Agricultural sustainability assessment: A network-based approach with evidence from Jiangsu Province, China

F Xiong1,2* and L Huang2

1 School of Economics & Management, Southeast University, Nanjing, China
2 School of Finance & Economics, Chongqing Three Gorges University, Chongqing, China

*E-mail: 230179734@seu.edu.cn

Abstract. Sustainability assessment is one of the fundamental ingredients in modern agricultural development. Various sustainability assessment approaches relying on macroeconomic indicators have been proved to be inappropriate in practice. This study aims to establish a concise and testable assessment approach by employing the network and evolutionary geographic economic theory. The big data of Chinese agricultural enterprises in Jiangsu Province has enriched our research fruit in terms of empirical evidence. Results indicated the agricultural sustainability has been generally increasing at the provincial level for the last twenty years, but diversified development paths have appeared referring to different cities. Relevant recommendations were focused on the openness governance and horizontal integration of the local agricultural industry.

1. Introduction

For decades, sustainability assessment has been considered as an essential work in agricultural development. It focuses on revealing vital industrial information such as systematic risk, creative capability and development path [1]. A challenging problem arising in this domain was what indicators should be employed to perfect the evaluation system. Most previous work have suggested applying macroeconomic and statistical indicators to construct sustainability profiles. However, similar approaches were quite controversial in practice due to their poor performance. Objections point out the systematical and evolutionary characteristics of sustainability should be taken into consideration, especially when the agricultural industries were organized in the form of clusters [2]. Unfortunately, few literatures to date has provided the non-equilibrium analysis framework in agricultural sustainability assessment.

Recent development of network theory and evolutionary economic geography brought some new insights into agricultural sustainability assessment. In agricultural technology scenarios, the network theory depicted enterprises as nodes with different scales and their technology relevance as links with different strength. The sustainability of specific agricultural systems thus could be explained as the network resilience and efficiency in a static sense. Moreover, the evolutionary economic geography concentrated on the dynamic process of technological relation adjustments for searching long-term growth paths. These ideas would converge to a network-based concept and a dynamic approach of agricultural sustainability assessment [3].

According to Crespo [4], mature sustainable agricultural networks should be well-integrated with
complete technological systems. Although industrial networks always evolved from the initial scattered structure to have several technological hub organizations, their adaptability diverged due to the different patterns of relation buildings and adjustments. It has been discovered that there were certain network structures would achieve sustainable targets with higher probability. Such networks showed characteristics of related variety [5] by adopting mixed evolutionary strategies. The natural intuition for agricultural sustainability assessment was to identify some topological indicators reflecting the networks structuring process.

This study aims to develop an empirically testable approach of agricultural sustainability assessment based on evolutionary agricultural technology networks. We shall introduce the proposed approach in terms of building networks with enterprises technology relevancy, measuring network structural properties as sustainability indicators and evaluating agricultural sustainability according to empirical standards. In addition, we applied the approach to an agricultural enterprises sample set from Jiangsu Province, China. Clear interpretation and straightforward recommendations were given to the empirical results.

2. Material and methods
2.1 Network construction
Technology relevancy has been wildly adopted in building industrial networks. The relevancy level can be explained by similarities among enterprises’ input factors, product characteristics and management process [6]. This research employed certain computer techniques such as collecting the industrial information by data mining, auto-categorizing enterprises based on technology similarities through text learning. We therefore applied our enterprises classification into the traditional network building model developed by Caves [7], where enterprises under the same sub-classification would link with each other with strength as their technology similarity. The main algorithm in text learning referred to the Topic Word Embedding (TWE) approach [8], which is shown as the flowchart Figure 1.

![Figure 1. The algorithm of text learning with TWE model.](image)

2.2 Sustainability Indicators
2.2.1 Degree distribution exponent. The degree distribution exponent ($\alpha$) could explain the growth mechanism of agricultural technology networks. When $\alpha$ is small, new entries would build their technological relations using the mode of preferential attachment. It shows leading enterprises own the competitive advantages in partner-searching. As this trend dominate the evolutionary process, networks would show core-periphery structure, which is considered as short-term efficiency but long-term path lock-in. On the contrary, new entries would select partners more freely when $\alpha$ is big. The network structure would exhibit random characteristics with high creative potential but low production rate. Continuous degree distribution exponent [9] is estimated as:

$$\alpha = 1 + n \left( \sum_{i=1}^{n} \ln \frac{k_i}{k_{min}} \right)^{-1}$$

(1)
Where $k_i$ is the degree of node $i$, $k_{\text{min}}$ is the lowest degree of the network, $n$ is the total number of nodes.

2.2.2 Degree correlation exponents. The degree distribution exponents ($\beta$) could explain the adjustment mechanism of agricultural technology networks. As enterprises tended to change their technological relations sometimes, they would choose partners more similar as themselves when $\beta$ close to 1. It implicated cooperation was primarily limit to the same production chain that would block the development of business variety. However, more technological relations among firms from different types would be established if $\beta$ close to $-1$. Since clear communication channels existed, the networks could generate multiple core components and maintain their size at the suitable level. In practice, modified Pearson Correlation [10] can be employed as:

$$\beta = \frac{M^{-1} \sum_{e_{ij} \in E} k_i k_j - [M^{-1} \sum_{e_{ij} \in E} \frac{1}{2} (k_i + k_j)]^2}{M^{-1} \sum_{e_{ij} \in E} \frac{1}{2} (k_i^2 + k_j^2) - [M^{-1} \sum_{e_{ij} \in E} \frac{1}{2} (k_i + k_j)]^2}$$

Where $k_{i,j}$ is the degree of node $i,j$, $e_{ij}$ is the link between node $i$ and $j$, $M$ is the total number of edges.

2.3 Evaluation standards
According to above sustainability indicators, we developed our evaluation standards referring to some basic facts: Firstly, abundant literatures have confirmed the degree distribution exponent of actual agricultural networks built on technology relevance ranged from 2 to 3. As there was a trade-off between efficiency and resilience [11], the best position should be at the middle range. Secondly, although most agricultural industries in cluster forms were proved with negative degree correlation exponent, as we stated above, the lower value would be more preferable for developing technology variety. Therefore, we designed our evaluation standards with 3 types: High sustainability zone, Mid sustainability zone and Low sustainability zone.

In particular, there were 3 sub-types in Low sustainability zone. Problem I indicated assortative tendency among enterprises. Industries were experiencing technological benefits now but at high risks of failure in the future. Problem II reflected issues with technological core components, either their scales were too big(II.a) or too small(II.b). Industries ought to redistribute the resource to form multiple core components with suitable scales. Problem III indicates there were double straits in collaboration and distribution among enterprises.

![Figure 2. The evaluation standards of agricultural sustainability.](image)
3. Results and discussion

In the empirical test, our sample set was acquired by the Big Data & ITFIN institution of Southeast University. It contains information from 5571 agricultural enterprises in Jiangsu Province, China and 12632 realized technology relationships to the date June, 2019. With the goal to illustrate the evolutionary process, we have grouped enterprises by their registration dates. We especially set the starting date of a paired technological relation as the time when the younger cooperator had been registered. Finally, we obtained 20 agricultural technology networks from year 2000 to 2019. Our first intention was to measure and evaluate their sustainability at the provincial level. Table 1 lists these results.

| year | Num. of Nodes | Num. of Edges | Degree Distribution Exponent | Degree Correlation Exponent | Sustainability Evaluation |
|------|--------------|---------------|------------------------------|-----------------------------|---------------------------|
| 2000 | 28           | 12            | 2.64                         | 0.122                       | Problem I                 |
| 2001 | 60           | 25            | 2.93                         | 0.174                       | Problem I                 |
| 2002 | 140          | 81            | 3.18                         | -0.123                      | Problem I                 |
| 2003 | 202          | 123           | 3.21                         | -0.139                      | Problem II.b              |
| 2004 | 335          | 207           | 3.09                         | -0.118                      | Problem II.b              |
| 2005 | 456          | 320           | 3.08                         | -0.125                      | Problem II.b              |
| 2006 | 593          | 496           | 3.15                         | -0.160                      | Problem II.b              |
| 2007 | 770          | 667           | 3.06                         | -0.141                      | Problem II.b              |
| 2008 | 971          | 919           | 2.89                         | -0.147                      | Mid Sustainability        |
| 2009 | 1158         | 1151          | 3.05                         | -0.144                      | Problem II.b              |
| 2010 | 1450         | 1614          | 2.85                         | -0.150                      | Mid Sustainability        |
| 2011 | 1847         | 2255          | 2.88                         | -0.137                      | Mid Sustainability        |
| 2012 | 2288         | 3188          | 2.83                         | -0.124                      | Mid Sustainability        |
| 2013 | 2764         | 4230          | 2.77                         | -0.122                      | Mid Sustainability        |
| 2014 | 3315         | 5679          | 2.64                         | -0.126                      | Mid Sustainability        |
| 2015 | 3885         | 7134          | 2.59                         | -0.128                      | Mid Sustainability        |
| 2016 | 4534         | 8878          | 2.53                         | -0.127                      | Mid Sustainability        |
| 2017 | 5036         | 10466         | 2.47                         | -0.125                      | Mid Sustainability        |
| 2018 | 5338         | 11356         | 2.46                         | -0.122                      | Mid Sustainability        |
| 2019 | 5571         | 12632         | 2.46                         | -0.122                      | Mid Sustainability        |

The evolutionary tendency of the agricultural sustainability in Jiangsu has experienced the typical phases of ‘Problem I - Problem II.b – Mid sustainability’ during last twenty years. The early stage of agriculture development was confronted with the issue of Problem I. Since the relation building patterns relied on few outmoded technical core components, the production and circulation processes were almost homogeneous. In addition, the short industrial chain further restricted technology innovations among enterprises with different specializations. However, the Blue Sea market could continuously attract new entries to step in and gathered around core components until the technical benefits was depleted. As competition intensified, inadequate creative power has enforced industrial structural adjustments through extending technological relations to heterogeneous enterprises. This strategy successfully decreased the degree correlation exponent to negative but raised the degree distribution exponent at the same time, which indicated an efficiency loss in a short time and impelled the sustainability to reach problem II.b. At last, as more technological core components have been generated, the sustainability achieved middle zone. One thing should be noticed was that no significant evidence showed this agricultural network was heading to the upper level of sustainability, because both indicators has presented stationary characteristics in recent years.
To further investigate the impact of regional sustainability, we have grouped enterprises by their registration cities. For simplicity, their evolutionary processes were checked by selected dates of year 2001, 2010 and 2019. Figure 3 shows the regional agricultural sustainability evaluation results of different cities in Jiangsu, where the sustainability has been hierarchically colored from green to red.

Evidence showed there was no strong correlation between sustainability and traditional economic measures, such as GDP and growth rates. The results were quite interesting but could be reasonably explained, because the sustainability was a measure focusing on evaluating technological development potentials rather than current economic performance. There were two specific findings from our regional sustainability assessment: Firstly, cities considered as developed areas were not guaranteed to have ideal sustainability. Metropolis as Nanjing, Wuxi showed low sustainability all the time while most undeveloped cities performed well in this assessment. In fact, the small scale of networks in backward cities ensured success in rapid structural adjustments. Those cities could adapt economic environment by adopting innovations and establishing new technological relations without any difficulties, while similar conducts would significantly shock large-scaled agricultural networks in developed cities. Secondly, although the agricultural sustainability of most cities has increased by dates, some cities
presented the reverse trend. Special attention should be paid to cities like Wuxi and Huaian, these areas probably have overemphasized the production efficiency but ignored the technology variety in some particular development stages.

According to the empirical results, the government should focus on industrial openness management and horizontal integration [12]. In specific, implementing high openness policies when the scale and agglomeration of networks were both at low levels. On this stage, industries should create more hub organizations to accelerate their production efficiency. However, entry restrictions must be imposed to those path-lock-in clusters, which typically presented distinct core-periphery network structures and required urgent structural transformations. Furthermore, industrial horizontal integration should be emphasized all the way since the relative variety was essential for technological innovations as well as sustainability development.

4. Conclusion
Agricultural sustainability is a general concept reflecting industrial capabilities of risk tolerance, effectiveness and innovativeness. This study designed a new approach to assess agricultural sustainability by employing network and evolutionary geographic analysis tools. Our empirical test showed this strategy was methodologically feasible and practically interpreting. It can provide valuable information for management decision making.

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