with all other firms fail. The fitness function is then used to calculate the fitness of each firm. We rank all firms from high to low and introduce newborn firms with randomly generated strategies to replace the firms with the lowest fitness ranking. The second lowest-ranked firm would learn the strategy from the highest-ranked firm and then proceed to the next round of the "production–exchange–evaluation–learning" process.

The whole simulation continues in this manner until stable product production, product exchange, and site selection strategies are developed. The developed strategies are the most competitive strategy under the current parameter setting.

The parameters of the simulation experiment are set as follows: the two-dimensional plane is divided into 16 square regions of equal area. The total number of firms $N = 200$, the number of product types $n = 4$, and the economic coefficients of production specialization α are 1.1, 1.2, and 1.3. The management cost $\gamma = 2$, the maximum size of firm $S = 10$, the factor of specialized production $\beta = 0.3$, the depreciation rate of the product $d = 0.5$, and the degree of interconnection level affected by distance $g = 0.2$. We take values of k from [0, 1] at equal intervals and conduct one simulation for each k value. One simulation runs until the competitive strategy evolves, and the average of the results of the last 10 steps is taken as the final result of this simulation. For each parameter setting, the simulation is repeated 50 times, and the average of the results is taken as the final result under this parameter setting.

2.2.5 Animation

We chose the map of northern China corresponding to the regional distribution in the decision model of this paper as the background and created an animation of population migration based on the simulation results to demonstrate the overall evolution process of the development trend of "decentralization of production or life" dynamically. In the simulation, the k values are set to 0, 0.2, 0.4, 0.6, 0.8, and 1, and the simulation is repeated 200 times at each k. The strategies are randomly generated before the experiment starts. The enterprise directly inherits the strategies from the previous round when the k changes. We use the solid blue dot to represent a person and draw the distribution of the crowd on the 2D plane once every four simulation rounds. The resulting pictures are used to create an animation of crowd migration.

3 Result and Dissussion

The simulation results in Fig. 2 show that with the increasing interconnected level from 0 to 0.55 (the current value of the interconnected level China is shown in Fig. 1), the personalization degree of goods and services (or consumption individuation degree) is initially high and then becomes lower, the size of enterprises grows from small to large, the distribution of enterprises changes from a highly dispersed state to a high degree of concentration, and the sharing degree of production and living tools gradually decreases. These simulation results coincide with the historical development of human society through hunter–gatherer, agricultural, and industrial societies. Additionally, the simulation results in Fig. 2 indicate that the future networked information society (with an interconnected level from 0.55 to 1) is evolving toward the personalization of goods and services, the downsizing of enterprises and organizations, the decentralization of production and life, and the sharing of production and living tools. The four evolution trends are referred to as the "Four Directions" in the following sections. The evolution trends of the "Four Directions" are consistent with the previous theoretical analysis of the basic characteristics of the future networked information society.

The simulation results in Fig. 2 indicate that the development status of China is as follows.

Considering products and services, Chinese society has only crossed the stage of large-scale standardized production and is evolving toward personalization. Considering enterprise-scale, Chinese society is currently at an inflection point where large-scale begins to evolve toward downsizing. Chinese society is currently at the apex of a high concentration of people considering the distribution of production and life. In terms of production and living tools, the trend of sharing is emerging, which is about to enter a stage of rapid ascent. The above conclusion is consistent with the status quo in China. Notably, the status quo and evolutionary trend of Chinese society are universal. The status quo of society presents differentiated characteristics due to the differences in the interconnected level in different regions, but the evolution trend is the same.

The future of a networked information society with extremely high interconnected levels and the primitive hunter-gathering society with extremely low interconnected levels shares similar characteristics. Thus, we call the future of networked information society the deeply interconnected "primitive society", which is an advanced return to the primitive hunter–gatherer society. The advanced point is as follows. The personalization of goods or services will substantially meet various personalized needs of people and significantly improve their living quality. The downsizing of enterprises or organizations and the decentralization of production and life are expected to solve fundamentally the traffic congestion, environmental pollution, and many other common problems caused by the excessive gathering of people in industrialized society. The sharing of production tools will maximize various resources, promote societies to embark on a road of intensive development, and help the sustainable development of human society.

4 Conclusion

Overall, the simulation results are consistent with the social status quo in China and the theoretical discussion of the basic characteristics of the future of a networked information society. Notably, the conclusions of this article are based on the absence of human intervention.

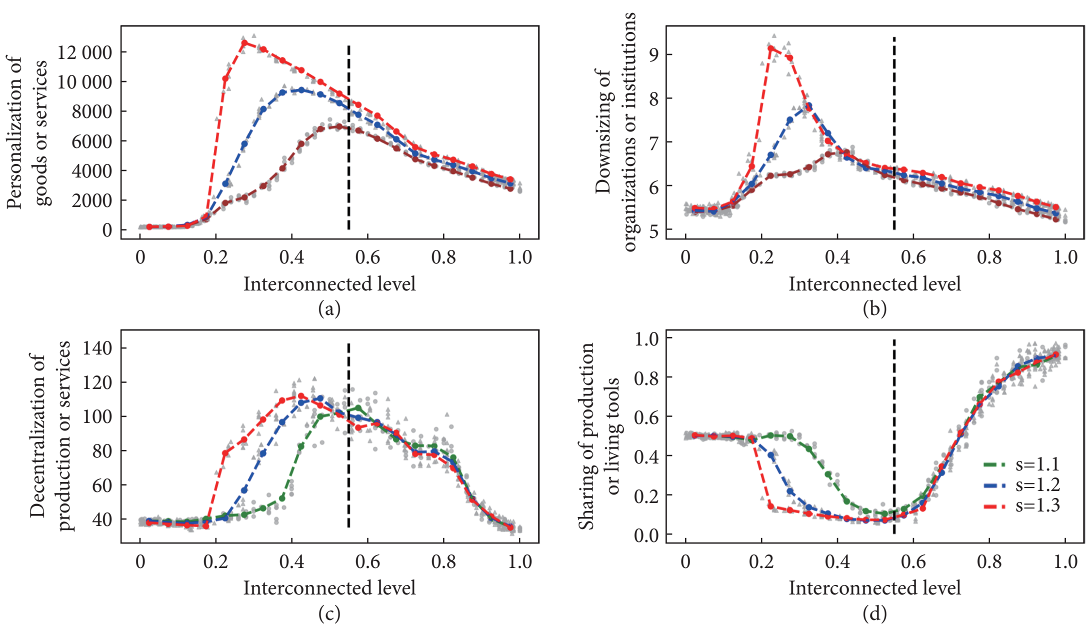

Fig. 2 Evolution trend of the "Four Directions". The change curve of the personalization of goods or services (a), the downsizing of organizations or institutions (b), the decentralization of production or life (c), and the sharing of production or living tools (d) with the interconnected level. We use the total number of people whose need is met by products of a single enterprise as an indicator of the personalization of goods or services. A large indicator denotes a low degree of personalization. The average number of employees in the enterprise is used as the indicator of the downsizing of organizations or institutions. A large indicator denotes small organizations or institutions. The largest number of people gathered in the geographical distribution is used as the indicator of the decentralization of production or life: a large indicator denotes a low degree of decentralization. The proportion of rental behavior in the exchange of goods or services is used as the indicator of the sharing of production or living tools. A higher indicator denotes a high degree of sharing. The green, blue, and red dotted lines in the figure represent the indicator changes when the specialization economic coefficient s = 1.1, 1.2, and 1.3, respectively. A large specialization economic coefficient indicates a small corresponding interconnected level when the indicator starts to change (a)–(d), and the change is substantial (a)–(c). The black dotted line corresponds to the current measured value of 0.55 for the interconnected level in China.

The development of human society has currently reached a critical "crossroads" on whether to continue the development model and path of industrialization or conform to the evolution trend of the future of networked information society, thereby opening up the development mode or path of the personalization of goods or services, the downsizing of enterprises or organizations, the decentralization of production or life, and the sharing of production or living tools. The conclusions in this paper indicate that the latter should be chosen, and suitable policies should be adopted to accelerate the future evolution of a networked information society to achieve the sustainable development of human society. Therefore, governments, non-governmental organizations, enterprises, and citizens must work together according to the basic logic and methodology of openness, interconnection, cooperation, and sharing.

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References

[1] R. Boyd and P. J. Richerson, The evolution of reciprocity in sizable groups, *J. Theor. Biol.*, vol. 132, no. 3, pp. 337–356, 1988.

[2] S. Bowles, Group competition, reproductive leveling, and the evolution of human altruism, *Science*, vol. 314, no. 5805, pp. 1569–1572, 2006.

[3] C. L. Apicella, F. W. Marlowe, J. H. Fowler, and N. A. Christakis, Social networks and cooperation in hunter-gatherers, *Nature*, vol. 481, no. 7382, pp. 497–501, 2012.

[4] M. A. Adelman, The large firm and its suppliers, *Rev. Econ. Stat.*, vol. 31, no. 2, pp. 113–118, 1949.

[5] D. Coen, The evolution of the large firm as a political actor in the European Union, *J. Eur. Public Policy*, vol. 4, no. 1, pp. 91–108, 1997.

[6] P. Crane and A. Kinzig, Nature in the metropolis, *Science*, vol. 308, no. 5726, p. 1225, 2005.

[7] O. D. Duncan, W. R. Scott, S. Lieberson, B. D. Duncan, and H. H. Winsborough, *Metropolis and Region*. New York, NY, USA: RFF Press, 2011.

[8] Y. Takane, Y. Kikegawa, M. Hara, and C. S. B. Grimmond, Urban warming and future air-conditioning use in an Asian megacity: Importance of positive feedback, *npj Climate Atmos. Sci.*, vol. 2, no. 1, p. 39, 2019.

[9] A. C. G. Varquez, N. S. Darmanto, Y. Honda, T. Ihara, and M. Kanda, Future increase in elderly heat-related mortality of a rapidly growing Asian megacity, *Sci. Rep.*, vol. 10, no. 1, p. 9304, 2020.

[10] S. Wang, J. Nan, C. Shi, Q. Fu, S. Gao, D. Wang, H. Cui, A. Saiz-Lopez, and B. Zhou, Atmospheric ammonia and its impacts on regional air quality over the megacity of Shanghai, China, *Sci. Rep.*, vol. 5, no. 1, p. 15842, 2015.

[11] D. H. Cusworth, L. J. Mickley, M. P. Sulprizio, T. Liu, M. E. Marlier, R. S. DeFries, S. K. Guttikunda, and P. Gupta, Quantifying the influence of agricultural fires in northwest India on urban air pollution in Delhi, India, *Environ. Res. Lett.*, vol. 13, no. 4, p. 044018, 2018.

[12] L. Yao, O. Garmash, F. Bianchi, J. Zheng, C. Yan, J. Kontkanen, H. Junninen, S. B. Mazon, M. Ehn, P. Paasonen, et al., Atmospheric new particle formation from sulfuric acid and amines in a Chinese megacity, *Science*, vol. 361, no. 6399, pp. 278–281, 2018.

[13] R. I. McDonald, P. Green, D. Balk, B. M. Fekete, C. Revenga, M. Todd, and M. Montgomery, Urban growth, climate change, and freshwater availability, *Proc. Nat. Acad. Sci. USA*, vol. 108, no. 15, pp. 6312–6317, 2011.

[14] M. R. Khan, M. Koneshloo, P. S. K. Knappett, K. M. Ahmed, B. C. Bostick, B. J. Mailloux, R. H. Mozumder, A. Zahid, C. F. Harvey, A. van Geen, et al., Megacity pumping and preferential flow threaten groundwater quality, *Nat. Commun.*, vol. 7, no. 1, p. 12833, 2016.

[15] E. Glaeser, Cities, productivity, and quality of life, *Science*, vol. 333, no. 6042, pp. 592–594, 2011.

[16] X. Bai, H. Nagendra, P. Shi, and H. Liu, Cities: Build networks and share plans to emerge stronger from COVID-19, *Nature*, vol. 584, no. 7822, pp. 517–520, 2020.

[17] J. Knight and R. Gunatilaka, The rural-urban divide in China: Income but not happiness, *J. Dev. Stud.*, vol. 46, no. 3, pp. 506–534, 2010.

[18] T. Kameda, M. Takezawa, and R. Hastie, The logic of social sharing: An evolutionary game analysis of adaptive norm development, *Pers. Soc. Psychol. Rev.*, vol. 7, no. 1, pp. 2–19, 2003.

[19] A. H. Maslow, *A Theory of Human Motivation*. Eastford, CT, USA: Martino Fine Books, 2013.

[20] R. H. Coase, The nature of the firm, in *Essential Readings in Economics*, S. Estrin and A. Marin, Eds. London, UK: Palgrave, 1995, pp. 37–54.

[21] O. A. Awe, N. Kulangara, and D. F. Henderson, Outsourcing and firm performance: A meta-analysis, *J. Strategy Manag.*, vol. 11, no. 3, pp. 371–386, 2018.

[22] V. M. Carvalho and B. Grassi, Large firm dynamics and the business cycle, *Am. Econ. Rev.*, vol. 109, no. 4, pp. 1375–1425, 2019.

[23] N. Bloom, F. Guvenen, B. S. Smith, J. Song, and T. von Wachter, The disappearing large-firm wage premium, *AEA Papers Proc.*, vol. 108, pp. 317–322, 2018.

[24] A. J. Scott and M. Gottdiener, Metropolis: From the division of labor to urban form, *Am. J. Sociol.*, vol. 95, no. 2, pp. 511–513, 1989.

[25] H. Heinrichs, Sharing economy: A potential new pathway to sustainability, *GAIA-Ecol. Perspect. Sci. Soc.*, vol. 22, no. 4, pp. 228–231, 2013.