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New structural economics and its applications in agricultural development

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Guest editorial

Guest editorial of the special section on new structural economics and its applications in agricultural development

China is a large agrarian economy. Despite the rapid progress in industrialization and urbanization in the past 40 years, there are still a wide arrange of important and urgent issues and problems that must be addressed and solved in the agriculture sector and in the rural area of China. In fact, 85 percent of the world population lives in developing countries, where the agriculture sector remains to be large and agricultural development, food availability, industrialization and urbanization remain to be top challenges. How China manages to industrialize and upgrade its agricultural sector could be useful for all developing countries.

New Structural Economics (NSE) is proposed by Professor Justin Yifu Lin, Dean of the Institute of New Structural Economics at Peking University. NSE adopts neoclassical economic approach to analyze the determinants, dynamics, and implications of economic structures in economic development. NSE highlights not only structural differences for countries at different development stages but also structural changes within the same sector over time. Moreover, NSE advocates that both efficient markets and facilitating states are necessary for successful industrial upgrading and economic development.

How helpful is the approach of NSE for the research on agricultural economics? How do researchers incorporate structural changes into their analyses of agricultural development in a more fruitful way? We hope to facilitate academic discussions and collaborations on such research questions in the international academic community. Both Professor Xian Xin, Editor-in-Chief of *China Agricultural Economic Review* (*CAER*), and Professor Baozhong Su, Editorial Coordinator of CAER, are very supportive of our idea, and thus we co-organized an international symposium on "New Structural Economics and its Applications in Agricultural Development" with *China Agricultural Economic Review* (*CAER*) at Peking University on October 21–22, 2017. It was also one of the academic events celebrating Justin Yifu Lin's 30th anniversary of teaching after he returned to mainland China with a PhD degree in Economics from the University of Chicago. Justin started his academic career as an agricultural economist and he has made great contributions to China's rural reforms both academically and through policy work.

After that, we co-organized another special forum on "Three issues of agriculture, the countryside, farmers and the New Structural Economics" with CAER at Peking University on December 17, 2018.

We received a large number of submitted papers for them both. All papers included in this special section were selected from the international symposium.

There are seven papers in total in this special issue. The first paper by Lin (2019) examines how to achieve the objective of no poverty in UN's SDGs by focusing on structural changes based on the NSE. The second paper by Chen (2019) proposes to clarify the panoramic significance of rural reform; the necessity, priority and long-term nature of the current rural development; and the important role of public policy in doing so. It also looks ahead to consider the prospects for future rural reform. The third one by Shouying (2019) gives a brief introduction to the structural characteristics of the Chinese land institutional arrangements, analyzes the reform process of the land system in the past 40 years and its path of change, and evaluates the historic contribution of the land institutional change to rapid economic growth and structural changes. The fourth paper by Yang (2019) examines the impact of nitrogen on soil quality over the long run, which is the shadow price of nitrogen.

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And the fifth paper by Wang (2019) explores how these processes of (de)industrialization and rural income distribution interact with each other and their implications for economic growth and welfare. The sixth paper by Yi *et al.* (2019) investigates the impact of mechanization services on farm productivity in Northern China from an empirical perspective, with the aim to identify the underlying market and institutional barriers. The seventh paper by Wang *et al.* (2019) investigates the impact of social capital on the mental health of older adults in rural China.

We believe that all the selected papers can help us better understand important aspects of China's agricultural economic issues, especially from the new perspectives of NSE. We look forward to continue working together with CAER on these important issues in the future. This special section is just the beginning of our collaboration.

Justin Yifu Lin and Yong Wang
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Structural change and poverty elimination

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Abstract

Purpose – The United Nations adopted 17 goals for sustainable development, which has been known as the 17 SDGs. Knowing how to achieve these goals will be very important for many countries. The first of the 17 is no poverty. The purpose of this paper is to analyze how to realize no poverty in UN's SDGs by focusing on structural changes based on the New Structural Economics.
Design/methodology/approach – This paper explains the relationship between structural changes and people' s income in both rural and urban areas, and then introduces how to eliminate poverty from a New Structural Economics' perspective. Finally, it discusses what to do to make these changes a reality.
Findings – To reduce and eventually eliminate poverty, increasing personal income becomes the first step. From national perspective, structural changes are related to an income increase. In rural and urban areas alike, the structural changes will usually be accompanied by new technologies and job opportunities, which will help people improve their incomes.
Originality/value – This paper explains relationship between structural changes and poverty elimination. How to increase people's income is also discussed according to New Structural Economics. This paper's findings may well be valuable for research on poverty elimination in the future.

Keywords Development economics, Sustainable development goals, New Structural Economics, Poverty elimination, Structural changes

Paper type General review

1. Introduction: the relationship between structural change and poverty elimination

The UN adopted 17 goals for sustainable development in 2015, hoping all countries would achieve them by 2030. The first goal is no poverty, which holds that position for good reason, given that the second is zero hunger, and the third is good health and well-being. People who rid themselves of poverty through having higher incomes certainly will not suffer from hunger, and will have better nutritional intake, thus having greater ability to take care of themselves. Under that situation, their health and well-being will also improve. Obviously, we cannot achieve the first goal by printing money and giving it to the poor. Improving the labor productivity is a better choice. In order to do so, we need to have technology innovation in the existing industries so that the labor can produce more or better quality outputs or have new higher value-added industries so that the labor can be relocated to new industries.

The UN's SDG pertaining to poverty elimination mainly considers individuals. But it can also be approached from a national level – how to turn a country plagued by poverty to one abounding with prosperity. Certainly, the two concepts are related. If everyone in a country becomes relatively rich, then country as a whole will be rich. Most poor countries are agrarian. Their people work on agriculture in rural areas. So, trying to think about these issues, we need to consider how to improve the income of the people in rural areas first. However, technological innovation and structural changes in rural areas alone are insufficient. All countries in the world were poor and agrarian at the beginning of their modernization. For those few countries successfully transformed from poverty to prosperity, they all converted from rural agrarian economies to urban industrialized economies.

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2. The New Structural Economics

The "New Structural Economics" is a framework for rethinking development. It uses the neoclassical approach to study the determinants and impacts of structure and structural changes in the process of economic development, including the structure of technology, industry, institutions, infrastructure and so forth in a country. By convention, this type of research is referred to as "structural economics," just like it would be if we had used the neoclassical approach to study agriculture, we would refer that field as agricultural economics, or to study finance, as financial economics. Hence, by using the neoclassical approach to study structure, the field should be referred as structural economics. The first edition of developmental economics, which appeared after the Second World War, was structuralism. In order to distinguish this approach from structuralism, we call it the "New Structural Economics." This is also the practice used by Douglass North when he proposed the use of neoclassical approach to study institutions and institutional changes. He should have referred his research as simply "institutional economics." Yet, because in the USA, there was an institutional school at the turn of the twentieth century, he distinguished his own approach by calling it the new institutional economics. The "new" in New Structural Economics has the same spirit as the "new" in new institutional economics.

For the New Structural Economics, the entry point for analysis is that the structures – regardless of its technological, industrial or institutional structure – are endogenous to the endowment structure of an economy at any specific time. The availability of land or natural resources, labor force as well as capital (both human capital and physical capital) are endowments. For any country, the endowments at any specific time are given, but they are changeable over time. Also, for the country at a different level of development, the endowments have different structure. Some countries are relatively abundant in natural resources and/or labor force; others are relatively abundant in capital and skills.

Those kinds of endowment structure will determine the technological structure and industrial structure. Different technology and industry will not only require a different infrastructure, but also different institutional arrangements to facilitate its investment, production as well as sale. The New Structural Economics proposes the use of endowment structure, which is given at any specific time, even though it is changeable over time, as a starting point for the study of structure and structural change in an economy.

3. Transformation and new technology in agriculture

A poor country's endowment is often relatively abundant in natural resources and labor force. Many types of agricultural production are land-intensive and, to some extent, are labor-intensive also – not requiring much capital inputs to begin with. All countries start with an agrarian stage and use traditional technologies for production with low labor productivity. Low labor productivity leaves people poor. If people want to improve their income, they need to use new technologies that can improve productivity and introduce new higher value-added cash crops and/or animal husbandry[1]. Once they have been provided with modern technology, compared to traditional agriculture, the country may start the transformation process, and the farmers can turn sand into gold. They can increase their incomes.

Nevertheless, this kind of new (especially modern) technology is not available spontaneously. Newer technologies, unlike traditional ones that are mainly derived from the experience of farmers, are the result of intentional research and development. The development of modern technology requires large-capital inputs and entails high risk, and is, therefore, beyond the capacity of individual agricultural households. Consequently, it is essential to have institutional arrangements to provide it to farmers. Both public research institutions and commercially orientated companies may engage in agricultural

research, thus providing new technologies to farmers. However, we know that agricultural technologies have certain characteristics. Except for hybrid seeds that must be bought every season, farmers only need to buy new higher-yielding seeds for use once; then they can produce seeds for sowing by themselves. Therefore, commercial firms have no incentive to do research in new higher-yield varieties and provide them to farmers. Thus, public research institutions must support the generation of new seeds, mainly new varieties with higher yields, which will help farmers increase their productivity. Indeed, public support will be essential.

Agricultural production has another key characteristic: its technology is location-specific, especially in cropping. It requires soil and water availability as well as adequate weather and climate conditions. There are different soil types and climates in different locations. Under these circumstances, unlike industries, one agricultural technology that is suitable for a given location may not be suitable for another. The state should thus be responsible for providing agricultural technologies with a decentralized national agricultural research system for innovating and testing different technologies that are suitable for different locations. Otherwise, even higher-yielding varieties may not help farmers attain higher incomes.

The farmers (especially poorer ones) will not be able to take much risk. If they use the new technologies, they will face many new challenges and uncertainties in using new technologies. They may not be able to cope with those kinds of uncertainties because they are poor. The state will have to step in and extend those available technologies, and perhaps do some demonstrations, showing farmers how to use new technologies and to know which ones are suitable for their locations. Once the demonstrations succeed, other farmers will have the incentive to adopt a new technology.

What is more, besides the availability of new technology, once traditional agriculture has been displaced by a modern variety, the infrastructure must also be improved, e.g. irrigation. In general, traditional crops have low yields but weather proof. Modern varieties must have irrigation, otherwise the new varieties may not produce higher yields. Hence, improving such infrastructure is essential for adopting new technologies.

Upgraded infrastructure is also needed because moving to modern varieties not only requires high-yield seeds, but also necessitates other purchases, like fertilizers that enhance potential yields for the new varieties. Traditional agriculture uses organic fertilizers and farmers can produce them by themselves. Once the move to modern agriculture is made, chemical fertilizers will be required, which farmers cannot produce, but instead must purchase on the market. However, such acquisitions depend on whether a market exists to provide them. With higher yield and larger output, the market needs to be expand, which also depends on infrastructure, such as roads: without improvement in road, the market's scope will be very small and farmer may not increase income with increase in outputs. This is because for most agricultural products, the elasticity of demand is small, so if the market size is limited, the price will drop quickly when output increases. Under that situation, farmers may not benefit from improved productivity. To overcome that problem, the market size must be increased so as to permitting famers to cope with diminishing-demand elasticity and increase their income.

In poorer countries, most farmers subsist from the crops they produce. Yet, because of low-demand elasticity, once they have modern agricultural technology to start modernizing, they will transform their efforts from traditional to modern agriculture. Technological improvement will bring output increases along with it, but even after the market's size increases – from village to the region, then to the nation – the low-demand elasticity will still constrain their incomes. Under those circumstances, it would be desirable to diversify away from subsistence agriculture to a non-subsistence variety that helps them cope with the low-demand elasticity. This kind of diversification is also important for farmers working in subsistence farming with crops like grains, which require limited labor inputs.

In China, if farmers produce grains, such as rice, wheat or corn, they only require working for about 20 days annually. To utilize their labor force fully, they must plant other labor-intensive crops like vegetables. To diversify to new crops like vegetables requires new technology, which is also location-specific. Once again, a better infrastructure for irrigation and road must be provided along with the required inputs in order to reach larger markets. At the same time, institutions should be improved. In traditional agriculture, farmers do not have much need for financial services. They produce what they need for themselves. After moving to modern agriculture, they need to partake of financial services so that they can purchase seeds, fertilizers and so forth. They need the support of financial institutions to undertake such investment.

Other institutional changes are also needed. If the traditional farmers trade at all, it will only take place in some periodic village markets usually, where people know each other and there is no need for written contracts or enforcement. Once they produce for regional, national market or international markets, some legal arrangements and enforcement will be required. Accordingly, the transition from traditional agriculture not only transforms farming due to technological changes, but also crop types, infrastructure and institutions.

Improving farmers' human capital makes this possible because with traditional agriculture, most farmers rely on experience, learning from older farmers how to plant crops. However, once they move to modern agriculture, they must frequently learn something new, whether in terms of a new technology or a new type of farm management or marketing activity. Thus, adopting new technology to widen their opportunities will compel them to face many new challenges and uncertainties. To be successful, educational improvement of human capital will be essential. This method stands to help a poorer country at an early stage to improve its farmers' incomes and to reduce poverty in rural areas.

4. Industrialization and urbanization

Transformation is insufficient if only happens in the agricultural sector. In the beginning, all the countries in the world are poor, at least relative to today's standards. Poverty is, of course a relative term, and one nation with even the slightest bit more can be said to be "richer" than others. According to Angus Maddison's historical data, the per capita GDP measured in $1,990 for different countries in 1700 AD was: UK, $1,250; USA, $527; Japan, $570; China, $600; and the average across Africa, $421. In 2008, Africa was considered to be the poorest continent, with its average per capita GDP at 1,780. Note that even though this figure is higher than the UK's at the beginning of the eighteenth century, African countries are considered to be poor by today's standards. Indeed, by today's standard, every country was "poor" prior to the eighteenth century, and certainly prior to the Industrial Revolution that began at the end of that century.

On the one hand, making poorer countries richer requires improving their agricultural productivity. On the other hand, if a country does move from poverty to prosperity, not only its agriculture productivity improved, their agriculture share also declines. Even today, some countries are still famous for exporting agricultural products, like the USA, Australia, Denmark and France; their rural population all be around 5 percent of their total current population. Moreover, their agriculture labor force contributes about 2~3 percent of their total labor force.

Changing a country from being poor to rich, and removing poverty, requires that people move from rural areas to urban areas in location, and from agriculture to non-agricultural production through industrialization.

When people move from rural areas to urban ones without jobs, they simply change from rural poor to urban poor. Poverty will remain. Therefore, when people move from rural areas

to urban ones, they need to have jobs to increase their income. There are two main types of jobs in urban areas: one is in the services, and the other is in manufacturing.

From the start, almost every economy engages in agricultural production and handicraft-type manufacture. At that stage, low productivity determines that their incomes must remain low, even though some people are working in urban, non-agriculture fields. Similarly, new technology in handicraft manufacturing increases their income. They also need to have new higher value-added sectors to emerge to further increase income. Then it will allow workers move from low value-added sectors to high value-added ones. This kind of transformation through industrialization has long been recognized by development economists. After the Second World War, newly independent countries started to pursue modernization and industrialization. In response to that need, development economics appeared as a new sub-discipline of modern economics.

The first wave of development economics, structuralism, had the goal of making developing countries enjoy similar income levels as high-income countries. That was the chief aim of modernization: how to reach income levels that approximate those found in high-income countries, which would also require similar labor productivity. That level of labor productivity demands advanced large-scale, capital-intensive industries. However, in developing countries, modern, large-scale, capital-intensive industries have not emerged spontaneously in the market. Therefore, many development economists concluded that there exists market failure and they attribute it to culture, behavior patterns of farmers and so forth. They advocate that government overcome such market failures by adopting a heavy industry-oriented development strategy or an input substitution strategy to do so. The intention is good, aiming to develop large modern industries. But after building those industries, they become white elephants. They are not competitive in market and rely on government subsidies and protection for their survival. Those kind of industries in a way go against the competitive advantages determined by their endowment structure.

From a New Structural Economics point of view, economic structure is endogenous to the endowment structure. Low-income countries lack a comparative advantage in capital-intensive industries. Firms in priority sectors, which go against the comparative advantages determined by their factor endowment structure, are not viable in competitive markets, but their states still want to build them up, thus requiring that the state provides them with subsidies and protection. Such subsidies and protectionism cause intervention and distortion. Such strategies cause not only misallocation of resources, but also rent and rent-seeking, lowering economic performance. Moreover, developing capital-intensive industries will generate relatively few jobs to accommodate the needs of outmigration of labor from agriculture to urban areas.

In China, the government controlled migration tightly during the implementation of heavy industries-oriented development strategy before the reform and opening up at the end of 1978. At that time, 81 percent of the population resided in rural areas and relied on agriculture for living. In Latin America and Africa, many farmers migrated to urban areas but they do not have jobs. They become the urban poor living in very desperate situations. The poverty issue remains.

To create productive jobs in urban areas, labor-intensive industries must develop. New Structural Economics provides a rationale for doing so.

In earlier stages of development, many countries have abundant supply of labor force, and labor-intensive industries are their comparative advantage. At that stage, wage is low, making their factor cost of production in those industries low internationally.

For developing countries starting with labor-intensive industries that are mature from a global perspective, they can enjoy latecomer advantages: they can imitate, borrow and learn from higher-income countries, and since those technologies are not protected by patents anymore, they can adopt them freely. Their cost and risk for innovation are low.

To be able to make this kind of industrialization continuous, entrepreneurs are required who will identify the sector where comparative advantages lie.

Nevertheless, entrepreneurship alone is insufficient to make such industrialization happen. Improvements to infrastructure, such as electricity supply, are needed when people move from handicraft to the modern labor-intensive industries. Individual entrepreneurs will not be able to improve the infrastructure by themselves. They also need to reach larger markets. If they just produce for their local markets, where markets are not big enough, the producers will not be able to use modern equipment, which has large economies of scale. Therefore, a road will be needed to expand market size. They also need better access to financial institutions to make large capital investments feasible. Larger markets necessitate improving the legal system, contracting and their legal enforcement in particular. Human capital is also essential. Workers need training to be able to work in new industries. Basically, they need an efficient market to help identify what sectors they have comparative advantages. They also need the state to play a facilitating role by improving a needed hard and soft infrastructure for new industries. Development according to comparative advantages will lead to the competitive industry only with the government's help in improving infrastructure and the institutions to reduce transaction costs. They can accumulate capital, changing their endowment structure once they can be competitive, then change their comparative advantage and climb up industrial ladders gradually. Again, this process requires an organic collaboration between the market and the state. In this process, starting from industrialization, urbanization must follow.

Urbanization is endogenous in some sense because in industrial production, the economies of scale are large, making concentration of work in one location important. While improving industries' logistical and divisional levels in terms of clustering or agglomeration, reinforcing the concentration of workforce and people in certain location can lead to urbanization, which may help them to avoid unemployment. To some extent, under the transformation starting in 1978, China's urbanization followed this kind of process. Industrialization is first, and then urbanization, meaning that there were little urban unemployment issues in China. But in other countries, urbanization occurs without industrialization, leading to urban unemployment and poverty; they just replace rural poverty with urban poverty.

5. Structural changes and job opportunities creation

There is some debate about service-oriented business development in an urbanization process and manufacturing-industrialization-oriented development in the urbanization process. If a service is needed, the demand for it will increase. In the process of industrialization, income rises. Working hours will decline. Once workers reduce their working hours, they are likely to have more entertainment, which requires more services. From another perspective, labor cost and opportunity costs of working will increase, then people will like to have more conveniences, which also require more services. At the same time, in the industrialization process, production will also require services, like financial, logistic and professional services. The service development will accompany industrialization. But in the 1980s and 1990s, there were some new types of services, which were high value-added, and especially the internet makes information processing services very profitable. India is famous for providing back-office processing services for high-income countries, and exporting those kinds of services. Traditionally, a country will gradually transform from an agrarian economy to manufacturing economy and finally a service-oriented economy. The development of manufacturing requires services. However, only informational types of services would not be able to help the country to transform from poverty to prosperity, because the information service will not generate many jobs. In 1978, China's per capita GDP was about 25 percent lower than India's. The populations in both

countries are about the same. Today, China has 1.4bn, while India has about 1.3bn. India follows a service-oriented modernization, while China follows manufacturing-oriented modernization. Today, India's per capita GDP is only 20 percent of China's today (US$8,600 for China vs US$1,600 for India). There are certainly many reasons for this disparity, but one main reason is job availability. The service sector in India generated only 2m jobs, whereas the manufacturing sectors in China generated 124m. As a result, the likelihood of migrating low-income farmers from the rural to urban areas for higher-income jobs was better in China. This kind of industrialization and urbanization process will also generate feedback for better rural development. Even if farmers migrate, land cannot migrate. Hence, there will be opportunities for land consolidation to increase farmers' income in rural areas.

Urbanization and industrialization also lead to more job opportunities in rural areas. Farmers do not use all of their labor inputs, and may have some spare time, allowing them to work part-time in nonfarm jobs to increase their incomes, and to increase their budgets for purchasing modern technology and inputs to further increasing their income.

6. Conclusion

Elimination of poverty is a desirable goal for any nation, and especially considering the UN's SDGs. The elimination of poverty requires increasing the income of poor people with a decent Job. The jobs can be in rural areas or urban areas. In either case, technological innovation and structural change are essential. Industrialization, innovation and infrastructure improvement are essential in this transformation. These are goals numbered 8 and 9 in the SDGs.

Some SDGs are goals and others are the means for goals. From a New Structural Economics point of view, it is very important to understand the comparable advantages of each country in agriculture, industries and services, and in rural and urban areas. Only if a country follows the comparative advantages, determined by its factor endowments, in the development of agriculture, industries and services will the factor costs of their production be low. The market is essential for guiding a country's development according to its comparative advantages.

To make a country's economy competitive in the market, infrastructure and institutions that reduce transaction costs must also be appropriate. The state is responsible for the improvement of infrastructure and institutions. Hence, a market economy with a facilitating state is required for a country to grow dynamically. The New Structural Economics provides a framework for us to organize our thinking around this transformation and identify the areas for research to reduce poverty and achieve prosperity.

Note

1. Professor Theodore Schultz (University of Chicago) has extensively studied this type of transformation process. He published an influential book called *Transforming Traditional Agriculture (1964)*. In this book, he provided convincing arguments and evidence.

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Forty years of rural reform in China: retrospect and future prospects

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Abstract

Purpose – Bottlenecked by rural underdevelopment, China's overall development is bound to be inadequate and unbalanced. Through a brief retrospect of the reform directed against the "equalitarianism (egalitarianism)" in China's rural areas, as well as the Chinese Government's conceptual transformation and systemic construction and improvement thereof, the purpose of this paper is to clarify the panoramic significance of rural reform; the necessity, priority, and long-term nature of the current rural development; and the important role of public policy in doing so. It also looks ahead to consider the prospects for future rural reform.

Design/methodology/approach – This paper first reviews the rural reforms that were carried out in 1978. Second, it introduces the government's conceptual change regarding rural reform and the establishment and improvement of the system that underlies it. Finally, the future of rural reform is envisaged.

Findings – The initial rural reforms brought extensive and profound changes to China's rural areas. The experience of rural reform has been referred to and escalated by other fields of study. Hence, rural reforms have become something of global significance. Moreover, since the government can undertake reforms well beyond the reach of farmers, its views must be modified in a timely manner, and only then may it reasonably construct and improve the system pertaining to the "three rural issues (agriculture, rural areas, and farmers)."

Originality/value – This paper reviews the rural reforms carried out in 1978. It introduces the government's change of concept with respect to rural reforms and the establishment and improvement of the system based on the "three rural issues," thus looking forward to the future of rural reforms. The findings of this paper are of significance to the formulation of future agricultural policies.

Keywords Government, Rural reform, Agricultural development, Future prospects

Paper type General review

This paper takes the "retrospect and prospect of rural reform" as its central theme and then proceeds from three aspects. First, we briefly review the history of China's rural reforms and mainly introduce the reforms to solve the two "equalitarianisms": from "people's communes large in size and collective in nature (with a higher degree of public ownership than that of the cooperatives)" to "production team-based three-level ownership (of rural production materials belonging to the people's communes, production teams, and production teams, which is the basic system of the rural people's communes)," and then to "Fixing of Farm Output Quotas for Each Rural Household (FFOQERH)" and "a rural household-based contract system (RHBCS)." Second, the broad and profound impact of the FFOQERH and RHBCS system, especially the RHBCS one, on the rural areas during the initial stage of rural reform is discussed, as well as the panoramic significance of rural reform in China's myriad reforms. Second, the important role of the Chinese Government in the rural reform is introduced. In the beginning, the government's conceptual transformation in relation to agriculture, rural areas, and farmers was introduced. Then, the establishment and improvement of certain basic systems based on the transformed concept were introduced. Third, two aspects of the future of rural reform are briefly looked into: solving rural internal problems and creating an external environment that is more conducive to rural development.

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1. China's rural reform process and its significance

Deng Xiaoping once said that China's reforms began in rural areas. General Secretary Xi Jinping's speech in Xiaogang Village of Anhui Province in April 2016 stated that the rural reform started by adjusting the relationship between farmers and lands. Looking at the 39 years of reforms in China's rural areas, one may see that adjusting the relationship between farmers and land has not changed the ownership of rural lands, but rather seeks a more efficient form of realization of collective ownership of them. Although this initiative was first adopted by the farmers of their own accord, it was also directly related to, and in line with, the political atmosphere and ideological line of seeking truth from facts after the Third Plenary Session of the 11th CPC Central Committee (CCCPC), which allowed for the exploration of policies, and guided people to support reform and development.

1.1 Review of rural reform measures directed against "equalitarianism"

Before the rural reforms were carried out, rural land was operated jointly by collective organizations, who also took charge of the unified accounting and uniform distribution of the results of the operations. However, as stated in Professor Justin Yifu Lin's earlier paper, the difficulty in measuring and supervising labor in agriculture will lead to an egalitarian "big-pot" phenomenon when the uniform distribution of collective living materials is finally brought to a close, which considerably curbed the enthusiasm of farmers.

Before the reform, the biggest technical problem faced by the development of rural collective economic organizations and Chinese agriculture was the egalitarian "big-pot" phenomenon within the organization. Shortly after the people's commune movement began, Mao Zedong discovered this problem and proposed to make appropriate adjustments to the people's commune system. In particular, he explicitly proposed that the people's commune system be changed from the simple "people's communes large in size and collective in nature" to "production team-based three-level ownership." To this end, Mao once said that there are actually two egalitarian phenomena in the people's commune system. One is team-to-team egalitarianism within the production brigade (larger production unit covering production teams), and the other is the person-to-person egalitarianism within those teams. In order to solve this problem, the CCCPC issued the "working regulations of the people's communes" in 1962, that is, the "60-article regulations for agriculture." The core of the regulations is to clearly define the accounting system of the people's communes as "production team-based three-level ownership," where the "team" refers to a group of farmers, that is, the current villagers' groups and village committees. This means that the right of accounting fell into the hands of the land ownership units, and thus the size of the accounting units was significantly reduced. The reduction of accounting units solved the first egalitarian problem, but did not solve the second one, which has persisted until 1978 due to Mao's strong opposition to the "FFOQERH and RHBCS System," although he might have realized that that system could solve it.

In 1978, the farmers spontaneously implemented the "FFOQERH and RHBCS system" to solve the second egalitarian problem that Mao described as solving the problem of person-to-person egalitarianism within the production teams via household contract management of collective lands. But simply changing the operating system only solves this problem theoretically and structurally. In fact, if this problem really was to be solved, the distribution system, i.e., the system of unified accounting and uniform distribution of the peoples' communes at that time must also be reformed.

1.2 Impact of initial rural reform on rural areas

Talking about rural reform, many people will think of the FFOQERH and RHBCS system. "FFOQERH" denotes that by contracting production tasks to rural households, any excess quota may be commissioned, but the contracted basic quota is still handled by the team for

unified accounting and uniform distribution. The "RHBCS (household-based contract system)" approach, however, combines the operation and distribution systems. It was not until the implementation of "RHBCS" in Xiaogang village, that the rural reforms were really stimulated and embarked upon in a fast-track style. The distribution system of "RHBCS" is, simply put, to "turn over the due quota to the country, turn in the due quota to the collective, and the rest is the contractor's own." Under this system, the grain and agricultural products levied by the country, and the collective gains and other retentions made by the collectives will not be reduced due to "RHBCS," while the farmers can retain all remaining products and income. This was, to some extent, a distribution method that could be accepted by all three parties, thus permitting that the reform could move forward smoothly.

In the context of this combination of the operation and distribution system reforms, profound and extensive changes have taken place in rural China, which have far exceeded people's pre-reform understanding:

(1) Planting structural changes. After the implementation of the "FFOQERH and RHBCS system," because the state and collective incomes were relatively fixed, the more production was developed, the more farmers would receive – far exceeding the farmers' own consumption. In this context, the first type of farmers will, on the basis of meeting the needs of the state and the collective, and their own consumer demands, observe the market and make production decisions according to market dynamics rather than state requirements, and the results were surprisingly good. This type of farmers' creative reform is equivalent to the introduction of market mechanisms into agriculture and the allocation of their limited household contracted lands according to the needs of the market – a very profound change indeed.

(2) The formation of individual economies and private enterprises. Unlike the first type of farmers, the second type did not simply adjust their planting structure, but instead sold surplus grain on the market in return for currency, which was further used to purchase corresponding production materials, such as tractors, cars, etc. for transport, processing machinery at home for small processing plants, or even sewing machines and hosiery machines for small projects. Such behavior enriches the economic structure of rural areas and increases employment opportunities for farmers. More importantly, on the basis of "RHBCS," a piece of private and free assets belonging to the farmers is derived in rural areas. The farmers began to form China's so-called initial individualist economy and private enterprises.

(3) The emergence of a mixed economy. The "FFOQERH and RHBCS system" has not changed the collective land ownership in rural areas, but all the production tools and inputs that work on agriculture and on the arable land are privately owned by farmers. This formed the earliest mixed-ownership economy.

(4) The emergence of urban–rural integration. The family business under the "FFOQERH and RHBCS system" pays great attention to the autonomy of the farmers. Under this framework, surplus funds that the rural labor force and farmers gradually accumulated began to flow, i.e., the production factors flowed. Furthermore, this flow even spanned urban and rural boundaries. In this sense, the mechanism of "FFOQERH and RHBCS system" broke down the wall between urban and rural areas.

1.3 The panoramic significance of rural reform

The aforementioned four changes were not realized by the people before the reform, but they actually appeared, and subsequently convinced many people to start exploring, on the

one hand, the causes of these changes and, on the other hand, the replicability of these experiences within other fields. The panoramic significance of rural reform lies actually in the change the traditional practices of rural areas, agriculture, and farmers. The CCCPC continuously investigates, interprets, refines, enhances, regulates, and gradually forms the policies, which were gradually promoted to the entire economic sphere apart from rural areas. Consequently, rural reform has had a very significant effect on China's overall reform. In this sense, it has been of important panoramic significance.

In 2008, the CCCPC convened the Third Plenary Session of the 17th Central Committee and adopted the "decision on major issues pertaining to promoting rural reform and development." One paragraph of this decision highly praised the panoramic significance of rural reform, namely, "the great practice of rural reform and development has greatly mobilized the enthusiasm of hundreds of millions of farmers, greatly liberated and developed social productivity in rural areas, and greatly improved the material and cultural life of the majority of farmers." More importantly, the great practice of rural reform and development has made creative explorations for the establishment and improvement of the basic economic system and socialist market economic system at the primary stage of China's socialism, achieved a historic leap in the people's livelihood from inadequate food and clothing to overall moderate prosperity, made great contributions to the advancement of socialist modernization, laid a solid foundation for overcoming various difficulties and risks to maintain the overall stability of society, and accumulated valuable experience in successfully opening up the path and forming a theoretical system of socialism with Chinese characteristics." In the drafting process of the "decision," compilers from various fields conducted repeated consideration of the entire contents, if it were not for this passage, the experts involved in its drafting generally believed that such evaluation is appropriate and constitutes an affirmation of the most important contents for the achievements of China's rural reform. From 1978 to the present, the field of rural reform has become very broad, covering rich and varied content. However, all follow-up reforms have been based on this reform, returning agricultural operations and distribution to their own natural courses. Although the farmers' ideas were very simple in carrying out this reform, it has evolved into something producing extraordinary results.

The content of rural reform is very rich, but its essence lies in the fact that it has not changed the basic system of rural China, i.e., the rural land system, which is of paramount significance for China. It is precisely because of the collective ownership of rural land that rural areas of China have had collective economic organization, a basic operating system, and a system of self-governance for villagers. Changes in the basic system are likely to cause subversive results. The smart and competent nature of the Chinese farmer lies in his practice of breaking through the operating system and changing the mode of operation rather than subverting the collective ownership of land, so that the original foundation system has found its most efficient form of realization. This experience is very important for China's reforms. Moreover, the experience of rural reforms has been extended to all other fields, including the basic economic system in the primary stage of socialism, the socialist market economic system, the path of socialism with Chinese characteristics, and the theoretical system for socialism with Chinese characteristics, which have, in effect, originated from the land reform and the farmers' wisdom.

2. The role of government's effectiveness in deepening rural reform

China's reforms have reaped numerous achievements that are inalienable from public policy's effective actions, which have also made important contributions to the continuous deepening of rural reforms. The aforementioned reform of the "FFOQERH and RHBCS system" is within the scope of farmers' abilities, but reforms in many areas are beyond the scope of the farmers' control and dominance, such as the reforms pertaining to the rural tax

and fee system, the circulation system of important agro-products, and the household registration system, etc. Such global reforms involving very complex interest relationships could hardly be pushed forward by grassroots farmer organizations alone. Without the government's effectiveness and a clear reform orientation on top of its concept change. Therefore, from the perspective of the success of rural reforms, China's reforms must be a process of mutual promotion and interaction between the grassroots level and the top-design level. The deeper the reforms are, the more complex the interests that need to be adjusted. How to correctly handle the appeals and overall situation of agriculture, rural areas, and farmers, as well as the relationship among other areas and fields constitutes a major test of government feasibility and competence. In this sense, the Chinese Government has been, by and large, successful in the process of leading rural reforms for more than three decades despite its occasional mistakes.

2.1 Changes in the government's concept of handling the "three rural issues"

Looking back at the history of rural reform for more than three decades, the Communist Party and the government have thrice shifted their views on agriculture, rural areas, and farmers. The first conceptual shift took place at the Third Plenary Session of the Eleventh Central Committee. The CCCPC, in summarizing the government relations with farmers for decades and the profound historical lessons, put forward a very important guideline on the relationship of the party and government with the farmers, namely., the two principles of "securing the material interests of the farmers economically, and respecting the farmers' democratic rights politically." In simple terms, this basic guideline is to protect the economic interests and respect the democratic rights of farmers. It is precisely because of the emergence of the Communist Party's understanding of this basic guideline that "FFOQERH" was not suppressed, order was brought out of the chaos of the Cultural Revolution, the ideological line of seeking truth from facts was truly established, and the ideological foundation of reform and opening up was solidly laid. In this sense, the Third Plenary Session of the 11th Central Committee was very important historically. Since the reform of this session to date, the Communist Party has always adhered to these two principles when formulating rural policies; therefore, they are called a basic guideline, which is also embodied in the "Report of the 19th National Congress of the Communist Party of China" delivered by General Secretary Xi Jinping. In future policy-making related to agriculture, rural areas and farmers, this criterion shall still hold.

The second conceptual shift is from administrative intervention to market orientation. Due to the success of the initial rural reforms, some of the farmers' practices had substantially impressed the Party Central Committee and State Council, although at the time the mentioning of "market economy" was still a political taboo (the wording of "planned commodity economy" emerged only after 1984), but it can be seen that from the successful reforms in rural areas, at that time, the government had become aware of the imperative to reduce administrative intervention in agriculture and rural areas as much as possible, and allow farmers to operate autonomously, that is, to allow managers to allocate resources to organize production according to the needs of the market, so as to achieve effective leadership in the three rural issues. This policy of allowing farmers to have business autonomy and the direction toward market orientation has continued to date and has never been reversed or deviated from. At the Third Plenary Session of the 18th CCCPC, it was proposed that it would "let the market play a decisive role in allocating resources and better play the government role."

The third conceptual shift is to clarify the important position of the three rural issues in the grand picture, that is, to take unswervingly the solution of the three rural issues as the top priority of the work of the CPC, which was accentuated again in General Secretary Xi's "Report to the 19th CPC National Congress." Comparing the previous statement of

agriculture as the foundation for the entire national economy, this conceptual shift had an even more profound meaning. It showed that the Communist Party recognizes that agriculture and rural development are lagging behind in the entire modernization process and the urban–rural gap is the biggest gap in China. Therefore, we must place the three rural issues on the top agenda of the whole Party.

The transformation of these three concepts in the process of reform and opening up is a very important experience summarized from previous historical experiences and lessons, and the ongoing farmer-initiated reforms. It has formed some important guidelines for the party to guide work in agriculture, within rural areas and with respect to farmers.

2.2 The government's systemic construction and improvement of the "three rural issues"

On the basis of the important guidelines for the work of agriculture, rural areas, and farmers, the party and the government are, on the one hand, endeavoring to reform and get rid of old ideas. On the other hand, they are putting forth efforts to build new systems. Of the many new systems, there are roughly three major aspects covered under some of the most important ones related to the "three rural issues."

The first aspect is the improvement of the basic rural operation system. Regarding household contracting, since the two-tier operating system combining centralized collective operation and decentralized household operation was clearly defined as the basic operating system in the rural areas and Chinese agriculture, the Communist Party and the government have always stressed the need to consolidate and improve the basic rural operating system – so does the "Report of the 19th CPC National Congress." The content of the basic rural operation system in China has been incessantly expanding and the term of contract is continuously being extended. In 1984, the No. 1 Document of the CCCPC clearly stated that the land contract term for arable lands should be no less than 15 years; in 1993, the No. 1 Document of the CCCPC clearly stipulated that the land contracting period shall be extended for thirty years upon expiry of the first round contracting; in the "Report of the 19th CPC National Congress," it was made clear that the term would be extended for yet another thirty years upon expiry of the second round of contracting. The extension of the contract period can enhance the farmers' confidence and sense of stability, but we also need to continuously consider how to improve the efficiency of farmland use, especially the issue of the operation of many idle lands in the wake of those farmers' migrating from the rural areas to urban ones. This elicits the concept of land circulation, which was originally put forward also in the CCCPC Document No. 1 of 1984. It purports to encourage the congregation of farmlands to abler hands upon expiry of land contracts, which is actually a land circulation (transfer). In addition to the extension of the contract term and the transfer of land, the No. 1 Document of 1984 also proposed that farmers be allowed to settle down in rural market towns for work or business with household certificate registered as those "taking care of their own grain rations" in contrast with agricultural and non-agricultural households. This is actually a starting point for urbanization. From these three perspectives, the No. 1 document is of great significance.

The party and the government have been consistently implementing the above-mentioned reform measures. In recent years, the central government has also put forward a clear definition of the "separation of three farmland rights," namely., clarifying land ownership, stabilizing land contracting rights, and liberalizing land management rights, which actually existed in many places long ago. For example, from the late 1980s, many farmers in Zhejiang and Jiangsu Province already knew this. The reason for regarding the "separation of three farmland rights" as a major institutional innovation in recent years is because the government or legislation has only really begun to make it clear of late. In past documents and laws, there have been frequent expressions of articles like "stabilizing land contractual management rights,"

"encouraging circulation (transfer) of contractual land use rights and contractual land management rights," and "allowing mortgage guarantees," etc. This policy evolution shows that previous documents and legislation do not realize that there are differences in these concepts. Under the existing system, land ownership remains unchanged, and the entities of land contracting rights are also limited to the farmer households within the same collective, only the management rights are subject to *laissez faire* and invigoration. As the contractor rights still belong to farmer households, even if the operation rights are transferred, the farmers will not hold misgivings. For effective "separation of three farmland rights," making it a better system moving forward, we must first ensure the rights-confirming registration of land. By the first half of 2017, such rights for national rural land management rights had been completed (approximately 73 percent of it), and it is estimated that by the end of 2018, more than 95 percent will have been completed. On this basis, it is possible to implement the "separation" of the three farmland rights. Of course, the "separation of three farmland rights" will also involve many complicated legal issues, which need to be further explored, to gradually allow the system to be clarified and refined so that it can better guide the practice. The second aspect is to continuously strengthen the coordination of urban and rural development and establish the institutional mechanisms for urban and rural economic and social integration. Although the allusion of "allowing farmers to settle down in rural market towns for work or business with household certificate registered" as those "taking care of their own grain rations" in Document No. 1 of 1984 actually allows farmers to enter small towns and small cities from the countryside, it was not until the "2002 Report of the 16th CPC National Congress" that it was first propounded. At that time it really proposed to coordinate and balance urban and rural socio-economic development. "The Report of the 16th CPC National Congress" announced that China had built a moderately prosperous society in general. The next step was to move from a moderately prosperous society in general to one that was so in an all-around way. The central government clearly understands that an all-around moderately prosperous society will not be realized if the urban–rural gaps are not narrowed. Therefore, the agricultural issues cannot be resolved solely by relying on the self-development of rural areas. What is more important is to implement urban–rural balanced development via integrated institutional measures. Since 2000, the reduction or exemption of agricultural taxes were piloted, by 2006, agricultural taxes had all been abolished. On this basis, the government further implemented supportive and protective policies for farmers, such as subsidies for grain production, seeds, agricultural machinery, and production materials, to gradually form a development trend featuring urban–rural mutual support. Later on the concept of "two-wheeled drive and parallel development of urbanization and the construction of a new socialist countryside" was unequivocally proposed.

No matter whether it is the construction of a new countryside, or the revitalization of rural areas, or the revitalization of rural strategies, such policies will never exclude urbanization. Given its special national conditions, China has many rural populations. Within a short period of time, or for quite a long period of time, a large proportion of the population may still live in rural areas. Therefore, the moderate prosperity of the entire country would be like an air castle if rural areas continued to lag behind. From that point of view, just as General Secretary Xi often expressed, even if our urbanization population reaches 70 percent, the remaining 30 percent would be still as many as 400m people. If by 2030 the total population reaches 1.5bn , at least 450m people will reside in rural areas. When the People's Republic of China was founded in 1949, the rural population was 484m. This is to say, after 81 years of development, the rural population in China has remained basically unchanged.

Given the huge rural population in China, the modernization of the overwhelming majority of population would be an arduous journey. Just as General Secretary Xi Jinping mentioned in his speech, there must be "sufficient historical patience." In Xi's myriad

speeches, the expression of "sufficient historical patience" probably only appeared twice. One was stated at the Urbanization Working Conference in December 2013 as "regarding the issue of population urbanization, we must have sufficient historical patience"; the other was stated in his visit of Xiaogang Village in April 2016: "scale operation is an important foundation for the development of modern agriculture, which can hardly be built upon the decentralized and extensive agricultural management models. However, we must also realize that changing these models takes a relatively long historical process that takes time and conditions, and cannot be rushed. Many problems must be examined in the grand picture of the historical process, and there must be sufficient historical patience." He also mentioned three conditions: urbanization, agricultural science and technological progress, and the development of an agricultural socialization service system. In this context, rural areas must be well built in the process of urbanization, that is, new urbanization and new rural construction must be implemented in parallel and driven by the "two wheels."

The third aspect is the prioritized development of agriculture and rural areas, the "Report of the 19th CPC National Congress" clearly stated that priority should be given to the development of rural areas to remedy these shortcomings as soon as possible. This statement, albeit not explicitly proposed before the 18th CPC National Congress, has been clearly put forward and repeatedly stressed thenceforward. Moreover, General Secretary Xi has repeatedly stated that in the process of the synchronization of the "four modernizations (of industry, agriculture, national defense and science and technology)," agricultural modernization remains a "short leg." In the process of building a moderately prosperous society in all respects, rural development remains a "short board," therefore we must speed up the remedying of the short-leg and short-board to truly achieve all-around moderate prosperity. Xi also expressed in a lot of popular terms that "the key of a well-off society lies in our fellow villagers." Then he added: "The key lies in fellow villagers in poverty-stricken areas." That is, we must make up for the shortfalls. In the "Report of the 19th CPC National Congress," a priority was pinpointed to develop agriculture and rural areas. The actual situation in China is that the relative development is inadequate and imbalanced and, in fact, bottlenecked by the "three rural issues."

To speed up the system construction in these three areas, we must first consolidate and improve the basic rural operation system to persistently uphold the enthusiasm of farmers. Second, we must promote urban and rural balanced development, so that the city's wealth and productivity can drive the development of agriculture and rural areas more effectively, such that rural areas will not be left to waste. Third, to remedy the shortcomings of the "three rural issues" with the least delay in order to accelerate the building of an overall well-to-do society and modernization.

3. The prospect of rural reform

The implementation of the strategy of "Revitalizing rural areas and rejuvenating the countryside," as stated in the "Report of the 19th CPC National Congress," has given us good inspiration for future prospects for rural reform. This strategy is different from the "new rural construction," which focuses on the existing conditions of rural areas and reforms them on a microscopic basis. It can be summarized in five sentences (i.e. ten English catchwords for 20 Chinese characters): "production development, affluent life, countryside civilization, village neatness, and democratic management." While participating in the drafting of a document on the construction of a new socialist countryside, the author was very concerned about the unequivocal articulation of the connotation and denotation of the concepts, which would enable the policy implementers to follow the top–down instructions rather than acting upon their own interpretations. That is to say, without clear conceptualization, the actions of grassroots enforcers and the masses cannot be successfully guided. Although the above five sentences (things) and ten catchwords for the construction

of a new socialist countryside have been approved by the central leadership, in practice, the grassroots governments are prone to do just one thing, namely., "village neatness." Since it is difficult for other things to achieve the desired effect, the goal of tidying the village can be, however, easily achieved. Facts have proved that this was the case with the initial new rural construction. For example, when I chatted with local farmers during an inspection tour in northern Shaanxi, I discovered that they understood new rural construction as "rich people build houses, poor people paint walls." The rural revitalization strategy refers to the implementation of the five-in-one (i.e. economic, political, cultural, social, and ecological civilization) constructions in rural areas, which also expands the five sentences of the original new rural construction to match the five major national constructions. Bearing this model in mind, there will be a clearer direction as to how rural areas should develop and reform.

3.1 Properly solving rural internal problems

The next step in rural reform is roughly twofold. The first aspect is to solve many internal problems in rural areas. At present, there are three most pressing issues to be resolved:

(1) Accelerate the structural reform on the supply side of agriculture, change the current situation which is fraught with undersupply or oversupply, hulky agriculture with low efficiency and competitiveness.

(2) Further protect the farmers' legal property rights, that is, to comprehensively promote the reform of the property rights system in rural areas, including the right-confirming registration and certificate issuance of the land and the further reform of collective economic assets.

(3) Speed up the advancement of innovation in agricultural science and technology and the innovation of agricultural management systems. Without these two innovations, the structural reform of the agricultural supply side will only become a quantitative increase or decrease, instead of the improvement of quality and competition.

3.2 Creating conditions and an environment that are conducive to the development of agriculture and rural areas

The second aspect is that in order to ensure the better development of agriculture and rural areas, the state must create more favorable conditions and environment for their development. At this level, three aspects of reforms can be promoted:

(1) Promote new urbanization. Urbanization is a long and difficult process. The current threshold and cost for the transformation of the agricultural population into full citizens are still too high. It remains very difficult for those qualified candidates to settle down in urban areas. For urban migrants, i.e., those who do not wish to settle in, the central government has proposed a residence permit system to achieve equalization of basic public services within the same urban area. There are many things that need to be solved meticulously in the process of urbanization. For example, the 13th Five-Year Plan has set a standard: by 2020, the urbanization rate of the resident population and registered population shall reach 60 and 45 percent, respectively. In 2016, the urbanization rate of the resident population and registered population was 57.4 and 41.2 percent, respectively. Given the difficulty in escalating the urbanization rate of the registered population, the goal (45 percent) is virtually unattainable by 2020. However, in October 2016, CCTV reported that 31 provinces, municipalities, and autonomous regions barring Tibet have all

announced the cancellation of their two types (with urban and rural discrimination) of household-registered accounts, which are being replaced in a two-in-one manner. That is to say, the evaluation index of the urbanization rate of registered population has gone with the wind. However, this system is likely to confuse urban and rural population and cause serious problems. For another example, the population of the urban population at the end of 2016 was less than 800m. According to the natural growth rate of the urban population of 5 percent, the number of urban residents naturally accrued each year would be 4m. In 2016, however, the number of rural residents entering the city only increased by 500,000. The natural increase of the urban population plus the rural population entering the city denotes the total increase in urban population. According to the National Bureau of Statistics (NBS), the annual increase in urban population is 20m, which outweighs by far our calculations. Professor Cai Fang justified this issue via an explanation that by changing the administrative system, one can derive the number given by the NBS. It is proposed that the village committee be changed into a neighborhood committee, the township be changed into a street, and the county be changed into a city or district. As mentioned in the above two examples, such changes in the administrative system or assessment indicators are not true urbanization; it takes a lot of authentic effort to promote new urbanization.

(2) Accelerate the equalization of urban and rural areas in terms of infrastructure social undertakings, basic public services, and basic social security. General Secretary Xi referred to this process when he mentioned that there must be "sufficient historical patience" for population urbanization. Other countries have achieved this goal for ages, and China has to do so in a stepwise rather than a leapfrog manner. Once the above equalizations are basically realized in urban and rural areas, farmers will not be affected by non-equalization of rights and public services regardless of their choices to stay in cities or rural areas. This change is of paramount importance.

(3) Support and encourage the development of new industries and new operation types in rural areas, and promote the integration of rural primary, secondary, and tertiary industries. The job opportunities provided by cities cannot satisfy the demands of the vast rural population, the full employment of whom would necessitate the creation of a "third employment space" for farmers. The "first employment space" refers to the contracted land, the "second employment space" refers to work and business in urban areas, and the "third employment space" denotes job opportunities within the countryside but not depending on arable land, such as e-commerce, online shopping, handicrafts, rural tourism, old-age care and health regimen, etc., which will invariably, to some extent, have no side effects on the scale of operations required for agricultural modernization. In the 1980s, with the sudden rise of township and village enterprises, farmers could leave their farmland and seek employment without leaving their native land. However, in 1996, the "Law of the People's Republic of China on Township Enterprises" was issued, and township and village enterprises basically disappeared. In the late 1990s, there was a wave of migrant workers hunting for jobs in cities. In 2016, the total number of peasant workers was 282–170m of who were in urban areas. From an incremental point of view, the growth rate of migrant workers entering the city was 5–7 percent in 2011 and 2012, falling to just 0.4 and 0.3 percent in 2015 and 2016, respectively. The above examples of the growth rates of township enterprises and migrant workers show that times are constantly changing, and reforms must seize the moment. Furthermore, the national condition of the huge number of Chinese farmers must

be taken into serious consideration. The most difficult part of China's modernization process is the employment and income of the rural population. All rural reforms must be carried out around this issue, and efficiency must not be raised at the expense of the employment and income of farmers.

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The structure and changes of China's land system

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Abstract

Purpose – The purpose of this paper is to analyze the structure and changes of China's land system. To achieve this aim, the paper is divided into four parts. The first part gives a brief introduction to the structural characteristics of the Chinese land institutional arrangements; the second part analyzes the reform process of the land system in the past 40 years and its path of change; the third part engages the discussion about the historic contribution made by the land institutional change to rapid economic growth and structural changes; and the final part is conclusion and some policy implications.

Design/methodology/approach – After 40 years of reforms and opening up, China has not only created a growth miracle unparalleled for any major country in human history, but also transformed itself from a rural to an urban society. Behind this great transformation is a systemic reform in land institutions. Rural land institutions went from collectively owned to household responsibility system, thereby protecting farmers' land rights. This process resulted in long-term sustainable growth in China's agriculture, a massive rural-urban migration and a historical agricultural transformation. The conversion of agricultural land to non-agricultural uses and the introduction of market mechanisms made land a policy tool in driving high economic growth, industrialization and urbanization.

Findings – Research shows that the role of land and its relationship with the economy will inevitably change as China's economy enters a new stage of medium-to-high speed growth. With economic restructuring, low-cost industrial land will be less effective. Urbanization is also shifting from rapid expansion to endogenous growth so that returns on land capitalization will decrease and risks will increase. Therefore, China must abandon land-dependent growth model through deepening land reforms and adapt a new pattern of economic development.

Originality/value – This paper gives a brief introduction to the structural characteristics of the Chinese land institutional arrangements, analyzes the reform process of the land system in the past 40 years and its path of change, and evaluates the historic contribution made by the land institutional change to rapid economic growth and structural changes.

Keywords Structural change, Economic performance, Land institution

Paper type Research paper

Land institution is a fundamental arrangement in China's political and economic system. Land institutional reform is a key and sensitive area of China's overall reform. The unique disposition of the land institutions and its change are the engine of China's rapid economic growth and structural change. The reform of the rural land system in the early 1980s marks the beginning of China's reform and opening-up, promoting its rural transformation and system transition, while change of the urban land system since the late 1990s has promoted the shifting of China from a rural country to an urban-rural society, giving rise to a historic transformation.

This paper is comprised of four parts. The first part gives a brief introduction to the structural characteristics of the Chinese land institutional arrangements; the second part analyzes the reform process of the land system in the past 40 years and its path of change; the third part engages the discussion about the historic contribution made by the land institutional change to rapid economic growth and structural changes; and the final part is conclusion and some policy implications.

1. The structure of China's land institution

From the perspective of the land institution's impact on Chinese economic and social transition, the Chinese land system is a complete institutional structure, made

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of farmland institutional arrangement, rural homestead land institutional arrangement, land conversion institutional arrangement and urban land use institutional arrangement.

1.1 Farmland household contract system under collective ownership

Rural contracted land has the largest percentage among all types of land in the country and involves the largest percentage of the population. At the end of 2015, China had a total of 645,456,800 hectares of agricultural land, of which 134,998,700 hectares were farmland (2 billion and 25 million acres)[1], with a total of 134,236,800 hectares, accounting for 99.44 percent of the total farmland, contracted to 23,057,400 households (Dongyu, 2015). The rural contracted land system was deemed to be a basic arrangement influencing agricultural performance, farmers' rights and social stability.

Compared with other rural institutions in history, since the Communist Party of China (CPC)'s ruling, the rural land system has thoroughly changed China's countryside. In traditional rural China, rural land was privately owned by farmer households. Family farming, mainly consisted of self-employed and tenant farmers were the main operators of small-scale farmland. The ownership rights and management rights of the farmland have been equally protected by law and contract, and the cultivation rights to a large extent had the de facto attributions and functions of ownership (Xiaotong and Haoxing, 2007). After the CPC came to power, it installed socialism based on public ownership, promoting China's transition from a rural economy to an industrial one (Zedong, 1991). For this purpose, the new regime conducted a series of state-led system recreations in rural areas (Runsheng, 2005). As a result, a unique collective ownership system of rural land was formed, which had the following characteristics: first, as a form of public ownership in rural areas, collective ownership was applied to rural land and the state implemented comprehensive political and economic control over the rural areas through people's communes, production brigades, and production teams. Second, the collective land property right, in fact, was exercised by the state. The land use right in the production teams was controlled by senior officials. Production teams were not entitled to selecting what crops would be planted, and the right to revenue was truncated due to procurement by the State. The public accumulation and the distribution to the production team members were conditioned by first completing the task assigned to them by the State. Third, the agricultural economic activities and labors were arranged in a unified way by the production team, and production results were distributed in a uniform way based on the working points (Qiren, 1995).

Due to the change in the political climate and the inefficiency of the state-controlled collective ownership and unified operation system, China launched the rural land reform in the late 1970s and early 1980s. Through grassroots innovations, official support and policy implementation (China Rural Development Research Group, 1984), a new rural land system acceptable to relevant agents was formed, stating that the rural land was owned by the collectives and contracted to the village households. The system first, stated that the reform should adhere to the premise of land collective ownership under the socialist system of public ownership. At this point, the state continuously produced documents to declare collective ownership unchanged and emphasize that land contracted to each household is different from private ownership[2]. The collective ownership framework was reserved as "three levels of ownership and the production team as the basic unit." The relation between peasants and the land was defined as a contractual relationship. Under collective ownership, rural land was not allowed to be bought or sold. Second, contracts were formed between the state, collectives and households. The initial contract arrangement was tacitly selected by farmers, something later regarded as a tripartite contract. The contract structure was "contributing adequately to the state, paying enough to the collectives, and retaining the remaining part." This meant that under the premise of commitment and fulfillment of the

national tasks and collective obligations, farmers could obtain the residual claim of the collective land. Third, collective ownership was explicitly defined as ownership of the collective members.

Different from the "commune members" in the collective farming period, who contributed to the nation with his own labor and gained certain income, the "collective members" under the household responsibility system could not only equally obtain the land and the assets owned by the collective, but also enjoy the rights to all assets grown out of collective land. The collective ownership after the reform, in fact, became an entitlement set of collective members, which strengthened the identity of collective membership. Fourth, the clarification of property right in the contracting of farmers on the agricultural land meant the separation of the collective ownership from the right of use, making that contracting right was a real right, strengthening the dominant position of the farmers, constantly improving farmers' right to use the contracted land, and granting them the right to revenue and transfer. Fifth, the implementation of the family farming system: by eliminating the farming system under which production teams organized production and distributed revenues, families replaced the production teams to be the unit of agricultural production, economic decision-making, and income allocation. Farming households then became the operating entity of agricultural management, institutionalized by passing relevant laws.

1.2 Rural homestead system under collective ownership

The rural homestead system is regarded as a crucial arrangement with political and social impact. Among all rural lands, the homestead land is an important one concerning farmers' residence and property right. As of 2015, there are 140,134 hectares of village-use land (Huizhen, 2015), of which the homestead is approximately 133,300 hectares (Huizhen, 2015).

Historically, farmers' residence and homestead land have been the private rights of farmers, and land rights are inseparable with the right to residence on the land (Xiaojun and Shengsan, 2010). During the land reform and in the period of Cooperative Movement, the homestead land and the residence on it are privately owned by farmers. It is in the period of the people's commune, when it begins to, respectively, establish the rights of homestead and the residence, in which it is not permitted to rent or sell the homestead, but in which the right to use in the long-term belongs to each household. The house is always owned by the members and can be bought, sold or rented (Shufeng, 2015). By the early 1980s, when rural reform started, the structure of the homestead system, which was collectively owned and used by farmers, was still in its infancy: first, homestead ownership was owned by the production team, and commune members were prohibited for renting, buying and selling homestead (Shouying, 2014). Second, a homestead was separated from its residence rights, the farmer household had the long-term right to use the homestead, and had the exclusive ownership of the residence, which could be bought, sold, leased, mortgaged or pawned, and the right to use the homestead was transferred with the sale and lease of the residence (Shouying, 2014). Third, it was established that the homestead could be acquired for free in accordance with the application of the collective membership (Shouying, 2014).

1.3 Land conversion arrangements under the dual ownership

In the past 40 years, China's high-speed economic growth has been accompanied by a rapid industrialization and urbanization. The scale and model through which of the agricultural land is converted into non-agricultural land have had a significant impact. From 2003 to 2015, 11,561,800 hectares[3] of agricultural land were turned into non-agricultural land. The conversion of agricultural land into construction land included the urban and rural construction land. From the perspective of ownership, there were two ways, i.e., conversion by the collective and expropriation by the government.

From the beginning of the rural reform to the revision of The Land Administration Law in 1998, the channel for the conversion of agricultural land to collective construction land was open. In the early 1980s, a large number of surplus labor force was released along with agricultural reforms, and the government encouraged farmers to use collective land to set up township and village enterprises. As a result, rural construction land increased rapidly. Land utilized by township and village enterprises in China was estimated to be 15,700 hectares in 1978 and about 56,300 hectares in 1985. The scale of land utilized by town or village enterprise was expanded by 2.6 times. From 1981 to 1985, the average new farmers' residence was more than 600 million square meters per year.

Till 1987, when the old Land Administration Law was implemented, there were three channels for rural land to be converted to non-agricultural construction: first, as long as the construction was in conformity to the township (town) village construction planning, and the county level people's government approval was obtained, "rural residential construction, township (town) village enterprise construction, township (town) village public facilities, public welfare construction and other township (town) village construction could be carried out." Second, in the event that a collective agricultural economic organization needed land to organize joint ventures with enterprises owned by the whole people, or enterprises of collective ownership, it "may requisite the land in accordance with the provisions of the State construction requisition. The agricultural collective economic organization can also, according to the contract, use the land use rights as its contribution to joint management." Third, residents with non-agricultural hukou could use the collectively owned land for residential construction, under the approval by the county people's government (Shouying, 2008).

On the other hand, land requisition was the main tool for agricultural land converted to non-agricultural use. Especially after the passage for collective construction land was closed, land conversion by expropriation was the only legal way. The Constitution of 1982 backed the principle of the Constitution of 1954 in which the state may, in the interest of the public, conduct land requisition. However, it also put forward for the first time that urban land shall be owned by the state, and the rural land shall be owned by the collective, a land ownership structure in which two ownership systems coexisted and were divided[4]. The Land Administration Law promulgated in 1987 insisted the principle of public interest for land requisition. However, the definition of public interest is very broad: the State may conduct land requisition "for economic, cultural, national defense, and social and public undertakings," and the land requisition compensation was based on the principle of original use. The sum of land compensation and resettlement subsidies were raised to be no more than 20 times the average annual output of the three years prior to the requisition of the land. Additionally, employment and hukou status were provided to the peasants whose land was taken[5].

1.4 Urban land use system under state ownership

Before the reform, China implemented a system of free and indefinite flow of land supply. The Land Administration Law of 1987 stipulated two types of land use modes, administrative allocation and paid transfer. The urban land-use institutions after the conversion of land into state-owned not only provided land security for the rapid advancement of industrialization and urbanization, but also was an important source of capital for urban construction.

2. Land institutional change in the reform era

2.1 Rural land system has moved toward the direction of strengthening farmers' property rights

2.1.1 Legally clarifying the connotation of collective ownership. The Rural Land Contract Law and the Property Law defined the connotation of collective ownership as "land collectively

owned by peasants in rural areas that is fundamental to the basic rural operation system"[6], and that "the collective owner of collective land, in accordance with the law, is entitled to possess, utilize, dispose and obtain profits from the collective land" (see footnote 6). The "peasant collective" as the subject of land ownership has three levels – namely "the village peasant collective," "the intra-village peasant collective," and "the township (town) peasant collective" (Liming and Youjun, 2012).

2.1.2 Improving property rights of the farmers for the contract land. Land contract rights are a special type of usage property rights, and contracted land is the farmer's property (Suinian, 2002). Legislation clearly states that contracting farmers are entitled in accordance with the relevant law to use and obtain profits from the contracted land, to transfer the land contract rights, and to organize production, operation and disposal of the products. If contracted land is expropriated by law, the contractor shall have the right to receive the appropriate compensation (see footnote 6). During the contract period, the collective shall not recover or adjust the contracted land so as to continuously extend the right to subcontract (see footnote 6). In order to restrict any infringement of the public authority on farmers' land property rights, it is expressively stipulated that within the statutory period of the contract, no organization or individual shall interfere in farmers' production and management autonomy, the contracted land shall not be unlawfully adjusted or claimed, the wishes of farmers shall not be contravened by forcing the transference of the contracted land, and farmers shall not be illegally encroached on contracted land[7].

2.1.3 Extending the land contract period for contracting farmers. The land contract period of 15 years in 1984[8] was extended to 30 years for a second round of the contract[9]. The third plenary session of the 15th Central Committee of the CPC held in 1998 granted farmers a long-term and guaranteed land-use right[10]. During the third plenary session of the 17th Central Committee of the CPC, "the contracting farmers' land rights can't be changed for a long time" was proposed[11] and the third plenary session of the 18th Central Committee of the CPC further reaffirmed this provision[12].

2.1.4 Redefining membership rights of collective ownership. The Central Rural Policy Research Office conducted a pilot experiment in Meitan County, Guizhou Province, in the late 1980s, in which "neither increase nor reduction in family members lead to an increase or reduction in the land for the family." In 2002, the previously mentioned pilot results were written into the rural land contract law. The land contract law clearly states that "the State shall protect the long-term stability of the rural land-contracted relationship," and that "within the contract period, the collective should not adjust the contracted land."

2.1.5 Changing the contract conditions. On the one hand, the obligations to the state attached to the land were changed gradually. First, the task of providing grain by farmers was reduced. Farmers began entitled to plant freely beyond their tasks and were allowed to exchange food for currency. This reduced the link of farmers' land to grain tasks. Second, the central government implemented grain marketing system reform, the state bought grain in a market-oriented way. Grain tasks from peasants and land were terminated. Finally, the state provided farmers with grain subsidies. On the other hand, the collective obligation changed. In the 1990s, farmers had to provide a collective accumulation fund, and a public welfare fund. The assessments of burdens on contracting farmers were overwhelming. Subsequently, the "one act, one discussion" way adopted. The farmer's obligation was not linked to the burden with the contracted land. Changes in State and collective obligations amplified the residual claim of farmers' land rights (Qiren and Shouying, 1997).

2.1.6 The family farming system as a constitutional approved system. In 1991, it was proposed for the first time that "the two-tier management system based on household contract management that combines unification and separation shall be stabilized in the long term, and constantly enriched and perfected as a basic system of the Chinese rural

collective economic organization" (see footnote 11). The Constitution of 1999 explicitly states that "rural collective economic organizations implement the two-tier management system based on household contract management and combining unification and separation." The Law on the Contracting of Rural Land of 2002 formally proposed the "national implementation of rural land contracted management system." In 2008, the third plenary session of the 17th Central Committee of the CPC emphasized that, "the two-tier management system based on household contract management combining unification and separation is suitable for the Socialist market economy, which is in line with the characteristics of the basic rural management system for agricultural production, constitutes the cornerstone of the party's rural policies, and must be unwaveringly adhered to" (see footnote 11).

2.2 The homestead land system was toward the direction of land use control

2.2.1 The collective organization has the actual ownership right for collective homestead. Unlike the ownership of the cultivated land was moving toward membership rights of collective ownership, the collective organizations had stronger power to control the homestead. For the owner of the homestead, the collective organization was by no means a legal level of entity, but one exerting real rights to control, usage and income (Shouying, 2015). And the collective body was entitled to the allocation of the village's land for homestead, to recovery of the part possessed by farmers in excess of the size stipulated by law, and to control of the collectively owned vacant land, public use land and business use land (Shouying, 2015). In some villages that conduct village reconstruction and land improvement, the collective controls the right to revenue from the balance of the homestead indicator.

2.2.2 The households in the village enjoy the residence right of homestead land. The law stipulated that the holders of the rights of homestead use had the right to possess and use all land owned by the collective and had the right to use the land to build houses and its ancillary facilities. However, provided that one family could only own one homestead, any application by a rural villager who has sold or rented their house would not be approved. If the homestead was destroyed by natural disasters or other causes, the use right of the homestead was eliminated. The villagers who lost their homestead would receive new homestead (Shouying, 2015). However, the right to use the homestead could not be transferred, mortgaged or benefited. But the farmer's house was private property, and they were entitled to buy, lease, mortgage and transfer it.

2.2.3 Only members of the collective economic organization were eligible to apply and obtain a homestead (Shouying, 2015). Non-members of the collective economic organization could not obtain it. The restrictions on the acquisition of homestead by non-members were gradually tightened. In 1982, the application of retired staff, soldiers and Overseas Chinese who settled in rural areas could be granted[13]. The Land Administration Law of 1987 permitted non-agricultural residents in cities and towns to build houses after the approval of the county people's government, and the Regulations on the Implementation of the Land Administration Law of 1991 were still open to using collective land for housing by urban non-agricultural residents. By 1999, a significant change occurred. It was stipulated that "the farmer's residence should not be sold to urban residents. Urban residents cannot begranted to use farmers' collective land for housing[14]." The document No. 28 of 2004 "prohibited urban residents from buying homestead in rural areas[15]."

2.2.4 The strengthening of homestead use control. Rural homesteads that occupied agricultural land were included in the annual plan. It was stipulated that the indicator representing rural homestead to occupy agricultural land should be added among the annual plan indicators that each province (district, city) issued to each county (city) for urban and rural construction. The previous indicators should be related to the newly increased cultivated area in the rural construction-land consolidation.

The county (city) land and resources management department should prioritize the allocation of the same amount of land conversion indicators for the construction of farmers' houses from the overall annual plan indicator after the new cultivated land area was inspected and verified (Shouying, 2015). However, in fact, this was difficult to implement. The reason was that the approval of the homestead was conducted by each county (city) according to the rural homestead occupation of agricultural land planning indicator assigned to the county (city) by the province and the actual needs of rural villagers for housing construction. The county (city) at the beginning of each year submitted applications to the province (district, city) for approval of agricultural land transition. Upon approval, the county (city) would approve the provision of the homestead house by house. For the houses that could be built by villagers on the idle land, old curtilage base or unexploited land, the village, township (town) could review level by level and implemented by township (town) one by one after the batch approval by the county (city) (Shengping and Shouying, 2007).

2.3 The land conversion is monopolized by local government

Since 1992, China has changed the policy on land conversion to collective construction activities. The rural land has to go through requisition and transfer as state-owned land when it is used as construction land[16]. The revised Land Administration Law, promulgated in 1998 legally restricted the passages for agricultural land conversion into collective non-agricultural construction land, excluding farmers using collective land for non-agricultural construction, except the "use of land collectively owned by peasants of the collective economic organization approved in accordance with the law for the establishment of township and village enterprises and construction of residences by villagers, or use of land collectively owned by peasants approved in accordance with the law for the construction of village (township) public facilities." The law explicitly stipulated that "the right to use of land collectively owned by peasants shall not be transferred, retransferred or leased for non-agricultural construction," and it reserved the provision that "rural collective economic organizations may jointly organize enterprises with other units and individuals in the form of equity participation of land use rights and joint operations."

The Land Administration Law of 1998 followed the principle of land requisition for public interest, and the structure of urban and rural dual ownership, and original-use-based compensation principle, but the sum of land compensation and resettlement subsidies were raised to no more than 30 times the average annual output of the three years prior to the requisition of the land. This law also made two provisions that have a significant impact on land conversion: first, the establishment of the "land use control system." The state shall formulate a general plan for land use, stipulate land use, control the total amount of land used for construction, and examine and approve annual construction land quota[17]; second, if any unit or individual is required to use land for construction, they shall apply for the use of the state-owned land in accordance with the law (see footnote 17).

The problems arising from land requisition became more and more serious as the process of industrialization and urbanization accelerated. The Ministry of Land and Resources began a pilot reform of the land requisition system in 2001[18], and based on the pilot project, implemented on a trial basis in 2005 the standard of unified annual production and the comprehensive price of land requisition within the area. The calculation of the comprehensive price follows this principle: within the construction land designated by the general plan of the urban district, both zone classification and the calculation of land requisition compensation standard were based on the types, output value, location of the land, agricultural land grade, per capita cultivated land quantity, land supply and demand relation, local economic development level, lowest living standard of urban residents, etc.[19]. Although the comprehensive zone price of land requisition considered the land development rights of land-requisitioned farmers,

the scope of implementation of this standard was limited to the urban and town areas, and a large number of land requisitions outside this range were still carried out in accordance with the production (i.e. the original use) standard (Yuzhe *et al.*, 2008).

After 2003, the central government clearly called for the reform of the land expropriation system. The Third Plenary Session of the Sixteenth Central Committee of the CPC pointed out that the content and direction of the reform of land requisition were "in accordance with the principle of safeguarding the rights and interests of farmers, controlling the scale of land requisition, improve the land requisition procedures, and strictly define the public and the business use. Land requisition should meet the general planning and use control of land, and give the farmers reasonable compensation in time." The Fifth Plenary Session of the Sixteenth Central Committee of the CPC called for "improving the reasonable compensation mechanism for land-requisitioned farmers"[20]. The Sixth Plenary Session of the Sixteenth CPC Central Committee called for "the strict control of the scale of land requisition, acceleration of the reform of land requisition system, improvement of the compensation standard, exploring effective ways to ensure farmers' interests and long-term stable income, and arrangement of farmer's employment and social security of land-requisitioned farmers"[21].

The Central Government No. 1 document in 2006 clearly called for "speeding up the pace of land requisition system reform, and based on the requirements of reducing the scope of land requisition and improving the compensation method, expanding the resettlement approaches and standardizing the requisition procedure to further explore the reform experience"[22]. The Central Government No. 1 document in 2008 clearly called for "continuing to promote the reform of land requisition system, standardize the procedures of land requisition and raise the compensation standard, improve the system of social security for farmers whose land was requisitioned, and establish the dispute mediation adjudication mechanism for land requisition"[23]. The Third Plenary Session of the Seventeenth CPC Central Committee proposed that "for the land that is beyond the urban construction land use planning, farmers shall be allowed to participate in the development and operation of the non-public welfare projects, that subject to approval, occupy rural collective land, in a variety of ways in accordance with the law and that the lawful rights and interests of the farmers shall be protected" (see footnote 11).

In 2010, the Ministry of Land and Resources set up a pilot reform of the land requisition system in 11 cities within the national comprehensive reform pilot zone, the main content of which included: the distinction between public welfare and non-public welfare land, the reduction of the scope of land requisition, the improvement of compensation and placement mechanism of land requisition, as well as the way of examination and approval for agricultural land conversion and requisition. The non-public welfare land project stipulated in the Guidance on Pilot Work, mainly included tourist entertainment, commercial services, industrial warehousing and other types of facilities which were built subject to the approval in accordance with the law. It affirmed narrowing the scope of the land requisition. It stipulated that, within the scope of urban construction land identified in the general plan of land utilization, in addition to the peasant collective land that may be used in accordance with law, the construction land involving collective land shall be allowed in principle to be expropriated. The land beyond the scope of urban construction land identified in the general plan of land utilization, non-public welfare land, should be withdrawn from the land requisition scope, and the rural collective land shall be, subject to the approval, obtained in other ways. Unfortunately, due to the short time and the small scope, the pilot was not effective (Tang, 2011).

The Third Plenary Session of the Eighteenth CPC Central Committee decided to make a general deployment of the land system reform, the content of which was as follows: under the premise of conforming to planning and use control, the rural collective construction land

shall be allowed to be leased, transferred and to participate in equity, and enter into the market at identical price and rights to the state-owned land; to narrow the scope of land expropriation, standardize the land requisition procedure, and improve the safeguard mechanism for the land-requisitioned farmers, that shall be reasonable, standardized and multivariate; to expand the range of paid use of state-owned land and reduce the allocation of non-public welfare land; to improve the secondary market for land lease, transfer and mortgage; to establish a reasonable mechanism to adjust the price ratio of industrial land to residential land, and raise the price of industrial land. The above pilot program was carried out across the country[24]. The adoption on February 27, 2015 at the Thirteenth Session of the Standing Committee of the Twelfth National People's Congress of the Decision to Authorize the State Council to Temporarily Adjust the Relevant Legal Provisions in the Administrative Areas of the 33 Pilot Counties (Cities and Districts) in Daxing District, Beijing (NPC Regular Session (2015) No. 1), and the implementation of the General Office of the CPC Central Committee and the General Office of the State Council of the Opinions on Rural Land Expropriation, putting collective-owned operational construction land into market, homestead system reform pilot work (Zhongbanfa (2014) No. 71), officially began the rural land three system reform.

2.4 Capitalization of urban land

On December 1, 1987, the land use right for a land lot of 8,588 square meters was publicly auctioned for 50 years in Shenzhen. This was the first time that land use rights in China entered the market as assets (Shouying, 2008). The amendment of the Constitution in April 1988, deleted the provision that land shall not be rented, at the same time added the provision that "land use rights can be transferred in accordance with the provisions of the law." In May 1990, the State Council issued the Interim Regulations on the granting and transfer of the right to use state-owned land in cities and towns, which clearly stipulated that land use rights can be transferred in three ways, agreement, bidding and auction.

The Land Administration Law of 1998 clearly stipulated that "the land use right can be transferred in accordance with the law" and "the State shall implement the system of paid use of state-owned land in accordance with the law." The State shall, as a representative of the land owner, transfer the state-owned land use rights in a certain period of years, by agreement, bidding, or auction, to the land users, which shall pay for the land use rights to the State in accordance with the agreement of the assignment contract. Since 1999, the land paid use system reform has been increased continuously, which reduced the proportion of allocation and increased the proportion of paid use.

In May 2002, the Ministry of Land and Resources issued the Provisions on the Assignment of the State-owned Land Use Right by Means of Bid Tendering, Auction and Listing, Decree No. 11, stipulating that business, tourism, entertainment and commercial housing, and other types of business use of land, must be transferred by bid tendering, auction or listing. The total land area transferred by Shouying (2012) "bid tendering, auction and listing," and the price, increased from 6,600 hectares and 49.2bn Yuan in 2001 to 66,500 hectares and 549.2bn Yuan in 2006, respectively. Since the issuance of the State Council No. 28 document in 2004, which stipulated that the transfer of industrial land must be carried out by bidding, auction, or listing, the proportion of state-owned construction land transferred by bidding, auction and listing was rising annually. In 2001–2010, the proportion of land transferred by bidding, auction and listing increased from 7.3 to 88.3 percent. The proportion of the revenue through bidding, auction and listing accounted for 92.23 percent of the total revenue in 2010 (see Table I).

Under the current land system, the government not only is the sole arbiter in the transformation of rural land into urban land, but also has the exclusive power to transfer the land from the countryside to the city in the process of land conversion. With the land

Year unit	BAL Area 10,000 ha	BAL percentage (%)	BAL Price Billion RMB	BAL percentage (%)	State-owned land transfer Area 10,000 ha	State-owned land transfer Price Billion RMB
2001	0.66	7.30	49.2	–	9.04	–
2002	1.81	15	96.924	–	12.05	–
2003	5.19	27.78	–	–	18.68	293.776
2004	5.21	29.16	325.368	55.20	17.87	589.414
2005	5.72	35.05	392.009	71.21	16.32	550.515
2006	6.65	28.60	549.209	71.54	23.25	767.689
2007	11.53	50.91	1,007.486	82.47	22.65	1,221.672
2008	13.36	81.91	952.874	92.87	16.31	1,025.98
2009	18.83	85.30	1,509.85	94.90	22.08	1,591.02
2010	25.73	88.27	2,600	95.94	29.15	2,710
2011	30.47	91.25	3,020	95.87	33.39	3,150
2012	29.3	90.77	2,550	94.80	32.28	2,690
2013	33.88	92.32	4,040	96.19	36.7	4,200
2014	25.15	92.53	3,180	95.21	27.18	3,340
2015	20.44	75.20	2,860	85.63	22.14	2,980

Table I. Transferred land and the land transferred by bidding, auction, and listing (BAL) in the past few years

Source: Collected from the *Bulletin of China Land and Resources*

conversion, the government replaces the peasant collective as the owner of land and the operator of urban land. This has become the main tool for the mode of seeking development with land (Shouying, 2012).

3. The economic performance of land system change

China's high economic growth over the past 40 years is well known as the "economic miracle" (Yifu *et al.*, 1999). In the period between 1978 and 2016, the GDP annual average growth rate reached 14.996 percent, the industrial value added rate grew by 14.14 percent annually, and the urbanization rate increased by an average of 3.11 percent annually. Land system change has had a major impact on the economic growth. The agricultural land reform has promoted the growth of agricultural production and released a large population out of the villages, providing a micro-foundation for China's economic transformation. Although strict farmland protection system has been implemented, the ample supply of land in the region with development opportunities has ensured high economic growth. Attracting investment at the distorted industrial land prices by local governments and land supply to provide industrial park infrastructure, has contributed to high-speed industrialization, which has made China a world-class manufacturing factory. Land capitalization and land finance has provided the enormous amount of capital needed by China's urban development and promoted the rapid urbanization.

3.1 Land is the engine that drives China's high economic growth

China's traditional development model relies on high growth and high investment. Because the municipal and county governments are the real land owners, land was the main tool for local governments to pull up growth and promote investment. Over the past 40 years, the land had in fact undertaken dual function: on the one hand, the central government had to implement the most stringent farmland protection system to safeguard national food security; on the other hand, various governments loosely managed the land to ensure high growth. They were reflected as follows: first, under the pursuit of GDP, through the ample supply of land to pull local economy. During 2003–2012, the total annual supply of state-owned construction land increased from 286,400 hectares to 690,400 hectares, an average annual increase of 10.27 percent. Second, the supply of land increases when

economic growth slows down (see Figure 1). Third, ensuring growth by regional policy of land supply. The land supply targets before the global financial crisis focused on coastal areas with large demand for land, which guaranteed the demand for land in high speed development regions; fourth, under the control of the annual plan, local construction land quota, which were increasingly scarce, were mostly used for the development of capital cities and major development zones. The flexible supply of construction land under the strict farmland protection ensured the high economic growth.

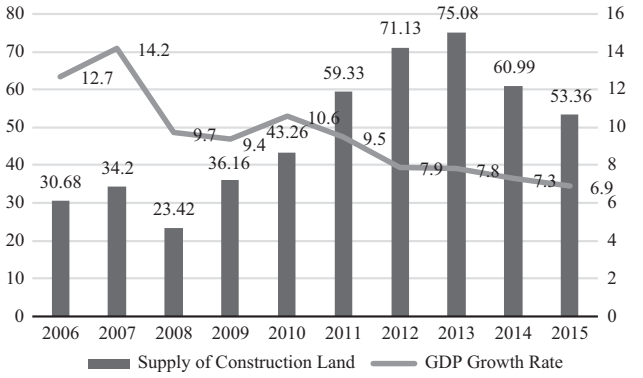
3.2 Farmland reform and agricultural transformation

A stable and efficient rural land institution was the prerequisite for China to promote overall reform and structural change in the past 40 years. The first function of rural land institution in China, a country that has long been based on agriculture, is to stabilize both food supply and society. The rural land reform improve land use efficiency in the direction of clarifying property rights, but also made it possible to launch the structural change in rural areas:

(1) The family management system has been established and persisted in agriculture, which became the microcosmic foundation of China's agricultural growth. The family management system was generalized since 1984. In 2016, despite the growth of new types of agricultural management, the family contracted land still accounted for 99.4 percent of the cultivated area, The production of food crops increased from 407.305 million tonnes in 1984 to 616.25 million tonnes in 2016, which can be attributed to the progress of agricultural technology, the increase of modern investment, and the stability of the family management system which is also fundamental.

(2) The reconstruction of human relationship to the land has promoted the structural transformation. In traditional rural China, farmers were tied to the land; during the state industrialization period, the peasants were excluded from the process of industrialization, and even were bounded to the collectively owned land; after the implementation of the family contract system, the peasants were able to participate in the local industrialization of the rural areas and subsequently go out from their villages to participate in the industrialization of other places, becoming the main force to promote China's structural revolution.

(3) The rural institutional reform and structural change promoted the transformation of the agricultural development model. The farmland transfer accelerated, reaching



Source: Land and resources China statistical yearbook and data from the National Bureau of Statistics

Figure 1.
Supply of construction land (10,000 ha) vs GDP growth rate (percent)

36 percent in 2016, agricultural inputs shifted mainly from the manpower to machinery. The driving force of agricultural development has shifted from focusing on the improvement of the agricultural productivity of the land to the improvement of its labor productivity (see Table II).

3.3 The allocation method of industrial land and high-speed industrialization

After the reform and opening-up policy, China entered a new road of industrialization, including the rural industrialization of collectively owned land in the countryside from the 1980s to the mid-1990s and park industrialization after 1990s. With the new pattern of industrialization, China has become the world's factory. The supply method of industrial land under the unique land system has played a significant role.

The rural industrialization after the mid-1980s was driven by the fact that much surplus labors looked for a way out after the agricultural land reform. Under the restraint of rigidities of the urban system and the impossible entry of the rural labor force, the government could only permit peasants to build enterprises on collectively owned land, which amounted to permit the entry of collectively owned land into the non-farming land market. Prior to the revision of the Land Administration Law of 1998, the two main parts that used construction land in China were both located in the countryside. One was peasants who built houses with more income after the reform. The other was peasants who built township enterprises on collectively owned land. Between 1993 and 1998, the non-farming construction land increased from 224,824 hectares to 367,854 hectares, of which the land of township and village enterprises decreased from 13,943 hectares to 8,180 hectares representing a total of 4.5 percent (see Table III). Peasants have their own advantages in developing rural industrialization on

Table II.
Land system vs agricultural transformation

Year	2010	2011	2012	2013	2014	2015
Proportion of rural household contracting (%)	94.09	94.45	96.89	98.15	98.37	99.41
Farmland transfer rate (%)	14.67	17.85	21.25	25.70	30.32	33.29
Proportion of rural residents going out	58.38	59.49	59.87	61.61	63.16	63.68
Proportion of agricultural net income (%)	29.07	27.18	26.61	26.54	25.70	25.09
Total power of agricultural machinery (Million kWh)	927.8048	977.3466	1,025.5896	1,039.0675	1,080.566	1,117.281
Land productivity (kg/ha)	4,973.58	5,156.89	5,301.76	5,376.60	5,385.10	5,984
Labor productivity (Kg/person)	1,960.10	2,075.23	2,167.99	2,260.95	2,316.94	2,410.30

Source: *Agricultural Statistics of the People's Republic of China*, edited by China's Ministry of Agriculture, published by China Agriculture Press

Table III.
Statistics on the actual use of non-agricultural construction land (unit: hectare)

Year	Non-agricultural construction land	Township collectively owned construction land	Land of township enterprises
1993	224,824	30,183	13,943
1994	186,630	22,023	9,826
1995	190,376	19,909	11,621
1996	171,467	14,897	6,235
1998	367,854	16,558	8,180

Source: China Land and Resources Yearbooks

collectively owned land. Since the land belongs to collective ownership of peasants, they do not have to pay the land cost for building enterprises on their own land. They can avoid the restriction of impaired capital in the initial stage of enterprises. Rural enterprises would solve the problem of land utilization through land redistribution in the collective or acquire land usage of collectively owned land by low land rent. This development method also profits from the untying of national rural policy for peasants at that time. The rural industrialization on collectively owned land changes the layout of national industrialization radically. Until 1993, each of state-owned enterprises, township enterprises and foreign-owned enterprises accounts for one third of national value of the gross output (Xiaolin, 2003).

After the mid-1990s, rural industrialization on collectively owned land occupied a large amount of cultivated land, caused environmental pollution, and brought about scattered industries. The Land Administration Law of 1998 brought the institutional regulation for land use into effect and gradually closed the way of using collectively owned land for non-agricultural construction. Park industrialization gradually replaced rural industrialization as the main pattern for pushing Chinese industrialization and achieved success in east China and some parks in central and western regions. The success of park industrialization profited from distinctive system advantage, it also profited from distinctive land allocation pattern. First, the government conducted investment promotion using land. The essential condition that the government could provide was the land with a low price, so investing through land at low price (provided at low price, free or even negative price) had become a common method. Second, the government conducted park infrastructure construction through land. The method of implementing infrastructure construction by the local government was that it directly provided land for companies to carry out integral development and batch lease, or mortgaged land to the bank to acquire loans to construct. The park would maintain a balance with the revenue from the enterprises. Third, settled enterprises were provided with complete land usage rights for a sufficiently long period of time. Settled enterprises in the park could use the land for 50 years. Enterprise could mortgage, sublease and transfer the possession of the land, which stabilized investment expectation of enterprises and solved financing demand of enterprise development. Land is the secret of China's rapid industrialization. Due to the disadvantages of China's land endowments, if completely relied on land market allocation, the cost of the industrial land in China would be considerably higher than the economic entities of other land resources with better endowment, and Chinese industrialization would be hindered by rising land price. Since the late 1990s, China has been looking for development by industrial land supply at a high proportion. In total, 40 percent of the land has been used every year for industrial use. It is therefore up to the government to monopolize land supplying for the primary market to lower the price of industrial land (see Table IV). Between 2000 and 2016, the levels of the national comprehensive land price, the commercial services land price and the residential land price have been increasing at an average annual rate of 8.8, 9.61 and 12.35 percent, respectively. However, the average annual increase of the industrial land price has been only 3.5 percent per year, which is far lower than the amount of increase of commercial and residential land prices. The low cost of industrial land has guaranteed rapid industrialization, which has made China the world's manufacturing plant.

3.4 Land capitalization and rapid urbanization

After 2000, urbanization in China sped up. From 2000 to 2016, the urbanization rate of permanent resident population increased from 36.22 to 57.35 percent, growing at a pace of 2.91 percent every year. Land capitalization provided a huge capital demand for urban construction. The linkage between local government's maximization of land profit and the rising of housing asset value was the major driving force for urbanization.

Index Unit	Growth rate of industrial value added (%)	Growth rate of land for industrial and mining warehouse space (%)	Growth rate of industrial land price (%)
2007	21.09	−8.34	15.67
2008	17.94	−34.44	4.81
2009	4.83	52.31	1.53
2010	19.57	7.00	5.36
2011	18.18	26.35	28.30
2012	7.05	8.31	−16.98
2013	6.43	3.04	4.48
2014	5.18	15.83	6.00
2015	1.13	−49.53	2.43
2016	4.80	−4.54	2.89

Source: China Land and Resources Bulletins, CEINET and China Land and Resources Yearbooks

Table IV.
Industrial Land and Industrial Value Added

First, the arrangement of bidding, auction and listing for commercial land increased the value of land capitalization. Since 2003, the total area of land transacted by bidding, auction and listing in China has been 3,953,000 hectares. China has obtained land revenue of 31 trillion 587 billion 105 million RMB. The land revenue in 2016 was 89 times as high as in 2003.

Second, huge housing demand caused by housing commercialization reform and rapid population urbanization in this period has maximized the land revenue for local governments. From 2003 to 2016, the newly added housing in China has reached 25 billion 787 million 769 thousand square meters. Real estate loans to developers and residents purchase loans have been increased by 6.85 times from 2003 to 2016. Housing price has increased by 2.88 times. The constant increase of merchandise housing price has entailed the constant increase of land price. The rising land premium encouraged local governments to acquire greater land revenue through bidding, auction and listing for commercial land. In 2001, the area of the land sold by bidding, auction and listing covered 7.3 percent of total land sold. In 2014, it has reached 92 percent. The increasing revenue acquired by selling land, on the one hand, has provided financial resource for local governments to engage in urban infrastructure construction, and on the other hand has encouraged local governments to implement urban expansion for more land capitals. From 2000 to 2015, urban construction area in China has increased by 1.42 times (see Table V).

Third, land financing provided more capital for urban development. Especially, after 2008, governments of various levels established various financing platforms. Land mortgage has been significantly increased. From 2008 to 2015, the area and amount of land mortgaged have increased from 166,000 hectares in 2008 and 1 trillion 810 billion 700 million RMB in 2008 to 490,800 hectares and 11 trillion 330 billion RMB.

4. The conclusion

After 40 years of reforms and opening up, China has not only created a growth miracle unparalleled for any major country in human history, but also transformed itself from a rural to an urban society. Behind this great transformation is a systemic reform in land institutions. Rural land institutions went from collectively owned to household responsibility system, thereby protecting farmers' land rights. This process resulted in long-term sustainable growth in China's agriculture, a massive rural-urban migration and a historical agricultural transformation. The conversion of agricultural land to

Index	Urbanization rate	Urban construction area	Government land selling revenue	BAL percentage area	Land mortgage area	Land mortgage amount	Average selling price of commodity housing
Unit	(%)	Sq. km	Billion RMB	(%)	10,000 ha	Billion RMB	RMB/Sq.m.
2003	40.53	28,308.02	542.131	27.78	–	–	2,359
2004	41.76	30,406.19	641.218	29.16	–	–	2,778
2005	42.99	32,520.72	588.382	35.05	–	–	3,167.66
2006	43.9	33,659.8	807.764	28.60	–	–	3,366.79
2007	44.94	35,469.65	1,221.672	50.91	–	–	3,863.9
2008	45.68	36,295.3	1,025.98	81.91	16.6	1,810.7	3,800
2009	46.59	38,107.26	1,591.02	85.30	21.7	2,585.6	4,681
2010	47.5	40,058.01	3,010.893	88.27	25.82	3,530	5,032
2011	51.27	43,603.23	3,150	91.25	30.08	4,800	5,357.1
2012	52.57	45,565.76	2,690	90.77	34.87	5,950	5,790.99
2013	53.7	47,855.28	4,200	92.32	40.39	7,760	6,237
2014	54.77	49,772.63	4,294.03	92.53	45.1	9,510	6,324
2015	56.1	52,102.31	3,365.773	75.20	49.08	11,330	6,793

Source: CEINET Statistics database, *China Land and Resources Yearbook*, etc.

Table V.
Land capitalization and urban expansion

non-agricultural uses and the introduction of market mechanisms made land a policy tool in driving high economic growth, industrialization and urbanization. However, we need to recognize that the role of land and its relationship with the economy will inevitably change as China's economy enters a new stage of medium-to-high speed growth. With economic restructuring, low-cost industrial land will be less effective. Urbanization is also shifting from rapid expansion to endogenous growth so that returns on land capitalization will decrease and risks will increase. Therefore, China must abandon land-dependent growth model through deepening land reforms and adapt a new pattern of economic development.

Notes

1. Ministry of Land and Resources: 2016 Land and Resources Bulletin.
2. Refer to The Central Committee of the Communist Party of China, January 1, 1982: Summary of the National Rural Work Conference.
3. Refer to Ministry of Land and Resources. China Land and Resources Bulletin 2004 [Z] and Ministry of Land and Resources. China Land and Resources Bulletin 2016 [Z].
4. Refer to the National People's Congress: Constitution of the People's Republic of China (Adopted at the Fifth Session of the Fifth National People's Congress on December 4, 1982, Announcement, Promulgation and Implementation of the National People's Congress on December 4, 1982).
5. Refer to the Law of the People's Republic of China on Land Administration (Adopted at the 16th Session of the Standing Committee of the Sixth National People's Congress of the People's Republic of China on June 25, 1986, Promulgated by Order No. 41 of the President of the People's Republic of China on June 25, 1986 to go into effect on January 1, 1987).
6. Refer to the Law of the Peoples Republic of China on Land Contract in Rural Areas (Adopted at the 29th Session of the Standing Committee of the Ninth National People's Congress on August 29, 2002).

7. Urgent Circular of the General Affairs Office of the State Council on Properly Solving the Current Rural Land Contract Disputes. (Telegram No. 21 (2004) sent by the General Office of the State Council) [Z] (April 30, 2004).
8. Refer to Circular of the Central Committee of the Communist Party of China on Rural Work in 1984 [Z] (January 1, 1984).
9. Refer to A Number of Policy Measures Promulgated and Implemented by the Central Committee of the Communist Party of China and the State Council on the Current Agricultural and Rural Economic Development [Z] (November 5, 1993).
10. Refer to Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Agriculture and Rural Work [Z] (October 14, 1998).
11. Refer to Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Promoting Rural Reform and Development [Z] (October 12, 2008).
12. Refer to Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Comprehensively Deepening the Reform [Z] (November 12, 2013).
13. Refer to Regulations of the State Council on the Administration of Land for Construction of Villages and Small Towns (Guofa No. 29 (2004)) [Z] (February 13, 1982).
14. Refer to Circular of the General Office of the State Council on Strengthening Management of Transfer of Land and Strictly Banning Speculative Land Dealing (Guofa No. 39 (1999)) (May 6, 1999).
15. Refer to Decision of the State Council on Deepening Reform of Strict Land Management (The General Office of the State Council No. 28 (2004)) [Z] (October 21, 2004).
16. Refer to Circular of the State Council on Several Issues concerning the development of real estate industry (Guofa (1992) No. 61) [Z] (October 4, 1992).
17. Refer to the Law of the People's Republic of China on Land Administration (Revised and Adopted at the Fourth Session of the Standing Committee of the Ninth National People's Congress of the People's Republic of China on August 29, 1998).
18. Since the year 2000, Heilongjiang province has practiced the standard of unified annual production for the main types of land requisition in each city and county. Hangzhou city in Zhejiang province, Nanjing city and Suzhou city in Jiangsu province no longer estimated the compensation fees, but a comprehensive consideration of land use, land location conditions, local economic development level and land supply and demand and other factors, combined with the level of social security of local urban residents, to determine land requisition compensation standards.
19. Refer to the Circular on the Formulation of the Unified Annual Land Output Standards for Land Requisition and the Comprehensive Land Price of Land Requisition Plots (Guotuzifa No. 144 (2005)) [Z] (July 23, 2005).
20. Refer to the Decision of the Central Committee of the Communist Party of China on Some Issues Concerning the Improvement of the Socialist Market Economy (October 14, 2003).
21. Refer to the Decision of the Central Committee of the Communist Party of China on Several Important Issues in Constructing of a Socialist Harmonious Society (October 11, 2006).
22. Refer to Some Opinions of the Central Committee of the Communist Party of China on Promoting the Construction of a New Socialist Countryside (December 31, 2005).
23. Refer to Some Opinions of the Central Committee of the Communist Party of China on Strengthening Agricultural Infrastructure Construction and Further Promoting Agricultural Development to Increase Farmers' Income (January 1, 2008).
24. Refer to The Central Committee of the CPC, 2011: Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Comprehensively Deepening the Reform (Adopted at the Third Plenary Session of the Eighteenth Central Committee of the Communist Party of China), Offprint, People's Publishing House.

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The shadow price of nitrogen

A dynamic analysis of nitrogen-induced soil acidification in China

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Abstract

Purpose – The most recent and prestigious scientific research shows that nitrogen leaching caused by over-used nitrogen fertilizer rapidly acidifies all soil types in China, revolutionizing the basic understanding of the mechanism of soil acidification. The purpose of this paper is to study the impact of nitrogen on soil acidity over the long run, which is the shadow price of nitrogen.

Design/methodology/approach – In a discrete dynamic programming model, this paper compares the nitrogen application and soil pH between optimal nitrogen control that takes the shadow price of nitrogen into consideration and myopic nitrogen control that ignores that shadow price. Using a five-year panel experimental data on a rapeseed-rice rotation, this paper simulates and numerically solves the dynamic model.

Findings – Both theoretically and empirically, this paper shows that the over-use of nitrogen and the decline in soil pH are explained by ignorance of the shadow price of nitrogen. Compared with optimal nitrogen control, myopic nitrogen control applies more nitrogen in total, resulting in lower soil pH. In addition, over-use in the first season contributes to soil acidification and the carry-over effects mitigate that problem.

Originality/value – This paper enriches the literature by extending the study of the environmental impact of nitrogen leaching to its impact on the long-term loss in agricultural production, providing a new theoretical framework in which to study soil acidification rather than conventionally treating soil acidification as a secondary consequence of acid rain, and showing the possibility of using nitrogen control to mitigate soil acidification when lime applications are not feasible due to socio-economic constraints.

Keywords Dynamic programming, Nitrogen control, Soil acidification, Soil conservation

Paper type Research paper

Introduction

The average nitrogen application in China for each production season is around 22 kg/mu, which is about three times the world's average application rate and around 2.5 times the average application rate in the USA and Europe (MOA, 2015). Between 1980 and 2007, nitrogen application in China increased by 191 percent (Guo *et al.*, 2010), making China the biggest user of nitrogen fertilizer in the world (Norse and Zhang, 2010). The massive use of nitrogen is encouraged by a series of national policies on fertilization. From the supply side, the policies that are favorable to nitrogen production include but are not limited to a reduction in transportation costs through the railway system, heavy subsidies of the use of electricity and gasoline in nitrogen production and zero-interest-rate loans for winter nitrogen restocking (MOA, 2015). From the demand side, a price ceiling is set at 400 RMB/ton along with a subsidy of 100 RMB/ton that is delivered directly to nitrogen buyers (MOA, 2015).

The massive use of nitrogen improved agricultural productivity in China between 1980 and 2007. However, China's grain production declined after 2007 along with a continuously increasing nitrogen application rate (Zhang *et al.*, 2008). Meanwhile, after 30 years of monitoring fixed plots all over China, the most recent scientific research, Guo *et al.* (2010), published in *Science*, shows that nitrogen leaching caused by over-applied nitrogen fertilizer

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acidifies topsoil pH by 0.14 to 0.80 between 1980 and 2007 in all five soil types in China. While soil quality is always vaguely defined (Brady and Weil, 2002), soil pH is the most important and thorough index of soil quality that directly reveals what crops can be grown and what cannot (Brady and Weil, 2002). Soil acidification could devastate agricultural production. A 0.5 decrease in soil pH increases the amount of dissolved toxic elements 1,000 times (Bolan and Hedley, 2003; Brady and Weil, 2002). Thus, a small decline in soil pH immediately leads to higher levels of toxic elements in the topsoil (Zhang *et al.*, 2008), which burns roots and results in stunted, discolored growth and poor yield (Meng *et al.*, 2004). In the 2010s, nitrogen-induced soil acidification has greatly threatened the sustainability of agricultural productivity in China in all top 13 commodity grain production regions, accounting for 80 percent of national grain production (MOA, 2004).

Inasmuch as over-used nitrogen induces soil acidification, China's fertilization problem changed from a shortage in supply and low purchasing capacity (Ye, 1993) to excessive demand (Guo *et al.*, 2010; Ma *et al.*, 2014). Although nitrogen-induced soil acidification is a classical concept in soil science, the evidence recently found in China is the first empirical evidence of nitrogen-induced soil acidification anywhere in the world (Guo *et al.*, 2010). Hence, in the nitrogen recommendation system in use, the feature that nitrogen leaching could acidify soil is not taken into consideration, which increases the recommended nitrogen application rates and degrades the soil (Sheriff, 2005). In other words, the existing nitrogen control model ignores the shadow price of nitrogen, which is the value of nitrogen's effects on future soil quality and productivity (Zhang *et al.*, 2015). In contrast to the literature, this paper establishes a new nitrogen control model in a dynamic framework to study the shadow price of nitrogen, showing that ignorance of the shadow price of nitrogen explains the over-use of nitrogen and the decline in soil pH. Investigation of the effects of nitrogen control on soil acidification lies at the intersection of the classical literature on nitrogen leaching and the literature on soil acidification, which contributes to both streams of literature from the following perspectives.

In the literature on nitrogen leaching, although the environmental effects of nitrogen leaching on water quality and greenhouse gas emissions have been studied sufficiently (Kohl *et al.*, 1971; Bremner and Blackmer, 1978; Yadav, 1997; Vickner *et al.*, 1998; Shcherbak *et al.*, 2014; Kuwayama and Brozovic, 2017), the impact of nitrogen leaching on soil degradation has not been studied due to the lack of scientific evidence. The new scientific evidence on nitrogen-induced soil acidification enriches the literature by extending research on nitrogen leaching's environmental side effects to long-term loss in agricultural production. In addition, any policy implications derived from this study that mitigate soil acidification through reducing nitrogen application also potentially mitigate other non-point pollution problems associated with nitrogen leaching into the atmosphere and watersheds.

This study of nitrogen-induced soil acidification contributes to the literature on soil acidification in two ways. First, previous literature studies soil acidification as a secondary consequence of acid rain (Kaitala *et al.*, 1992; List and Mason, 2001; Li, 2014). Scientific evidence (Guo *et al.*, 2010; Ju *et al.*, 2004; Zhao *et al.*, 2010) shows that the power of nitrogen leaching on acidifying soil is about ten times that of acid rain. Thus, by introducing nitrogen leaching to the literature on soil acidification, nitrogen-induced soil acidification provides a new mechanism and essential economic intuitions with which to investigate and understand soil acidification. Second, lime applications were studied as the only approach to mitigate soil acidification (Myyra *et al.*, 2005). However, lime applications may not a feasible solution for developing countries including China.

Lime applications were compulsory investments for soil conservation during China's collective production era before the agricultural reform in the 1970s (Guo *et al.*, 2010). Due to the feature that the technology of lime application in China is labor-and-time-consuming, it became no longer cost-efficient in small-scale household production after the agricultural reform of the 1970s (Zhang *et al.*, 2016). Meanwhile, China's imperfectly protected land use

rights between the 1980s and the 2000s reduced farmers' investment incentives for practicing soil conservation, which further reduced lime applications and accelerated soil acidification (Li *et al.*, 1998; Jacoby *et al.*, 2002). Hence, reversing soil acidity using nitrogen control rather than lime applications provides a new solution to soil acidification, which enlightens policy design for soil quality recovering in developing countries where lime application is not feasible due to socio-economic constraints.

To fill in the blanks in the literature, this paper establishes a discrete dynamic programming model to calculate the optimal nitrogen application associated with the potential for nitrogen-induced soil acidification. This model measures the shadow value of nitrogen, which represents the value of nitrogen's effects on future soil productivity that is not captured by the market price of nitrogen. By setting up the model in a double-crop rotation, this model captures the impact of carry-over effects of nitrogen across seasons in a rotation on soil acidification, which responds to the classical literature that a carry-over effect reduces nitrogen leaching in watersheds and the atmosphere (Stauber *et al.*, 1975; Watkins *et al.*, 1998; Ribaudo *et al.*, 2011).

Moreover, this model compares the optimal nitrogen application and soil pH at the steady states between two possible nitrogen controls: optimal nitrogen control, which takes the shadow price of nitrogen into consideration, and myopic nitrogen control, under which nitrogen investment is fully driven by the market price while ignoring the shadow price of nitrogen. My model shows that if the initial soil pH is lower than the ideal soil acidity required for the rotation, myopic nitrogen control increases the total application of nitrogen and further reduces soil acidity at the steady states. As most current nitrogen control plans do not take the shadow value of nitrogen into consideration, this model of nitrogen-induced soil acidification calculates how current myopic nitrogen control contributes to acidification, which also indicates how important it is to adjust current policies on fertilization.

Using five-year panel data of rapeseed-rice rotation based on field production experiments conducted by the Anhui Agricultural Extension Office, this paper simulates and numerically solves a dynamic programming model using the parameters estimated by the experimental data. The simulation further verifies the conclusions derived from the theoretical model. First, the shadow price of nitrogen is positive if soil pH of the entire rotation is lower than the ideal soil pH, indicating a positive value of reducing nitrogen application at the steady states and preventing further soil acidification. Second, compared with optimal nitrogen control, myopic nitrogen control applies more nitrogen in total, resulting in lower soil pH at the steady state. Third, compared with optimal nitrogen control, myopic nitrogen control applies more nitrogen in the first season but less nitrogen in the second season, which shows that the over-use of nitrogen in the first season contributes to soil acidification but the carry-over effects mitigate the acidification problem. Correspondingly, this paper provides policy implications that potentially mitigate China's soil acidification problem.

The remainder of the paper is organized as follows: section 2 presents the theoretical framework of optimal nitrogen control that takes the shadow price of nitrogen into consideration. The model is established in a double-crop rotation context, which presents the important carry-over effect across seasons in a rotation. The optimal nitrogen control model is set as the baseline for the comparison between optimal and myopic nitrogen controls. Section 3 introduces the experimental data this paper uses to estimate the parameters and simulates the dynamic programming model using the parameters estimated. This section calculates the nitrogen application and soil pH at the steady state under both optimal and myopic nitrogen control and derives the comparisons between these nitrogen control models that verify the theoretical conclusions. A series of policy suggestions are provided that could mitigate soil acidification in China. Section 4 concludes with discussion of future research directions.

Theoretical modeling and analysis

General setup

This paper sets up a discrete dynamic programming model to investigate the shadow price of nitrogen facing potential nitrogen-induced soil acidification. To generalize the model in the commonly seen rotation system and capture the importance of nitrogen carry-over (Brady and Weil, 2002), this paper sets up the model in a double-crop rotation system, allowing for intra-seasonal nitrogen allocation (Stauber *et al.*, 1975; Watkins *et al.*, 1998). It describes the dynamic program by using soil pH value (S) as the stock variable and nitrogen application in the first season (X^1) and the second season (X^2) as the control variables.

According to the nitrogen mass balance method derived from the principle of nitrogen cycle (Huang and Uri, 1993; Gilliam and Hoyt, 1987), the yield of season i in year t is a function of the absorbed nitrogen (E_t^i) and the soil pH value at the beginning of year t (S_t):

$$y_t^i = f^i\left(E_t^i, S_t\right). \tag{1}$$

The absorbed nitrogen (E_t^i), affected by an absorption coefficient (α_i), which is constant across years but varying across crops, is a proportion of the total nitrogen application. Thus, the absorbed nitrogen in the first season is $\alpha_1 X_t^1$. Regarding the nitrogen carry-over effects, the absorbed nitrogen in the second season is $\alpha_2[X_t^2+(1-\alpha_1)X_t^1]$. This model assumes that y_t^i is increasing and concave in E_t^i. Corresponding to the nature of soil such that soil pH changes slowly (Brady and Weil, 2002; Hinsinger *et al.*, 2003), this model assumes that S_t does not change within a year. Since the crop for each season has a desired soil pH value ($\overline{S^i}$) determined by its biological instinct (Brady and Weil, 2002; Zhao *et al.*, 2010), y_t^i is increasing in S_t if $S_t \leqslant \overline{S^i}$ and decreasing in S_t if $S_t > \overline{S^i}$. This model assumes that y_t^i is concave in S_t and S_t does not affect the marginal utility of absorbed nitrogen ($f_{E_t^i S_t} = 0$).

The soil pH at the end of year t (S_{t+1}) is a function of the soil pH at the beginning of year t (S_t) and a nitrogen residual (R_t). Alternative mitigation instruments, such as lime application, are excluded from the model to study the optimal nitrogen control for developing countries, where lime application is not feasible for smallholders:

$$S_{t+1} = g(S_t, R_t) \tag{2}$$

Because natural acidification of soil takes centuries, g_{S_t} is close to but no greater than 1. Thus, $g(.)$ is increasing in S_t. The nitrogen applied, if not taken up by crops, becomes the nitrogen residual (R_t) and reacts with oxygen under normal temperature and pressure conditions (Hinsinger *et al.*, 2003), acidifying soil by creating nitrates (NO_3^-) and hydrogen ions (H^+) (Hinsinger *et al.*, 2003; Guo *et al.*, 2010; Huang *et al.*, 2010). Therefore, this model assumes that $g(.)$ is decreasing in R_t. To satisfy the material balance principle (Pethig, 2006) but also simplify the mathematics, this model assumes that nitrogen influx from the atmosphere and nitrogen efflux through denitrification, volatilization and water runoff are negligible. Relaxing this assumption does not change the theoretical results of the model. Thus, the nitrogen residual after a double-crop rotation is the following:

$$R_t = (1-\alpha_2)\left[X_t^2+(1-\alpha_1)X_t^1\right]. \tag{3}$$

This model makes the assumption regarding $g_{R_t S_t}$ based on the buffering capacity of soil with respect to acidification (Brady and Weil, 2002). The buffering capacity of soil, equivalently to its resistance to acidification, is stronger as soil pH increases (Brady and Weil, 2002). Therefore, the more alkaline the soil, the more difficult to treat is

the soil acidified by the nitrogen residual, indicating $g_{R_t S_t} > 0$. This model assumes that $g(.)$ is a general concave function in both arguments and that it satisfies the second-order condition.

Optimal vs myopic nitrogen control

The shadow price of nitrogen measures the value of nitrogen in long-term soil-quality maintenance, which is distinct from its values to productivity in the short run but not measured in previous nitrogen control models. Let p_t^i denote the price of the outputs in the ith season in year t, w_t denote the price of nitrogen in year t, and δ denote the discount factor. The optimal nitrogen control model maximizes the present value of crop production, which is revenue less the cost of production and the discounted land value in all future periods. Given an initial soil pH value of S_0, the optimal nitrogen control model is subject to the state equation (Equation 2). The recursion equation for the stationary problem is the following:

$$V(S_t) = p_t^1 f^1\left(\alpha_1 X_t^1, S_t\right) + p_t^2 f^2\left(\alpha_2\left(X_t^2 + (1-\alpha_1)X_t^1\right), S_t\right) - w_t\left(X_t^1 + X_t^2\right) + \delta V(S_{t+1}), \quad (4)$$

where:

$$S_{t+1} = g\left(\left[(1-\alpha_2)\left(X_t^2 + (1-\alpha_1)X_t^1\right)\right], S_t\right).$$

The first-order conditions for the interior solutions are the following:

$$\alpha_1 p_t^1 f_{E_t^1}^1 + \alpha_2(1-\alpha_1) p_t^2 f_{E_t^2}^2 - w_t + \sum_{\tau=1}^{\infty} \delta^\tau (1-\alpha_1)(1-\alpha_2) g_{R_t}\left[p_{t+\tau}^1 f_{S_{t+\tau}}^1 + p_{t+\tau}^2 f_{S_{t+\tau}}^2\right] = 0, \quad (5)$$

$$\alpha_2 p_t^2 f_{E_t^2}^2 - w_t + \sum_{\tau=1}^{\infty} \delta^\tau (1-\alpha_2) g_{R_t}\left[p_{t+\tau}^1 f_{S_{t+\tau}}^1 + p_{t+\tau}^2 f_{S_{t+\tau}}^2\right] = 0. \quad (6)$$

In Equation (5), $\alpha_1 p_t^1 f_{E_t^1}^1 + \alpha_2(1-\alpha^1) p_t^2 f_{E_t^2}^2$ is the marginal value of applying an additional unit of nitrogen in the first season in year t. However, the additional unit of nitrogen applied in the first season in year t potentially acidifies the soil if it is not fully absorbed through the state equation, which is captured by $(1-\alpha_1)(1-\alpha_2)g_{R_t}$. Moreover, the nitrogen-induced increase in soil pH affects the marginal productivity of soil pH in all future τ years, which is captured by $p_{t+\tau}^1 f_{S_{t+\tau}}^1 + p_{t+\tau}^2 f_{S_{t+\tau}}^2$. Thus, the marginal value of applying an additional unit of nitrogen in the first season in year t equals to marginal cost of nitrogen in future productivity plus the cost of nitrogen. The same economic intuition applies to Equation (6), which equalizes the marginal cost of the nitrogen applied in the second season with the marginal value of that.

At the steady states of the optimal nitrogen control model, where $X_t^i = X_{t+1}^i$ and $S_t = S_{t+1}$, the first-order conditions are the following:

$$\alpha_1 p^1 f_{E_1}^1 + \alpha_2(1-\alpha_1) p^2 f_{E_2}^2 - w = \frac{\delta(1-\alpha_1)(1-\alpha_2) g_R\left(p^1 f_S^1 + p^2 f_S^2\right)}{\delta g_S - 1} \quad (7)$$

$$\alpha_2 p^2 f_{E_2}^2 - w = \frac{\delta(1-\alpha_2) g_R\left(p_1 f_S^1 + p_2 f_S^2\right)}{\delta g_S - 1} \quad (8)$$

$$g([(1-\alpha_2)(X_2 + (1-\alpha_1)X_1)], S) - S = 0. \quad (9)$$

Because the previous nitrogen control model ignores the impact of nitrogen residual on soil pH in the long run, the first-order conditions for myopic nitrogen control at the steady state are the following:

$$\alpha_1 p^1 f^1_{E_1} + \alpha_2(1-\alpha_1) p^2 f^2_{E_2} - w = 0, \tag{10}$$

$$\alpha_2 p^2 f^2_{E_2} - w = 0, \tag{11}$$

$$g([(1-\alpha_2)(X_2 + (1-\alpha_1)X_1)], S) - S = 0. \tag{12}$$

Comparing Equation (7) with Equation (10) and Equation (8) with Equation (11), the shadow prices of nitrogen in the first and second seasons, not captured by the myopic nitrogen control model, are the right-hand sides of Equations (7) and (8), respectively. Because $g_S \leqslant 1$ for all S, the denominators of the right-hand side in Equations (7) and (8) are negative. Therefore, the sign of the shadow price of nitrogen is consistent with the sign of $p^1 f^1_S + p^2 f^2_S$. Although the marginal productivity of soil pH could vary across seasons within one year, this paper categorizes the rotations based on the joint effects of soil pH on productivity within one year ($p^1 f^1_S + p^2 f^2_S$).

This paper defines an alkaline rotation as $p^1 f^1_S + p^2 f^2_S < 0$. In an alkaline rotation, the steady-state soil pH is higher than the desired soil pH ($\overline{S}$). In contrast, an acid rotation refers to a situation in which $p^1 f^1_S + p^2 f^2_S > 0$, indicating that the steady-state soil pH is lower than $\overline{S}$. At $p^1 f^1_S + p^2 f^2_S = 0$, the rotation is defined as a neutral rotation. The nitrogen-induced soil acidification is most harmful in the acid rotations, because the current soil pH is already below the ideal soil pH for the rotation. Although nitrogen-induced soil acidification could conceptually remove alkaline in an alkaline rotation, this approach is not recommended by soil scientists due to other properties of soil (Brady and Weil, 2002). Therefore, the following intuitive interpretation concentrates on nitrogen-induced soil acidification in acid rotations.

In the optimal nitrogen control mode, the shadow price of soil pH at the steady state (S*) is captured by δV_{S^*}, which is $\lambda^* = \delta(p_1 f^1_{S^*} + p_2 f^2_{S^*})/1 - \delta g_{S^*}$ derived from Equations (7) and (8). Thus, in an acid rotation, the shadow price of soil pH at the steady state is positive, indicating that reducing acidity would improve soil productivity. Consistently, the shadow prices of nitrogen in both seasons, shown by the right-hand sides of Equations (7) or (8) are positive, indicating a positive loss of future soil productivity caused by nitrogen application in an acid rotation. A positive tax could be imposed on nitrogen that equals the right-hand sides of Equations (7) or (8) to discourage nitrogen application and mitigate nitrogen-induced soil acidification.

The comparison between Equation (8) and Equation (11) shows that the marginal value of the absorbed nitrogen in the second season under myopic nitrogen control (E^2_M) is greater than that under optimal nitrogen control (E^2_*). The concavity of the production function ($f^2(.)$) further shows that:

$$E^2_M \geqslant E^2_*,$$

$$R_M \geqslant R_*.$$

Therefore, at the steady state, with a higher nitrogen residual (R_M) under myopic nitrogen control, myopic nitrogen control contributes to soil acidification ($S_M < S_*$).

Meanwhile, $E_M \geqslant E_*$ implies that $X^2_* - X^2_M < -(1-\alpha_1)(X^1_* - X^1_M)$. Combining Equations (7) and (8), the first equation for the first-order condition is rewritten as:

$$\alpha_1 p^1 f^1_{E_1} - w = 0. \tag{13}$$

The comparison between Equations (13) and (10) shows that the nitrogen applied in the first season under optimal nitrogen control is no greater than that under myopic nitrogen control ($X^1_M > X^1_*$). This paper summarizes the theoretical results from the comparison between optimal and myopic nitrogen control as *P1*:

P1. At the steady state of an acid rotation, ignoring the shadow price of nitrogen, myopic nitrogen control leads to a higher nitrogen residual than that under optimal nitrogen control, which results in nitrogen-induced soil acidification. Over-applied nitrogen in the first season contributes directly to soil acidification regardless of the nitrogen applied in the second season.

Dynamic transitions: the policy function of soil pH

The policy function of soil pH, mapping S_t into S_{t+1}, demonstrates the dynamic transitional path of soil pH toward the steady state. The policy function of soil pH depends of the following two lemmas (for proofs see the Appendix):

Lemma 1. As the optimal soil pH increases, X^1_t and X^2_t do not decrease at the same time.

Lemma 2. For an increment in optimal soil pH value, the decrease in X^2_t is no greater than the increase in $(1-\alpha_1)X^1_t$.

Because an increase in S_t improves the resistance of soil to acidity, Lemma 1 intuitively shows that ΔS_t increases nitrogen application within at least one season. Lemma 2 further shows that an increase in S_t decreases X^2_t but increases X^1_t, indicating that it is the carry-over effect that reduces nitrogen application and thus mitigates soil acidification. Hence, Lemma 2 is consistent with the argument in previous literature (Huang and Uri, 1993) that the carry-over effect in crop rotation reduces nitrogen waste and mitigates agricultural pollution induced by nitrogen. Because of Lemma *2*, $\left|-\Delta X^2_t\right| \leqslant (1-\alpha_1)\Delta X^1_t$, $\left|-\Delta X^2_t\right| \leqslant \Delta X^1_t$, indicating that the total application of nitrogen over one year ($X^1_t + X^2_t$) increases as soil pH increases.

Lemma 1 and Lemma 2 further compares myopic and optimal nitrogen control. *P1* argues that $S_M < S_*$, and thus, because both optimal and myopic nitrogen control follow the same transitional equation, Lemma 1 shows it cannot be true that $X^1_M > X^1_*$ and $X^2_M > X^2_*$. *P1* proves that $X^1_M > X^1_*$. Therefore, it must be true that $X^2_M > X^2_*$, which indicates that the carry-over effect applies to myopic nitrogen control. Lemma 2 further shows that $X^1_M - X^1_* > (1-\alpha_1)(X^1_M - X^1_*) > \left|-(X^2_M - X^2_*)\right|$. Hence, Lemma 1 and Lemma 2 facilitate deriving the conclusion that $X^1_M + X^2_M > X_{1*} + X^2_*$, enriching the steady-state analysis. This paper summarizes these theoretical results based on Lemma 1 and Lemma 2 as *P2*:

P2. At the steady state of an acid rotation, compared with optimal nitrogen control, myopic nitrogen control applies more nitrogen in the first season but less in the second season. However, nitrogen myopically increased in the first season is greater than nitrogen decreases in the second season, resulting in higher total nitrogen application under myopic nitrogen control.

The policy function of soil pH, the mapping of S_t into S_{t+1}, depends on Lemma 1 and Lemma 2. The policy function is derived by substituting X^i_t as a function of S_t, $\Psi^i(S_t)$, in the state equation:

$$S_{t+1} = g\left(\left(1-\alpha^2\right)\left(\Psi^1(S_t) + \left(1-\alpha^1\right)\Psi^2(S_t)\right), S_t\right). \tag{14}$$

The sign of $\partial S_{t+1}/\partial S_t$ determines the slope of the policy function. Differentiating Equation (14) with respect to S_t:

$$\frac{\partial S_{t+1}}{\partial S_t} = g_{R_t}\left\{(1-\alpha^2)\left[\frac{\partial X_t^2}{\partial S_t}+(1-\alpha^1)\frac{\partial X_t^1}{\partial S_t}\right]\right\}+g_S. \tag{15}$$

Lemma 2 ensures that the sign of the brace ($\{.\}$) is positive. Still, the sign of $\partial S_{t+1}/\partial S_t$ is undetermined because $g_R < 0$ and $g_S > 0$. The soil pH of year t affects the soil pH in year t+1 in two ways: direct and indirect impacts. The direct impact is measured by gS_t while the indirect impact is measured $g_{Rt}\{.\}$. The direct impact captures the natural resistance of soil to acidity, the buffering capacity. The soil pH in year t in directly affects S_{t+1} through nitrogen application. According to the magnitudes of the opposite direct and indirect impacts of S_t on S_{t+1}, this paper discusses the shape of the policy function for three cases:

(1) $\left|gRt\left\{(1-\alpha^2)\left[\partial X_t^2/\partial S_t+(1-\alpha^1)\partial X_t^1/\partial S_t\right]\right\}\right| < g_S$ for all S;

(2) $\left|gRt\left\{(1-\alpha^2)\left[\partial X_t^2/\partial S_t+(1-\alpha^1)\partial X_t^1/\partial S_t\right]\right\}\right| < g_S$ for some S; and

(3) $\left|gRt\left\{(1-\alpha^2)\left[\partial X_t^2/\partial S_t+(1-\alpha^1)\partial X_t^1/\partial S_t\right]\right\}\right| > g_S$ for all S.

- Case (i): the policy function is upward sloping. The steady state is locally stable.

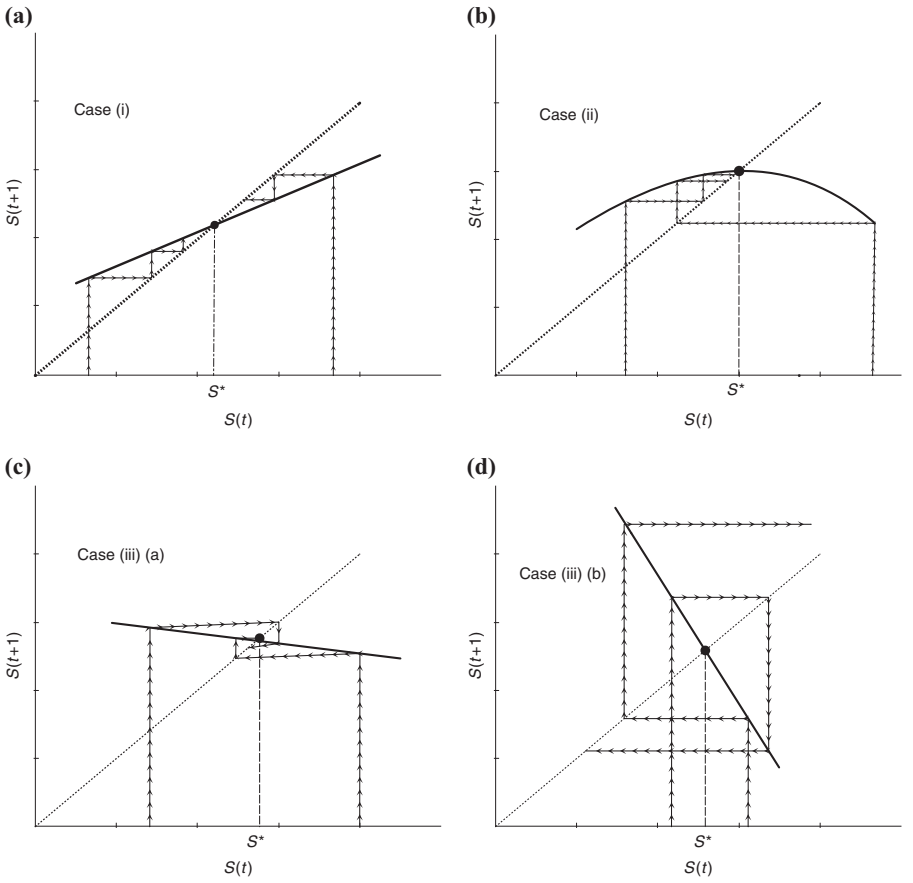
In Case (i), the magnitude of the positive direct impact is greater than that of the negative indirect impact for all S. The steady state exists and is locally stable. Because $g_S < 1$, the policy function is upward sloping with a slope flatter than the 45° line around the steady state (shown in Figure 1(a)). Intuitively, if the magnitude of soil-buffering capacity with respect to acidification is stronger than the indirect impact on S_{t+1} through nitrogen application, although nitrogen application acidifies soil if $S_t > S_*$, soil acidification happens slowly as the soil pH moves toward the steady-state soil pH (S_*) The strong buffering capacity prevents rapid and severe soil acidification. Case (i) represents the dynamic transition of soil pH in places where soil is not sensitive to acidity:

- Case (ii): the policy function is inverse-U shaped, reaching its peak at the steady state. The steady state is locally stable.

In Case (ii), the magnitude of the direct impact is greater than that of the indirect impacts for some possible S. Because g_S is decreasing in S, the possibility of a "V"-shaped policy function is ruled out. The steady state at the peak of the inverse-U shaped policy function is locally stable (shown in Figure 1(b)). The reason that the policy function goes down if $S_t > S_*$ is that the negative indirect impact through nitrogen offsets the positive direct impact through the buffering effect as S_t goes beyond the steady state. Regarding the dynamic path, the difference between Case (i) and Case (ii) is that soil pH declines rapidly toward a soil pH that is even lower than S_* if $S_t > S_*$ in Case (ii). Thus, Case (ii) describes the dynamic transition of soil pH with comparatively weaker buffering capacity. The problem of nitrogen-induced soil acidification affects the soil pH more severely in Case (ii) than that in Case (i):

- Case (iii): the policy function is downward sloping. The stability of the steady state depends on the slope of the policy function.

In Case (iii), the indirect impact is greater than the direct impact for all S. The stability of the steady state depends on the slope. A flatter slope $\left(\left|\partial S_{t+1}/\partial S_t\right| \leqslant 1\right)$, as shown in Figure 1(c), creates a stable steady state, ensuring that the soil pH moves toward the



Notes: (a) Policy function of case (i); (b) policy function of case (ii); (c) policy function of case (iii-a); (d) policy function of case (iii-b)

Figure 1.
Policy functions of Cases (i)–(iii)

steady state soil pH spirally. With an unstable steady state under a steeper slope ($\left|\partial S_{t+1}/\partial S_t\right| > 1$), the soil pH moves away from the steady state. With an unstable steady state, soil pH at any value could experience severe soil pH. Even for a stable steady state, soil pH takes a longer pathway than in the situations of Case (i) and Case (ii) to move toward the steady state, jumping between a soil pH value higher than S_* and a soil pH value that is lower than S_* several times with rapid and huge changes in soil pH. Therefore, the weak buffering capacity contributes to the most severe nitrogen-induced soil acidification.

Simulation analysis

This paper conducts a simulation exercise to numerically solve optimal and myopic nitrogen control models at the steady state to verify the theoretical results in *P1* and *P2* using farming experimental data from rapeseed-rice rotation provided by the Anhui Agricultural Extension Office (Qian, 2010). The simulation analysis includes two steps: estimating the production function and the state equation and numerically solving optimal and myopic

dynamic programming models based on the theoretical framework. The empirical hypotheses derived from *P 1* and *P2* are listed as follows:

H1. In an acid rotation, the shadow price of nitrogen is positive, indicating a positive value of nitrogen in future production through soil pH maintenance.

H2. In an acid rotation (the sum of the marginal values of soil pH in two seasons is positive), compared with optimal nitrogen control, myopic nitrogen control applies more nitrogen in total, resulting in higher soil pH.

H3. In an acid rotation, compared with the optimal nitrogen control, a myopic nitrogen control applies more nitrogen in the first season but less in the second season.

Data description

This paper uses experimental data on rapeseed-rice production in Anhui Province to estimate the production function and state equation of soil pH. The experimental data cover all the national long-term nine monitoring fields in Anhui Province in experiments conducted from 2005 though 2010, which is also a subsample of the data used in Guo *et al.* (2010). Anhui Province is located in central China and encompasses all three types of terrain (plains, hills, and mountains) and all five types of soil. Thus, experimental data collected in Anhui province are representative of agricultural production nationwide.

The experimental data populate a five-year panel data set on 36 plots. Rapeseed rotation is a common practice that occupies 70% of farmland in Anhui Province (Wang and Luo, 2006). The first season, for rapeseed production, runs from mid-October to late May. The second season, for rice production, runs from late May to early October of the next year. The order of the rotation is determined by climate related factors. The data are taken from records of nitrogen applications and yields for each season and the soil pH at the end of an entire rotation. Nitrogen in each season is applied at six possible levels, ranging from 5 to 10 kg/mu, 10 kg/mu to 15 kg/mu, 15 kg/mu to 20 kg/mu, 20 kg/mu to 25 kg/mu and 25 kg/mu to 30 kg/mu. At each possible nitrogen level, on six plots the same levels of nitrogen were applied in each season. With varying combinations of nitrogen levels over two seasons, the experiment included 36 types of nitrogen application plans. Rapeseed yields ranged from 269 kg/mu to 432 kg/mu and rice yield ranged from 450 kg/mu to 1,392 kg/mu. Data on soil properties were recorded annually at the end of the second season. Soil pH varied from 4.6 to 8.4, which covers weakly acidic to weakly alkaline soil pH (Brady and Weil, 2002).

Parameter estimation

The production functions for crops and the state equation of soil pH are estimated in a reduced form with arguments X_t^1 and S_t Being consistent with the assumptions of the theoretical model, this paper imposes quadratic functional forms for production functions and the state equation:

$$f^1\left(X_t^1, S_t\right) = a_0^1 + a_1^1 X_t^1 + a_2^1\left(X_t^1\right)^2 + a_3^1 S_t + a_4^1 (S_t)^2 + a_5^1 S_t X_t^1 + e_t^1, \tag{16}$$

$$f^2\left(X_t^2, S_t\right) = a_0^2 + a_1^2 X_t^2 + a_2^2\left(X_t^2\right)^2 + a_3^2 S_t + a_4^2 (S_t)^2 + a_5^2 S_t X_t^2 + a_6^2 X_t^1 + e_t^2. \tag{17}$$

The error terms,e_t^1 and e_t^2, are independent independent and identically distributed for each plot. The production function also allows for interactions between nitrogen application X and soil pH S. Based on the assumptions associated with the state transition equation (Equation 2), the estimated state equation is quadric in S_t and linear in X_t:

$$S_{t+1} = k_0 + k_1 S_t + k_2 (S_t)^2 + k_3 X_t^1 + k_4 X_t^2 + k_5 S_t X_t^1 + k_6 S_t X_t^2 + \varepsilon_t. \tag{18}$$

In Equation (18), ε_t is an independent and identically distributed error term. Soil pH at the end of the rotation (S_{t+1}) is determined by nitrogen applications in both seasons and the interaction between nitrogen applications and *St*.

Applying plot fixed effects and year fixed effects, this paper estimates Equations (16)-(18) ordinary least squares by OLS. The results are shown in Table I. Due to a limited number of observations, this paper applies Monte Carlo to test the applicability of the OLS approach. The OLS results shown in Table I are similar to the results derived from Monte Carlo shown in Table II. Comparing the results shown in Table I with those shown in Table II, the OLS estimates are close to the mean of the Monte Carlo coefficients. Thus, the OLS results are unbiased and reliable for further empirical analysis.

In rapeseed production, all the coefficients are jointly significant at the 0.01 significance level. The coefficients associated with X_t^1, $(X_t^1)^2$, and $X_t^1 S_t$ are jointly significant at the 0.05 significance level. The coefficients associated with S_t and S_t^2 are both significant at a 0.01 significance level. Plugging in the range of nitrogen applications, the desired range of soil

	Rapeseed (y_t^1)	Rice (y_t^2)	State equation (S_t+1)
X_t^1	21.07 (39.90)	9.17 (8.92)	0.39** (0.16)
$(X_t^1)^2$	−1.34** (0.53)		
X_t^2		71.98 (50.01)	0.03 (0.29)
$(X_t^2)^2$		−4.11** (1.32)	
S_t	413.52*** (71.04)	31.09 (88.33)	2.09*** (0.42)
S_t^2	−26.25*** (4.99)	−6.19 (9.95)	−0.03 (0.07)
$S_t X_t^1$	2.04 (5.42)		−0.07 (0.03)
$S_t X_t^2$		3.31 (7.82)	−0.00005 (2.00)
No. of Observation	180	180	180
R^2	0.32	0.41	0.80
Year fixed effects	*Y*	*Y*	*Y*
Plot fixed effects	*Y*	*Y*	*Y*
F-stat. of non-constant terms	77.55***	14.27***	23.72***
Chi-stat. of X_t^i related terms	11.58**	2.79**	4.59**
Chi-stat. of S_t related terms	161.68***	554.22***	23.73***

Notes: Robust SE clustered at the village level in parentheses. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table I. Estimation of crop production functions and state equation

	Rapeseed (y_t^1)	Rice (y_t^2)
X_t^1	20.62 (16.92)	9.13*** (3.37)
$(X_t^1)^2$	−1.32** (0.65)	
X_t^2		74.26** (34.30)
$(X_t^2)^2$		−4.21* (2.40)
St	411.47*** (103.50)	34.52 (99.47)
S_t^2	−25.28 (23.88)	−6.40 (24.97)
$S_t X_t^1$	1.94 (13.76)	
$S_t X_t^2$		2.96
(18.63)	(6.70)	
No. of Observation	180	180
Year fixed effects	*Y*	*Y*
Plot fixed effects	*Y*	*Y*

Notes: Robust SE clustered at the village level in parentheses. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table II. Monte Carlo simulation of crop production

pH ($S^{\overline{rapeseed}}$) is between 8.0 and 8.8. Rapeseed yields increase with soil pH if $S_t \leqslant S^{\overline{rapeseed}}$ and decrease if $S_t > S^{\overline{rapeseed}}$. The desired range of soil pH for rapeseed production is between 8.03 and 8.79, as determined by plugging in the range of nitrogen applications for all rapeseed observations. Rapeseed yield increases with soil pH if the soil pH is less than $S^{\overline{rapeseed}}$. According to the parameter estimation, the rapeseed production function is increasing and concave in S and X_t^1 because the quadratic terms are associated with negative coefficients. Rapeseed yield reaches its peak at $X_t^1 = 12.8$ kg/mu.

In rice production, all the coefficients' parameters are jointly significant at the 0.01 significance level. The coefficients associated with X_t^2, $(X_t^2)^2$ and $X_t^2 S_t$ are jointly significant at the 0.05 significance level. The coefficients associated with X_t^1, X_t^2 and $(X_t^2)^2$ are jointly significant at the 0.01 significance level, showing the importance of the carry-over effect from the previous season. The coefficients associated with S_t and its quadratic term are jointly significant at the 0.05 significance level. The rice yield increases with soil pH if the soil pH is less than the desired soil pH for rice ($S^{\overline{rice}}$). The estimated $S^{\overline{rice}}$ is between 5.2 and 6.41. Rice production reaches its peak at $X_t^2 = 12.4$ kg/mu. Consistent with assumptions mentioned in the theoretical considerations, the rice production function is concave and increasing with nitrogen and soil pH.

Consistent with the assumption, the state equation is concave with soil pH because the coefficient associated with $(S_t)^2$ is negative. The marginal product of soil pH (f_{S_t}) is less than 1 within the range of nitrogen application in the data set. Nitrogen applications X_t^1 and X_t^2 are jointly significant at the 0.01 significance level. The interaction terms for nitrogen and soil pH are jointly significant at the 0.01 significance level. Within the range of soil pH of the data set, an additional kilogram of nitrogen applied in the first season decreases the soil pH by at least 0.03, while an additional kilogram of nitrogen applied in the second season increases the soil pH by no more than 0.02. The estimation of the state equation shows that the carry-over effects maintain soil acidity (Huang and Uri, 1993).

Numerical solutions at the steady state

The steady states are characterized by Equations (7)–(9). The specific function forms with the estimated parameters are used to calculate the steady states of the optimal nitrogen control in a rapeseed-rice rotation. The parameters that are not significant in the estimations of production functions and the state equations are not eliminated because all coefficients are jointly significant. The average transaction price of pure chemical nitrogen between 2011 and 2014 was 2.2 RMB/kg (FERT, 2014). Between 2011 and 2014, the average farm-gate price of rapeseed was 4.5 RMB/kg (NRDC, 2011a) and the average farm-game price of rice was 2.4 RMB/kg (NRDC, 2011b). In the following analysis of steady states, δ is set at 0.9. The numerical solutions are reported in Table III.

At the steady state, the optimal nitrogen application for rapeseed is 13.29 kg/mu and the optimal nitrogen application for rice is 12.06 kg/mu. The steady-state soil pH is 7.86, which is weakly alkaline. The shadow price of nitrogen in rapeseed production is positive at 26.27 RMB, which is 4.8 times greater than its market price. The shadow price of nitrogen in rice production is 4.92 RMB, which almost doubles its market price. Based on the theoretical results, the positive shadow price of nitrogen indicates that nitrogen, if not applied, adds

Table III. Optimal vs myopic nitrogen management at the steady state

	X^1	X^2	S	X^1+X^2
Optimal nitrogen control	13.29 kg/mu	12.06 kg/mu	7.86	25.35 kg/mu
Shadow price of nitrogen	26.26 RMB	4.92 RMB		
Myopic nitrogen control	15.90 kg/mu	11.50 kg/mu	7.09	27.4 kg/mu

positive value to production in the future, which mitigates soil acidification caused by nitrogen leaching. Thus, *H1* is successfully tested.

The rapeseed-rice rotation is an acid rotation with a positive $p^1 f_S^1 + p^2 f_S^2$. The steady state under myopic nitrogen control is calculated by setting the shadow price of nitrogen at 0. The myopic nitrogen applied in the first season is 15.90 kg/mu, which is greater than the optimal nitrogen application at 13.29 kg/mu. Myopic nitrogen applied in the second season is 11.50 kg/mu, which is lower than the optimal nitrogen application at 12.06 kg/mu. The total nitrogen applied under myopic nitrogen control is 27.40 kg/mu, which is higher than the total nitrogen applied in the optimal nitrogen control at 25.35 kg/mu. Under myopic nitrogen control, the steady-state soil pH is 7.09, which is more acidic than the steady state under optimal nitrogen control at 7.86. Thus, this paper empirically verifies both *H1* and *H2*.

Policy implications

While most of China's current fertilization policies are designed to encourage the use of nitrogen fertilizer, the shadow price of nitrogen is not fully considered in the nitrogen recommendation system designed by the agricultural extension office. Therefore, the current recommended nitrogen control plans ignore the shadow price of nitrogen and are therefore equivalent to myopic nitrogen control, which induces the problem of soil acidification. Based on the simulation results of a rapeseed-rice rotation, a representative acid rotation, this paper empirically tests the theoretical framework and derives three policy implications for addressing the problem of nitrogen-induced soil acidification in China. As nitrogen fertilizer is unconditionally encouraged in agricultural production in Africa (Lunduka *et al.*, 2013; Jayne *et al.*, 2013) and lime applications are also not feasible in Africa, the lessons for soil acidification learned by China and the potential for using nitrogen control to mitigate soil acidification could be enlightening for policy design in African countries.

First, agricultural extension offices could establish education programs that focus on increasing awareness of the shadow price of nitrogen in long-term agricultural production (Pan *et al.*, 2017). The comparison between optimal and myopic nitrogen control shows that erroneous instructions for nitrogen control decrease soil pH from 7.86 to 7.09. Even a 0.5 decrease in soil pH increases the amount of dissolved toxic elements 1,000 times (Bolan and Hedley, 2003; Brady and Weil, 2002), which greatly but negatively affects agricultural production (Brady and Weil, 2002). Thus, an education program that guides nitrogen control scientifically and sustainably by considering the shadow price of nitrogen could help correct the distorted investment incentives in nitrogen and mitigate soil acidification.

Second, both the theoretical and empirical results show that although total nitrogen applied is important in affecting soil acidity, the allocation of nitrogen across seasons plays an even more important role in the process of soil acidification. In the simulation of a rapeseed-rice rotation, although myopic nitrogen control applies 2.05 kg/mu more nitrogen than optimal nitrogen control over the entire rotation, the difference in soil pH is huge. The shadow price of the first season is more than five times of that of the second season. Thus, even while keeping the current total nitrogen application the same, applying less nitrogen in the first season mitigates nitrogen-induced soil acidification, which reduces the total loss associated with the over-applied nitrogen in total. Therefore, if agricultural extension offices could provide precise nitrogen recommendations for each season, nitrogen-induced soil acidification could be mitigated.

Third, a regular taxation policy might be unenforceable because the shadow prices of nitrogen differ in the two seasons (Martinez and Albiac, 2006). In a rapeseed-rice rotation, a tax of 26.26 RMB/kg should be added to nitrogen applied in the first season and a

tax of 4.92 RMB/kg should be added to nitrogen applied in the second season. However, because nitrogen fertilizer is storable, a greater purchase in the second season that avoids the high tax for nitrogen in the first season could lead to nitrogen application in the first season that is higher than the optimal application rate. In addition, a one-time nitrogen purchase within a year is time-saving for farmers. A taxation policy that requires two purchases in one year is not practical for regulating nitrogen applications. Therefore, on the one hand, crop rotation reduces soil acidity through the carry-over effects while, on the other hand, such rotation makes it challenging to provide the right economic incentives that encourage farmers to benefit from the implications of optimal nitrogen control.

Conclusion

The problem of soil acidification has concerned agricultural economists for ages. However, the soil acidification problem has not been structured under the framework of nitrogen control without lime application. Meanwhile, nitrogen leaching is also a classical problem in agricultural pollution. However, the pollution caused by nitrogen leaching into soil and thereby harming soil quality has not been studied. Relying on the most up-to-date scientific research, this paper establishes a new dynamic framework for nitrogen control to solve for optimal nitrogen applications in a double-crop rotation that considers the effects of nitrogen on soil acidity.

Theoretically, this paper measures the shadow price of nitrogen. Then, the paper concludes that the shadow price of nitrogen is positive if the soil pH of the entire rotation is lower than the ideal soil pH (an acid rotation), which prevents further nitrogen investment that would lead to more serious soil acidification. Comparing optimal nitrogen control with a non-negative shadow price of nitrogen with myopic nitrogen control, this study finds that myopic nitrogen control applies more nitrogen in total but with a higher nitrogen application in the first season and a lower nitrogen application in the second season. Thus, it is the over-use of nitrogen in the first season that contributes to soil acidification with myopic nitrogen control.

The theoretical results correspond to three testable empirical hypotheses. Using experimental data from an agricultural extension office, this paper numerically solves dynamic programming model for both optimal and myopic nitrogen controls. In addition to verifying the theoretical results by comparing these two types of nitrogen control at the steady state, this paper calculates the shadow price of nitrogen for each season and derives three policy implications that facilitate future policy design in mitigating nitrogen-induced soil acidification.

Although ignoring the shadow price of nitrogen in nitrogen control explains the decline in soil pH and over-use of nitrogen, the application rate of nitrogen in some regions is even higher than the application rate guided by myopic nitrogen control, which results in a further decline in soil pH. However, this phenomenon could not be fully explained by the theoretical framework of this paper. Thus, further theoretical and empirical research could focus on the impacts of other socio-economic factors on nitrogen application and institutional constraints on the feasibility of lime applications. Specifically, the trade-off between a precautionary action (reducing the amount of nitrogen applied) and a preventative action (lime application) should be more rigorously studied within a dynamic framework. Meanwhile, changes in the Chinese rural land property rights system over the past several decades and the process of labor-switching from the agricultural sector to non-agricultural sectors are also major factors that affect investment incentives in nitrogen and lime applications, which are worth studying in the future with a panel of fixed-point household data with information on agricultural production and soil quality.

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Appendix

Proof of Lemma 1

In the social optimal farm management, the first-order conditions for interior maximum are:

$$\alpha_1 p_t^1 f_{E_t^1}^1 + \alpha_2(1-\alpha_1) p_t^2 f_{E_t^2}^2 - w_t + \delta(1-\alpha_1)(1-\alpha_2) g_{R_t} V_{S_{t+1}} = 0, \tag{A1}$$

$$\alpha_2 p_t^2 f_{E_t^2}^2 - w_t + \delta(1-\alpha_2) g_{R_t} V_{S_{t+1}} = 0. \tag{A2}$$

Lemma 1 is proved by contradiction in three steps as shown below.

Step 1: prove that $\alpha_2 p_t^2 f_{E_t^2}^2$ is greater in $X^1(S^0)$, $X^2(S^0)$, and S^0.

Suppose there exists $S^* < S^0$, such that $X^2(S^*) > X^2(S^0)$ and $X^1(S^*) > X^1(S^0)$, by having $f_{ES} > 0$ and the concavity of $f(.)$ in E and S, I derive:

$$\alpha_2 p_t^2 f_{E_t^2}^2 \left(X^1\left(S^0\right), X^2\left(S^0\right), S^0\right) > \alpha_2 p_t^2 f_{E_t^2}^2 \left(X^1\left(S^0\right), X^2\left(S^0\right), S^*\right)$$

$$> \alpha_2 p_t^2 f_{E_t^2}^2 \left(X^1(S^*), X^2(S^*), S^*\right). \tag{A3}$$

Step 2: prove that $\delta(1-\alpha_2) g_{R_t} V_{S_{t+1}}$ is greater in $X^1(S^0)$, $X^2(S^0)$, and S^0.

Since $X^2(S^*) > X^2(S^0)$ and $X^1(S^*) > X^1(S^0)$, I get $R_t^0 < R_t^*$. Because $g(.)$ is concave in R, I have $g_{R_t^0} > g_{R_t^*}$. Since $g(.)$ is super modular in R and S, $g(R_t^0, S_0) > g(R_t^*, S_0) > g(R_t^*, S_*)$. In other words, $S_{t+1}^0 > S_{t+1}^*$. Again, the concavity of value function makes $V_{S_{t+1}^0} < V_{S_{t+1}^*}$. Thus:

$$\delta(1-\alpha_2) g_{R_t^0} V_{S_{t+1}^0} > \delta(1-\alpha_2) g_{R_t^*} V_{S_{t+1}^*}. \tag{A4}$$

Step 3: prove that Equation (A2) is greater in $X^1(S^0)$, $X^2(S^0)$ and S^0.

Adding Equations (A3) to (A4):

$$\alpha_2 p_t^2 f_{E_t^2}^2 \left(X^1\left(S^0\right), X^2\left(S^0\right), S^0\right) + \delta(1-\alpha_2) g_{R_t^0} V_{S_{t+1}^0} >$$

$$\alpha_2 p_t^2 f_{E_t^2}^2 \left(X^1(S^*), X^2(S^*), S^*\right) + \delta(1-\alpha_2) g_{R_t^*} V_{S_{t+1}^*} = 0. \tag{A5}$$

Here, in Equation (A5), there is a contradiction because as $X^1(S^0)$ and $X^2(S^0)$ maximize the value function when soil pH is S^0, $X^1(S^*)$ and $X^2(S^*)$ also maximize the value function when soil pH is S^*. The contradiction is derived by comparing Equation (A5) with Equation (A2). Thus, I arrive at Lemma 1. As soil pH goes up, the optimal nitrogen application of seasons 1 and 2 do not decrease at the same time. Intuitively, since nitrogen induces soil acidification, the higher the soil pH value, the more tolerate the soil is to acidification. Thus, absolute decrease of nitrogen in both seasons is not reasonable.

Proof of Lemma 2

After knowing how nitrogen in seasons 1 and 2 influenced by soil pH, it is the right time to know exactly how nitrogen in seasons 1 and 2 interact. A similar contradiction is constructed by using Equation (A1):

Suppose there exists $X_{1t}^* > X_{1t}^0$, such that $X_{2t}^* > X_{2t}^0$; in this case, I arrive at the similar contradictory condition that (compared with Equation (A1)):

$$\alpha_1 p_t^1 f_{E_{1t}}^1 \left(E_{1t}^0, S_t\right) + \alpha_2(1-\alpha_1) p_t^2 f_{E_{2t}^0}^2 \left(E_{2t}^0, S_t\right) + \delta(1-\alpha_2) g_{R_t^0} V_{S_{t+1}^0} >$$

$$\alpha_1 p_t^1 f_{E_{1t}^*}^1 \left(E_{1t}^*, S_t\right) + \alpha_2\left(1-\alpha^1\right) p_t^2 f_{E_{2t}^*}^2 \left(E_{2t}^*, S_t\right) + \delta(1-\alpha_2) g_{R_t^*} V_{S_{t+1}^*} = 0. \tag{A6}$$

Thus, I prove that when X_t^1 increases at the optimal, X_t^2 does not increase. When optimal nitrogen application in season 1 increases, keeping the absorption coefficient constant, the nitrogen residual from season 1 increases, as well. The residual is involved in the crop production in season 2. Thus, without increasing nitrogen application in season 2, the availability of nitrogen in season 2 improves. For any level of soil pH, if increase in X_t^1 increases X_t^2, then the residual after the entire rotation goes up. Soil pH cannot stay at the same level if residual after season 2 goes up via the state equation. Thus, for optimal management, at any level of soil pH, carry-over effect of season 2 reduces the application of nitrogen. I summarize this result as:

Lemma 2. For any levels of soil pH value, any increment of optimal nitrogen in season 1 decreases optimal nitrogen in season 2.

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A model of industrialization and rural income distribution

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Abstract

Purpose – The purpose of this paper is to explore how the processes of (de)industrialization and rural income distribution interact with each other and their implications for economic growth and welfare.
Design/methodology/approach – This paper takes a dynamic general-equilibrium and theoretical approach.
Findings – The author develops a dynamic general-equilibrium model to analytically characterize how (de) industrialization interacts with rural income distribution, and also explores the implications for aggregate GDP growth, the evolution of rural income distribution as well as welfare. Redistributive policies are shown to sometimes enhance GDP and welfare by boosting the production of the goods with high desirability (or productivity) but constrained by depressed demand due to income inequality, and internalizing the dynamic impact of private production and consumption decisions on future public productivities.
Practical implications – The research suggests that rural income distribution and (de)industrialization are intrinsically related, so policies or institutional distortions on one process would, in general, affect the other. Redistributive policies are shown to sometimes enhance GDP and welfare by enhancing industrialization.
Originality/value – The paper contributes to the literature of industrialization and structural change at large in several aspects. First, a key novel feature of our model is that the Engle's law is captured by a quasi-linear utility function, which differs from the standard non-homothetic functions in this literature. Second, our paper contributes to the literature of structural change by showing how (de)industrialization works when sectorial productivity changes are endogenous. The paper also sheds light on the determination of rural income distribution and its evolution in the process of structural change and rural-urban migration.

Keywords Economic growth, Human capital, Structural change, Income distribution, Non-homothetic preference

Paper type Research paper

Introduction

Less developed countries are all featured by unfinished industrialization and a large proportion of rural population. How labor is reallocated from the agriculture sector to the non-agriculture sector (industrialization) and how rural income distribution evolves over time are two important structural processes of economic development. The primary objective of this paper is to explore how these two processes interact with each other and their implications for economic growth and welfare. Whereas the existing pertinent literature studies these issues mainly from the partial-equilibrium and empirical perspectives, we will take a general-equilibrium and theoretical approach. The advantages of this different approach are obvious. First, any market forces that drive industrialization and income distribution must involve changes in prices of output and production factors, which should be endogenously explained rather than taken as exogenous as in all partial-equilibrium analyses. Second, we are still lack a sufficient understanding about the theoretical mechanisms how industrialization (structural change) and evolution of rural income distributions take place and interact with each other.

Therefore, we develop a heterogeneous-agent dynamic general-equilibrium model with two sectors: agriculture and non-agriculture (including manufacturing and service). Households have non-homothetic preferences over agriculture and non-agriculture goods following

JEL Classification — E21, E60, O00, O41

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Engle's law, which also serves as one of the important mechanisms that drive structural change. Moreover, households are heterogeneous in their human capital endowment, which is the root cause of income inequality. Due to the non-homothetic preference, micro-level income heterogeneity has a macro impact on the aggregate economy in terms of GDP level and its growth rate, sectorial reallocation of production resources, and rural/urban income distribution. The economic dynamics are driven by the sectorial productivity growth, which is, in turn, endogenous to the human capital allocation across sectors. We analytically characterize how initial sectorial productivities and household heterogeneity in human capital endowment jointly determine the levels and dynamics of employment shares, value-added shares, productivities, Gini coefficients of different sectors and the GDP growth rate, both on the transitional dynamics and in the long-run steady state.

To facilitate our understanding of the mechanisms, we divide the model into two parts: static and dynamic. In the static part (the second section), sectorial productivities are exogenous and they fully determine prices and incomes, which, in turn, determine demand and supply in both sectors, and hence resource allocation across sectors, rural and urban income distribution, as well as the aggregate output. We examine three different possible scenarios, namely: all households consume both agriculture and non-agriculture products; only rich households consume both products; and no households consume non-agriculture products. They translate into three different economic structures, manifested as endogenously different functional forms of the aggregate production function, which is a common technical feature of models in New Structural Economics (see Ju *et al.*, 2015; Lin and Wang, 2018). Moreover, we show that changes in relative sectorial productivities that result in the advance of industrialization may sometimes lead to non-monotonic changes in rural income inequality, depending on the extent to which rich and poor households are heterogeneous in their human capital endowment and their proportions in the population. Notice that value-added shares and employment shares in each sector are not necessarily equal in our model because workers are heterogeneous in human capital endowment.

In the dynamic part (the third section), sectorial productivities are endogenously changing, depending on the human capital allocation across the two sectors, which, in turn, depends on demand and supply of products in the two sectors governed by sectorial productivities and income distributions. A key feature of the dynamic equilibrium is path dependence: different levels of the initial sector productivities may lead to diametrically opposite processes of structural change and polarized steady states in the long run. More concretely, we show that there exists a unique steady state, in which the two sectors grow at the same constant rate without structural change and both rural and urban Gini coefficients stay unchanged. Moreover, the value-added share of the non-agriculture sector is independent of household heterogeneity or aggregate factor endowment, and it strictly increases with the price demand elasticity of agriculture goods and how strong the learning externality is in human capital. The aggregate GDP growth rate strictly increases with price demand elasticity of agriculture goods and the aggregate human capital endowment, but is independent of household heterogeneity. However, the sectorial employment shares and rural Gini coefficient do depend on the details of household heterogeneity. We also show that this steady state is unstable. Any small deviation from the steady state results in permanent divergence away from it, leading either to continuous industrialization that ultimately converges to an asymptotic steady state without agriculture, or to continuous de-industrialization till the economy reaches a new steady state with only agriculture. The rural Gini coefficient may change non-monotonically on the transitional dynamics, depending on the initial productivities and per household income ratio between rich and poor.

However, the Laissez-faire market equilibrium allocation in the static economy may be neither Pareto-efficient nor GDP maximizing because marginal rate of substitution between

agriculture and non-agriculture consumption (or, equivalently, the marginal rate of transformation between agriculture and non-agriculture inputs) may not be equalized across households with different income levels and non-homothetic preferences. We show how certain income redistribution policies could enhance total GDP. The dynamic market equilibrium is not Pareto-efficient for an additional reason: human capital externality, that is, households' private decisions on which sector to work, does not internalize the impact of their decisions on future productivities, similar to Lucas (2004). We show with several simple examples that the welfare-maximizing policies are not necessarily those which ensure the highest GDP growth rates; both initial productivities and details of household heterogeneity matter. All these policy analyses are in the fourth section.

Our paper contributes to the literature of industrialization and structural change at large in several aspects. First, a key novel feature of our model is that the Engle's law is captured by a quasi-linear utility function, which differs from the standard non-homothetic functions in this literature. More specifically, whereas Stone–Geary utility function (see e.g. Kongasmut *et al*, 2001) and the sequentially satiated utility function with zero or one unit of consumption for each variety (see Matsuyama, 2002), and Buera and Kaboski (2012) assume an exogenous level of minimum or maximum consumption of certain goods: our utility function does not make those restrictive assumptions. Our function also differs from the non-homothetic CES preference (Comin *et al*., 2018; Matsuyama, 2018) in that we impose constant price demand elasticity for agriculture goods but allow for variable income demand elasticity and variable substitution elasticity across sectors, but the opposite is true for the non-homothetic CES. Moreover, our utility function enormously helps improve the model tractability that brings new insights[1]. For example, we show that balanced sectorial growth (without structural change) is possible for both the long-run steady state and the transitional path with our utility function, whereas it is almost never possible with any other standard non-homothetic preferences in the pertinent literature. Given the fundamental importance of non-homothetic preferences in the literature of structural change this new utility function helps deepen our understanding on the mechanisms how non-homothetic preferences affect industrialization and economic growth[2]. Second, our paper contributes to the literature of structural change by showing how (de)industrialization works when sectorial productivity changes are endogenous. Note that most existing models of industrialization treat changes in productivities as exogenous (see e.g. Retsuccia *et al*., 2008; Herrendorf *et al*., 2014), but we treat them as endogenous by following Lucas (2004) and Matsuyama (2002). It enables us to explore the dynamic impact of today's productivities and industrialization on future productivities and industrialization, resulting in strong path dependence.

Our paper also sheds light on the determination of rural income distribution and its evolution in the process of structural change and rural-urban migration. Instead of highlighting the role of migration barriers such as labor market frictions (see Harris and Todaro (1970), Retsuccia *et al*., 2008; Trevor and Zhu, 2018), financial market frictions (Lagakos and Waugh, 2013), we highlight the role of heterogeneous endowment in human capital in the structural change process, echoing the theme of New Structural Economics (Lin, 2011). Different from the human capital model in Lucas (2004), who assumes that rural and urban sectors produce the same good, we treat agriculture and non-agriculture as different goods both in terms of preference and technology. Murphy *et al* (1989) and Matsuyama (2002) study how income distribution affects industrialization with the presence of non-homothetic preferences, but not the reverse impact of industrialization on income distribution. Our paper examines both directions with a particular focus on rural income distribution. We show when and how the derived rural Gini coefficient may change non-monotonically with industrialization, depending on the initial productivities and details of human capital heterogeneity across households. Roles of redistributive policies are also discussed.

The rest of the paper is organized as follows. In the second and third sections, we develop a static model and a dynamic model of industrialization and income distribution, respectively, to characterize the decentralized Laissez-faire market equilibrium. Redistributive policies are discussed in the fourth section. The last section concludes.

Static model

Environment

Consider an economy populated by a continuum of households with measure equal to unity. Households can be divided into two groups: a rich group with total measure equal to $\theta \in (0, 1)$ and a poor group with measure $1-\theta$. Households are identical within each group.

Preference. All the households have the same instantaneous utility function $u(c)$, where final consumption c is given by:

$$c = c_m + \frac{\epsilon}{\epsilon - 1} c_a^{\epsilon - 1/\epsilon}, \epsilon > 1, \tag{1}$$

where c_m denotes the consumption of non-agriculture good m and c_a denotes the consumption of agriculture good a. The parameter ϵ is the price elasticity of demand for good a, that is, consumption demand for good a increases by $\epsilon\%$ when its price decreases by 1 percent. We require that both c_m and c_a must be non-negative: $u(c) = -\infty$ if $c_m < 0$ or $c_a < 0$. $u(\cdot)$ is a strictly increasing and concave function. This quasi-linear preference captures the Engle's law: agriculture good a is a necessary good whereas non-agriculture goods m are more luxurious, that is, when income is sufficiently low, only good a is consumed, and when income is sufficiently high, only the demand for good m would increase.

Technology. All the technologies are constant returns to scales. One unit of human capital (effective labor) produces A_m units of non-agriculture good. One unit of human capital produces A_a units of agriculture good a. That is:

$$F_m(L_m) = A_m L_m, \tag{2}$$

and:

$$F_a(L_a) = A_a L_a. \tag{3}$$

Endowment and market structure. Every household in this economy is endowed with one unit of time. Each household in the poor group is endowed with L_p units of human capital and each household in the rich group is endowed with L_r units of human capital. Assume $L_r > L_p > 0$. So rich people are more productive than poor people. All the markets are perfectly competitive.

Let W denote the wage rate per unit of human capital (effective labor). Then the income of a rich household (I_r) and that of a poor household (I_p) are, respectively, given by:

$$I_r = WL_r;\ I_p = WL_p. \tag{4}$$

Obviously, $I_r > I_p$, which is the reason why we call them rich and poor, respectively:

P1. The Gini coefficient for this economy is given by:

$$Gini = \frac{\theta(1-\theta)\left(\left(L_r/L_p\right)-1\right)}{\theta\left(\left(L_r/L_p\right)-1\right)+1}. \tag{5}$$

Proof. See the Appendix. ∎

Observe from (5) that the Gini coefficient is always smaller than $1-\theta$ and is also strictly increasing in (L_r/L_p). Moreover, Gini coefficient increases with θ when $\theta \in (0, \sqrt{L_p}/\sqrt{L_r} + \sqrt{L_p})$ and decreases with it when $\theta \in (\sqrt{L_p}/\sqrt{L_r} + \sqrt{L_p}, 1)$. When $\theta = \sqrt{L_p}/\sqrt{L_r} + \sqrt{L_p}$, the society reaches the maximum level of inequality with $Gini_{\max} = (\sqrt{L_r} - \sqrt{L_p}\ /\sqrt{L_r} + \sqrt{L_p})$. Alternatively, when and only when $(L_r/L_p) < ((1-\theta/\theta))^2$, Gini coefficient increases with θ.

Market equilibrium

Let p_m and p_a denote the market prices for non-agricultural good and the agriculture good, respectively, then perfect competition implies:

$$p_m = \frac{W}{A_m},\ p_a = \frac{W}{A_a}. \tag{6}$$

Consider a consumer who wants to maximize his/her utility function (1) subject to the following budget constraint:

$$p_m c_m + p_a c_a \leqslant I, \tag{7}$$

where income $I \in \{I_r, I_p\}$, given by (4).

This yields the following optimal consumption c_m and c_a:

$$c_a = \begin{cases} p_a^{-\epsilon} p_m^{\epsilon}, & \text{if } I \geqslant p_a^{1-\epsilon} p_m^{\epsilon} \\ \frac{I}{p_a}, & \text{otherwise} \end{cases}, \tag{8}$$

and:

$$c_m = \begin{cases} \frac{I - p_a^{1-\epsilon} p_m^{\epsilon}}{p_m}, & \text{if } I \geqslant p_a^{1-\epsilon} p_m^{\epsilon} \\ 0, & \text{otherwise} \end{cases}. \tag{9}$$

Substituting (8) and (9) into (1) yields the real income (or final consumption) as follows:

$$c = \begin{cases} \frac{I}{p_m} + \frac{1}{\epsilon - 1}\left(p_a^{-1} p_m\right)^{\epsilon - 1}, & \text{if } I \geqslant p_a^{1-\epsilon} p_m^{\epsilon} \\ \frac{\epsilon}{\epsilon - 1}\left(\frac{I}{p_a}\right)^{(\epsilon - 1/\epsilon)}, & \text{otherwise} \end{cases},$$

which, together with (4) and (6), implies that the real income of a household with human capital $L \in \{L_r, L_p\}$ is:

$$c = \begin{cases} A_m L + \frac{1}{\epsilon - 1}\left(\frac{A_a}{A_m}\right)^{\epsilon - 1}, & \text{if } L \geqslant A_m^{-\epsilon} A_a^{\epsilon - 1} \\ \frac{\epsilon}{\epsilon - 1}\left(A_a L_p\right)^{(\epsilon - 1/\epsilon)}, & \text{otherwise} \end{cases}. \tag{10}$$

Discussion. It is analytically isomorphic to interpret (1) as the production function of the final consumption good, which is produced by combining two intermediate inputs: agriculture good and non-agriculture good. The non-homotheticity of (1) implies that income distribution matters for both aggregate demand and aggregate price levels given the non-negativity constraint on c_m. Moreover, (1) is of decreasing returns to scale when interpreted as a production function, so the more spread the production scale, the better. The natural minimum scale of production is at the household level, which is equivalent to the problem of household utility maximization when (1) is interpreted as part

of the utility function. Without the loss of generality, normalize the price of final consumption good defined in (1) to unity. There are two advantages to choose the final consumption good as numeraire. First, GDP and welfare will be in the same unit, which enormously simplifies the welfare analysis. Second, it is easier than other choices of numeraire to conduct GDP analyses with or without policy interventions, given the non-homotheticity of (1) with the potential binding non-negativity constraint on c_m.

Next we explore three different scenarios depending on whether $A_m^{-\epsilon}A_a^{\epsilon-1}$ is inside or outside the interval (L_p, L_r).

Scenario I: only rich households consume non-agriculture. Suppose the following is true:

$$L_r > A_m^{-\epsilon}A_a^{\epsilon-1} \geqslant L_p. \tag{11}$$

In this case (10) implies that the total GDP is given by:

$$Y = \theta\left[A_m L_r + \frac{1}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1}\right] + (1-\theta)\frac{\epsilon}{\epsilon-1}\left(A_a L_p\right)^{(\epsilon-1/\epsilon)}, \tag{12}$$

where the first term on the right-hand side is the total income of rich households whereas the second term is the total income of poor households. Since only rich households can afford non-agriculture good, so the aggregate demand for non-agriculture good and agriculture is given by:

$$D_m = \theta\left(A_m L_r - A_a^{\epsilon-1}A_m^{1-\epsilon}\right), \tag{13}$$

$$D_a = \theta\left(\frac{A_a}{A_m}\right)^{\epsilon} + (1-\theta)A_a L_p. \tag{14}$$

The equilibrium amount of human capital used in the non-agriculture and agriculture sectors (denoted by L_m and L_a, respectively) are, respectively, given by:

$$L_m = \frac{D_m}{A_m} = \theta\left(L_r - A_a^{\epsilon-1}A_m^{-\epsilon}\right), \tag{15}$$

and:

$$L_a = \frac{D_a}{A_a} = \theta A_a^{\epsilon-1}A_m^{-\epsilon} + (1-\theta)L_p. \tag{16}$$

The value-added share (equivalent to human capital share) of the non-agriculture sector (denoted by η_m) in the whole economy is given by:

$$\eta_m \equiv \frac{L_m}{L_a + L_m} = \frac{\theta\left(L_r - A_a^{\epsilon-1}A_m^{-\epsilon}\right)}{(1-\theta)L_p + \theta L_r}. \tag{17}$$

Obviously:

$$\frac{\partial \eta_m}{\partial L_r} > 0;\ \frac{\partial \eta_m}{\partial L_p} < 0;\ \frac{\partial \eta_m}{\partial \theta} > 0;\ \frac{\partial \eta_m}{\partial A_m} > 0;\ \frac{\partial \eta_m}{\partial A_a} < 0.$$

We assume throughout this paper that the non-agriculture sector gives priority to employing workers with high human capital. Let N_m denote the employment share in the non-agriculture sector, which is equal to the total head account of workers in that sector because the total measure of workers is unity). Then (15) implies:

$$N_m = \theta\left(1-\frac{A_a^{\epsilon-1}A_m^{-\epsilon}}{L_r}\right), \tag{18}$$

so a measure of $\theta(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r)$ workers with high human capital and all the workers with low human capital are employed in the agriculture sector. In this economy, all workers for the agriculture sector live in the rural region, while all workers for the non-agriculture sector live in the urban region.

The Gini coefficient in the urban region is zero because all residents are from rich households (namely, households with human capital L_r), whereas the Gini coefficient in the rural region can be computed as:

$$GINI_r = \frac{\theta(1-\theta)\left(1-\left(L_p/L_r\right)\right)A_a^{\epsilon-1}A_m^{-\epsilon}}{\left[L_p+\theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}-L_p\right)\right]\left[1-\theta+\theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r\right)\right]}, \tag{19}$$

the proof of which is delegated to the Appendix.

Scenario II: all households consume non-agriculture. When the following is true:

$$L_r > L_p \geqslant A_m^{-\epsilon}A_a^{\epsilon-1}, \tag{20}$$

(10) implies that both rich and poor households can afford to consume non-agriculture good, and the total GDP is:

$$Y = A_m\left\{\theta L_r+(1-\theta)\,L_p+\frac{1}{\epsilon-1}A_a^{\epsilon-1}A_m^{-\epsilon}\right\}. \tag{21}$$

The aggregate demand for non-agriculture good and agriculture is given by:

$$D_m = A_m\left[\theta L_r+(1-\theta)L_p\right]-A_a^{\epsilon-1}A_m^{1-\epsilon},$$

$$D_a = \left(\frac{A_a}{A_m}\right)^{\epsilon},$$

and the human capital allocated to the non-agriculture and agriculture sectors is, respectively, given by:

$$L_m = \frac{D_m}{A_m} = \left[\theta L_r+(1-\theta)L_p\right]-A_a^{\epsilon-1}A_m^{-\epsilon}, \tag{22}$$

and:

$$L_a = A_a^{\epsilon-1}A_m^{-\epsilon}. \tag{23}$$

The value-added share of the non-agriculture sector is:

$$\eta_m = \frac{L_m}{L_a+L_m} = \frac{\left[\theta L_r+(1-\theta)L_p\right]-A_a^{\epsilon-1}A_m^{-\epsilon}}{(1-\theta)L_p+\theta L_r}. \tag{24}$$

Obviously:

$$\frac{\partial \eta_m}{\partial L_r} > 0; \frac{\partial \eta_m}{\partial L_p} > 0; \frac{\partial \eta_m}{\partial \theta} > 0; \frac{\partial \eta_m}{\partial A_m} > 0; \frac{\partial \eta_m}{\partial A_a} < 0.$$

The employment share of the agriculture sector is:

$$N_a = \begin{cases} \frac{A_a^{\epsilon-1} A_m^{-\epsilon}}{L_p}, & \text{if } A_a^{\epsilon-1} A_m^{-\epsilon} < (1-\theta) L_p \\ \frac{(1-\theta)[L_r - L_p] + A_a^{\epsilon-1} A_m^{-\epsilon}}{L_r}, & \text{if } (1-\theta) L_p \leqslant A_a^{\epsilon-1} A_m^{-\epsilon} \leqslant L_p \end{cases},$$

and the employment share of the non-agriculture sector is given by:

$$N_m = \begin{cases} 1 - \frac{A_a^{\epsilon-1} A_m^{-\epsilon}}{L_p}, & \text{if } A_a^{\epsilon-1} A_m^{-\epsilon} < (1-\theta) L_p \\ \frac{[\theta L_r + (1-\theta) L_p] - A_a^{\epsilon-1} A_m^{-\epsilon}}{L_r}, & \text{if } (1-\theta) L_p \leqslant A_a^{\epsilon-1} A_m^{-\epsilon} \leqslant L_p \end{cases}, \quad (25)$$

which increases with L_p and is independent of θ. We can derive the rural Gini coefficient as follows:

$$GINI_r = \begin{cases} \frac{[A_a^{\epsilon-1} A_m^{-\epsilon} - (1-\theta) L_p](1 - (L_p/L_r))(1-\theta)}{A_a^{\epsilon-1} A_m^{-\epsilon}[(1-\theta) + (A_a^{\epsilon-1} A_m^{-\epsilon} - (1-\theta) L_p/L_r)]}, & \text{if } (1-\theta) L_p \leqslant A_a^{\epsilon-1} A_m^{-\epsilon} \leqslant L_p \\ 0, & \text{if } A_a^{\epsilon-1} A_m^{-\epsilon} < (1-\theta) L_p \end{cases}, \quad (26)$$

and the urban Gini coefficient is given as:

$$GINI_u = \begin{cases} 0, & \text{if } (1-\theta) L_p \leqslant A_a^{\epsilon-1} A_m^{-\epsilon} \leqslant L_p \\ \frac{\theta(L_r - L_p)[1 - \theta - (A_a^{\epsilon-1} A_m^{-\epsilon}/L_p)]}{[1 - (A_a^{\epsilon-1} A_m^{-\epsilon}/L_p)][(1 - \theta - (A_a^{\epsilon-1} A_m^{-\epsilon}/L_p)) L_p + \theta L_r]}, & \text{if } A_a^{\epsilon-1} A_m^{-\epsilon} < (1-\theta) L_p \end{cases}.$$

Scenario III: no households consume non-agriculture. When the following is true:

$$A_m^{-\epsilon} A_a^{\epsilon-1} \geqslant L_r > L_p, \quad (27)$$

(10) implies that no household can afford to consume non-agriculture goods, and the total GDP is given by:

$$Y = \theta \frac{\epsilon}{\epsilon - 1} (A_a L_r)^{(\epsilon-1/\epsilon)} + (1-\theta) \frac{\epsilon}{\epsilon - 1} (A_a L_p)^{(\epsilon-1/\epsilon)}, \quad (28)$$

so the aggregate demand for non-agriculture good and agriculture is:

$$D_m = 0; D_a = A_a [\theta L_r + (1-\theta) L_p].$$

All labor is employed in the agriculture sector and no industrialization occurs:

$$\eta_m = N_m = 0. \quad (29)$$

The rural Gini coefficient is the same as the Gini coefficient for the whole economy, given by (5).

Summary. Based on the analyses above for the three different scenarios, we summarize the total GDP, sectorial value-added shares and employment shares, and rural Gini coefficient in the market equilibrium. Define:

$$\Omega \equiv A_m^{-\epsilon} A_a^{\epsilon-1}. \tag{30}$$

P2. The endogenous aggregate production function, denoted by $F(L_r, L_p, A_m, \Omega)$, has the following functional forms:

$$F(L_r, L_p, A_m, \Omega) = \begin{cases} \frac{\epsilon}{\epsilon-1} A_m \Omega^{(1/\epsilon)} \left[\theta L_r^{(\epsilon-1/\epsilon)} + (1-\theta) L_p^{(\epsilon-1/\epsilon)}\right] & \Omega > L_r \\ A_m \left[\theta\left(L_r + \frac{1}{\epsilon-1}\Omega\right) + (1-\theta)\frac{\epsilon}{\epsilon-1}\Omega^{(1/\epsilon)} L_p^{(\epsilon-1/\epsilon)}\right], & \text{if } L_p \leqslant \Omega \leqslant L_r, \\ A_m \left[\theta L_r + (1-\theta)\left(L_p + \frac{1}{\epsilon-1}\Omega\right)\right], & \text{if } \Omega < L_p \end{cases} \tag{31}$$

and the equilibrium real wage rate per unit of human capital is:

$$W = \frac{F(L_r,\ L_p,\ A_m,\ \Omega)}{\theta L_r + (1-\theta) L_p},$$

where Ω is defined in (30).

Proof. Combine (12), (21) and (28) and use (30). ■

This proposition characterizes how total GDP Y and real wage rate per unit of human capital change with L_r, L_p, A_m and Ω. When holding A_m fixed, total GDP Y as a function of Ω is illustrated in Figure 1.

Clearly, the aggregate production function (expression for GDP) strictly increases with Ω but has different functional forms when Ω is on different intervals, which reflects the fact that the underlying economic structures are endogenously different for the three

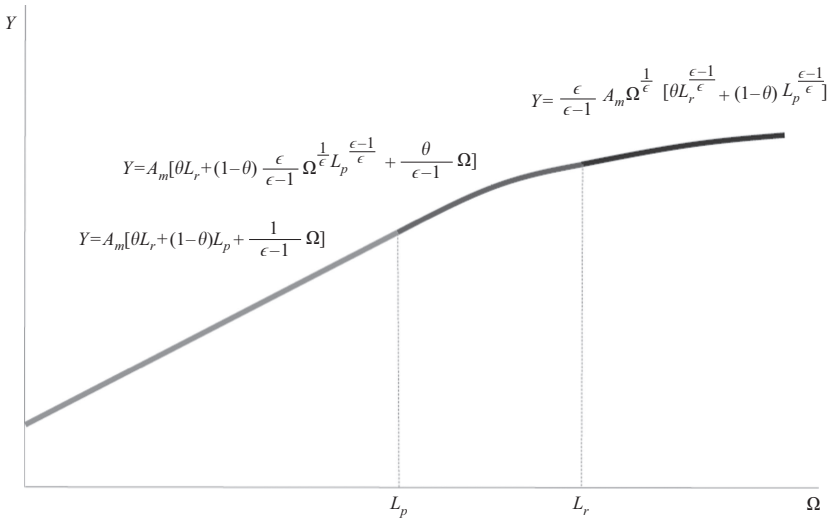

Figure 1.
GDP as a function of Ω

different scenarios analyzed above. It is in fact a common technical feature of models in New Structural Economics (see Ju, Lin and Wang, 2015; Lin and Wang, 2018). Interestingly, observe from (31) that when $\Omega > L_r$, the aggregate production function is a CES aggregate of human capital endowment of a rich household L_r and that of a poor household L_p, with substitution elasticity equal to ε, the price demand elasticity for agriculture products. When $L_p \leqslant \Omega \leqslant L_r$, the aggregate production function is a quasi-linear function of L_r and L_p up to an additive term that only depends on productivities. When $\Omega < L_p$, the aggregate production function is a linear function of L_r and L_p up to an additive term. Note that $A_a = A_m \Omega^{(1/\epsilon)}$, so when $\Omega > L_r$, the total GDP is independent of A_m.

Due to the non-homothetic preference, households with different income levels have different consumption structures (i.e. c_a/c_m is different), so the production structures are also different, depending on the income heterogeneity across households. When Ω changes, both household incomes and prices change, so the household heterogeneity and non-homothetic preference jointly determine the aggregate demand for agriculture and non-agriculture products, resulting in structural changes and changes in the functional form of the aggregate production function. The equilibrium wage rate in terms of the final good W also depends on the income heterogeneity.

To see the structural change more clearly, we have the following proposition:

P3. The value-added share of the non-agriculture sector η_m is as follows:

$$\eta_m = \begin{cases} 0, & \Omega > L_r \\ \frac{\theta(L_r - \Omega)}{(1-\theta)L_p + \theta L_r}, & \text{if } L_p \leqslant \Omega \leqslant L_r \\ \frac{\theta L_r + (1-\theta)L_p - \Omega}{(1-\theta)L_p + \theta L_r}, & \text{if } \Omega < L_p \end{cases}, \tag{32}$$

and the employment share of the non-agriculture sector N_m is given by:

$$N_m = \begin{cases} 0, & \Omega > L_r \\ \theta\left(1 - \frac{\Omega}{L_r}\right), & \text{if } L_p \leqslant \Omega \leqslant L_r \\ \frac{\theta L_r + (1-\theta)L_p - \Omega}{L_r}, & \text{if } (1-\theta)L_p \leqslant \Omega < L_p \\ 1 - \frac{\Omega}{L_p} & \text{if } \Omega \leqslant (1-\theta)L_p \end{cases}, \tag{33}$$

where Ω is defined in (30).

Proof. Combing (17), (24) and (29) yields (32). Combining (18), (25) and (29) yields (33). ■

More intuitively, Figure 2 shows how the value-added share of the non-agriculture sector η_m changes with productivities Ω, and Figure 3 plots how employment share N_m changes with Ω.

Observe that value-added share η_m and employment share N_m are different because workers are heterogeneous in human capital endowment. More explicitly, when $\Omega \leqslant (1-\theta)L_p$, all agriculture output will be produced by Ω/L_p poor households (or workers with low human capital), the remaining $1-\theta-\Omega/L_p$ poor households and all θ rich households will work in the non-agriculture sector. When $(1-\theta)L_p < \Omega \leqslant L_p$, the agriculture output will be produced by all $1-\theta$ poor households plus $(\Omega-(1-\theta)L_p/L_r)$ rich households, and the remaining $(\theta-\Omega-(1-\theta)L_p/L_r)$ rich households will work in the non-agriculture sector. When $L_p < \Omega \leqslant L_r$, the agriculture output will be produced by all $1-\theta$ poor households and $(\theta\Omega/L_r)$

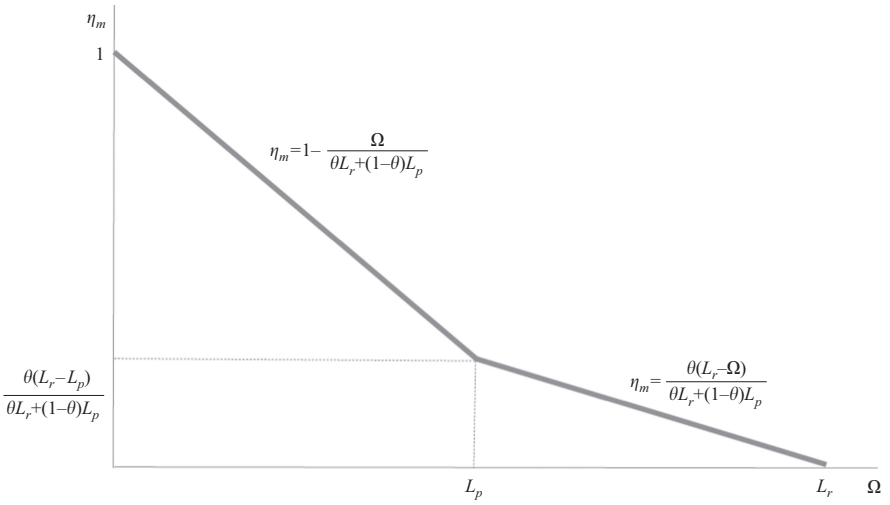

Figure 2.
How value-added share of non-agriculture sector changes with Ω

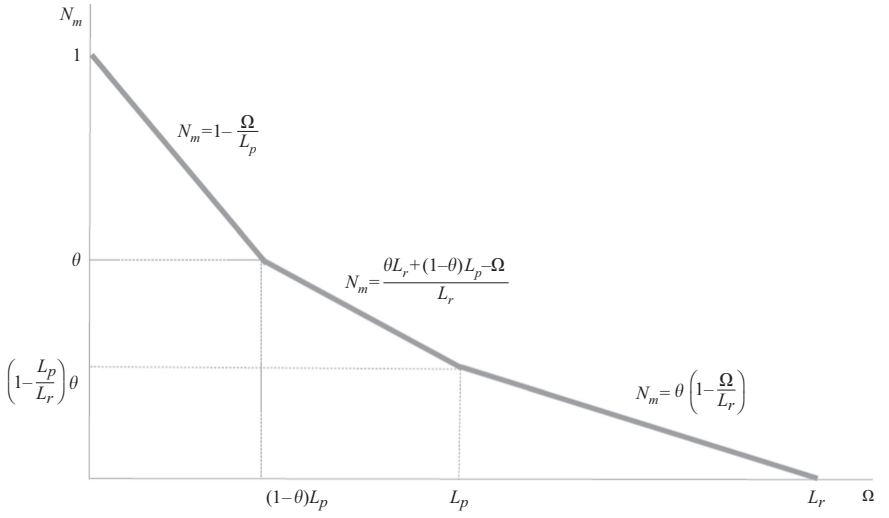

Figure 3.
How employment share of non-agriculture sector changes with Ω

rich households, and the remaining $\theta-\theta\Omega/L_p$ rich households will work in the non-agriculture sector. When $\Omega > L_r$, no one can afford to consume non-agriculture good, and all households will be working in the agriculture sector. These different regimes could explain why there are kinks in Figure 3. The reason why there is a kink when $\Omega = L_p$ in Figure 2 is because the aggregate (induced) demand for agricultural labor jumps down from Ω to $\theta\Omega$ once Ω crosses the threshold value L_p from below as the non-agriculture products suddenly become too expensive for poor households to consume, so only rich households, which account for θ fraction of the population, will each consume non-agriculture products with the amount produced by Ω units of human capital.

Using the definition of Gini coefficient, we can derive the rural Gini coefficient, which is summarized in the following proposition:

P4. The Gini coefficient in the rural region is given by:

$$GINI_r = \begin{cases} \frac{\theta(1-\theta)\left(\left(L_r/L_p\right)-1\right)}{\theta\left(\left(L_r/L_p\right)-1\right)+1} & \Omega \geqslant L_r \\ \frac{\theta(1-\theta)\left(1-\left(L_p/L_r\right)\right)\Omega}{\left[L_p+\theta\left(\Omega-L_p\right)\right]\left[1-\theta+\theta\left(\Omega/L_r\right)\right]} & \text{if } L_p \leqslant \Omega < L_r \\ \frac{\left[\Omega-(1-\theta)L_p\right]\left(1-\left(L_p/L_r\right)\right)(1-\theta)}{\Omega\left[(1-\theta)+\left(\Omega-(1-\theta)L_p/L_r\right)\right]}, & \text{if } (1-\theta)L_p \leqslant \Omega < L_p \\ 0, & \text{if } \Omega < (1-\theta)L_p \end{cases}, \tag{34}$$

where Ω is defined in (30).

Proof. Combine (19), (26) and (5), and use (30). ■

It turns out that $(\partial GINI_r/\partial\Omega) > 0$ when $(1-\theta)L_p \leqslant \Omega < L_p$. However, $GINI_r$ could change with Ω non-monotonically when $L_p \leqslant \Omega < L_r$. More specifically, when $L_r \leqslant ((1-\theta/\theta))^2 L_p$ and $\theta < (1/2)$, $GINI_r$ strictly increases with Ω for any $(1-\theta)L_p \leqslant \Omega < L_r$. This is plotted in Figure 4. The intuition is as follows. All workers are employed in the rural sector when $\Omega \geqslant L_r$, so the rural Gini coefficient is the same as the Gini coefficient for the whole economy, which is given by (5). Now suppose Ω decreases so that $L_p < \Omega < L_r$ holds, we learn from the previous proposition that workers with high human capital move from the agriculture sector into the non-agriculture sector. Note that the rich households are minority in the rural region ($\theta < (1/2)$) and (L_r/L_p) is small enough ($L_r \leqslant ((1-\theta/\theta))^2 L_p$), so when rich households leave the rural region, it is as if θ decreases, so the Gini coefficient decreases and the income distribution in the rural region is becoming more equalized.

However, when $L_r > ((1-\theta/\theta))^2 L_p$ and $\theta < (1/2)$, the rural Gini coefficient is plotted in Figure 5, where $\tilde{L} \equiv (1-\theta/\theta)\sqrt{L_p L_r}$. Observe that $GINI_r$ increases with Ω when $\Omega \in (L_p, \tilde{L})$ and decreases with Ω when $\Omega \in (\tilde{L}, L_r]$. The rural Gini coefficient $GINI_r$ reaches the maximum value $(\sqrt{L_r}-\sqrt{L_p}/\sqrt{L_r}+\sqrt{L_p})$ when $\Omega = \tilde{L}$.

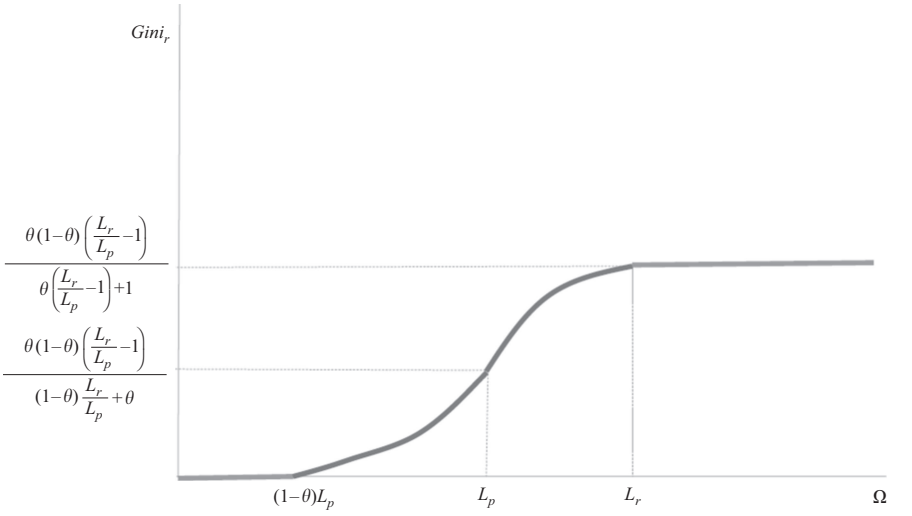

Figure 4.
Rural Gini Coefficient when $L_r \leqslant ((1-\theta/\theta))^2 L_p$ and $\theta < (1/2)$

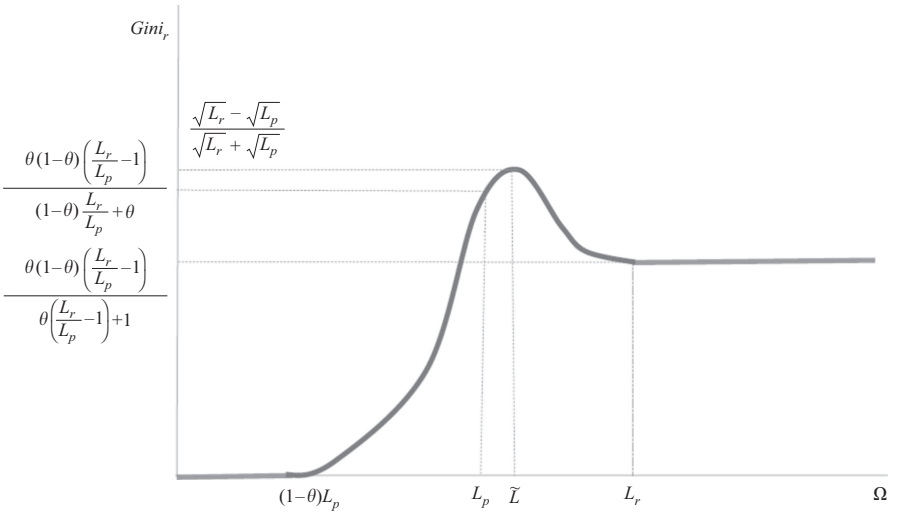

Figure 5.
Rural Gini Coefficient when $L_r > \left((\theta/1-\theta)\right)^2 L_p$ and $\theta \geqslant (1/2)$

Similarly, when $\theta \geqslant 1/2$ and $L_r > ((\theta/1-\theta))^2 L_p$, $GINI_r$ increases with Ω when $\Omega \in (L_p, \tilde{L})$ and decreases with Ω when $\Omega \in (\tilde{L}, L_r]$. This case is plotted in Figure 6. When $\theta \geqslant 1/2$ and $L_r \leqslant ((\theta/1-\theta))^2 L_p$, $GINI_r$ decreases with Ω for any $\Omega \in (L_p, L_r]$. This is shown in Figure 7. We leave the proof of how $GINI_r$ changes with Ω in the Appendix.

In this part, productivities A_m and A_a are exogenous. Next, we make the model dynamic by allowing A_m and A_a to change endogenously over time.

Dynamic model

Consider a continuous-time infinite-horizon world, where households' utility function is given by:

$$\int_0^{\infty} u(c(t))e^{-\rho t}dt, \tag{35}$$

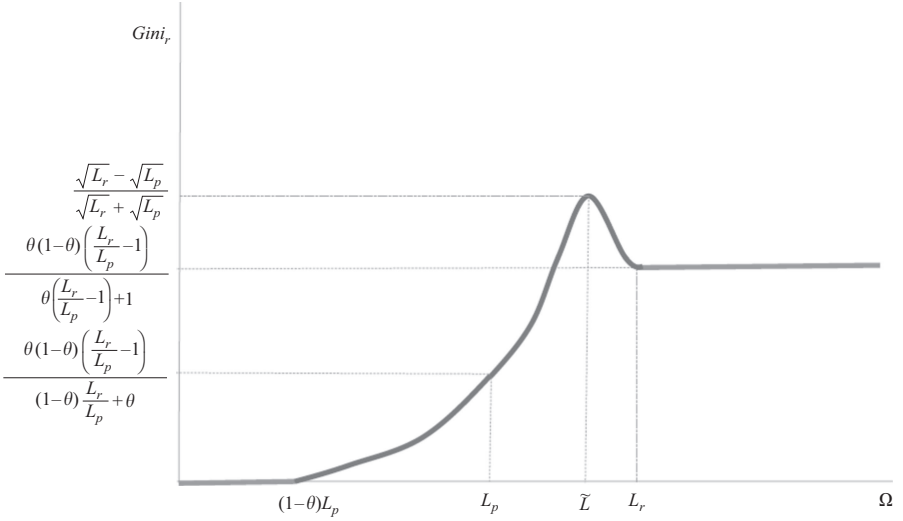

Figure 6.
Rural Gini Coefficient when $L_r > \left((1-\theta/\theta)\right)^2 L_p$ and $\theta < (1/2)$

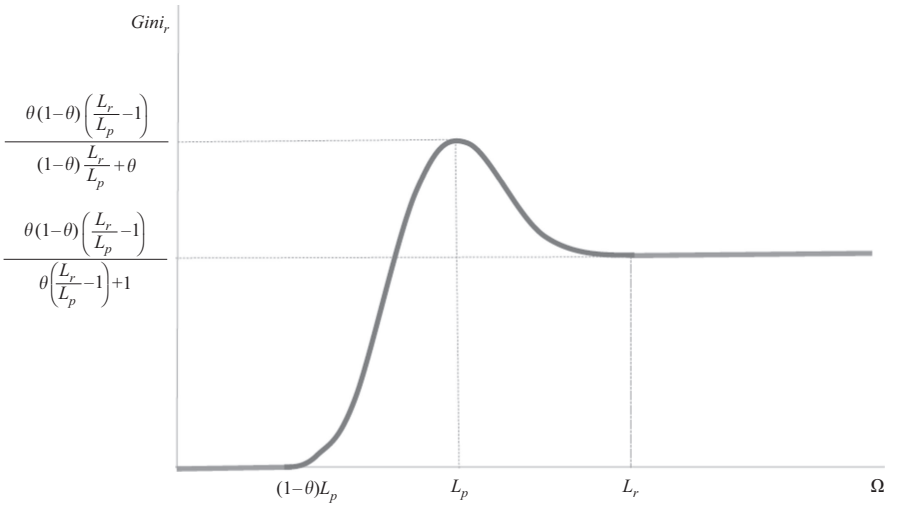

Figure 7.
Rural Gini Coefficient when $L_r \leqslant ((\theta/1-\theta))^2 L_p$ and $\theta \geqslant (1/2)$

where ρ is the time discount rate and is strictly positive and (1) holds for each time point t. For simplicity, assume all goods are non-storable. Suppose productivities in the two sectors evolve as follows:

$$\dot{A}_m = A_m L_m^{\alpha};\ \dot{A}_a = A_a L_a^{\alpha}, \tag{36}$$

where $0 < \alpha < 1$. That is, as more effective units of labor is employed to produce in a sector, the productivity of that sector increases due to learning by doing.

Using the definition of Ω in (30) and (36), we obtain:

$$\frac{\dot{\Omega}}{\Omega} \leqslant 0 \Leftrightarrow \left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)} \leqslant \frac{L_m}{L_a}, \tag{37}$$

where $\left(\dot{\Omega}/\Omega\right) = 0$ if and only if $((\epsilon-1/\epsilon))^{(1/\alpha)} = (L_m/L_a)$holds. Consider the decentralized competitive market equilibrium, in which each household maximizes (35) subject to (7) by choosing which sector to work, how much labor to supply, and $c_m(t)$ and $c_a(t)$ for all time $t \in [0, \infty)$ by taking all prices as exogenously given. When (11) is satisfied, substituting (15) and (16) into (37) yields $(\dot{\Omega}/\Omega) < 0$ if and only if $L_p \leqslant \Omega < L^*$, where:

$$L^* \equiv \frac{L_r - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((1/\theta)-1\right)L_p}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1}. \tag{38}$$

Obviously, $L^* < L_r$. Moreover, $L^* \geqslant L_p$ if and only if:

$$L_r \geqslant \left[1+\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\frac{1}{\theta}\right]L_p. \tag{39}$$

When (20) is true, substituting (22) and (23) to (37) yields $\left(\dot{\Omega}/\Omega\right) < 0 \Leftrightarrow \Omega < L^{**}$, where:

$$L^{**} \equiv \frac{\theta L_r + (1-\theta)L_p}{1+\left[((\epsilon-1)/\epsilon)\right]^{(1/\alpha)}}. \tag{40}$$

It turns out that $L^{**} \leqslant L^*$ if and only if (39) holds. Moreover, $L^{**} \geqslant L_p$ if and only if (39) holds. When (27) is true, $L_m = 0$ and so (37) implies $(\dot{\Omega}/\Omega) > 0$. These findings are summarized in the following lemma:

Lemma 1. When (39) is true, $\dot{\Omega} < 0$ if and only if $\Omega \in [0, L^*)$, and $\dot{\Omega} > 0$ if and only if $\Omega \in (L^*, \infty)$. When (39) is violated, $\dot{\Omega} < 0$ if and only if $\Omega \in [0, L^{**})$, and $\dot{\Omega} > 0$ if and only if $\Omega \in (L^{**}, \infty)$.

P5. Suppose (39) is true. There exists a balanced growth path (BGP) (referred as steady state 1 henceforth), on which all rich households consume both agriculture and non-agriculture goods and all poor households only consume agriculture goods. Moreover, the value-added share of the non-agriculture sector is:

$$\eta_m = \frac{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}}{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1}, \tag{41}$$

where the employment share is $N_m = ((\epsilon-1/\epsilon))^{(1/\alpha)}/((\epsilon-1/\epsilon))^{(1/\alpha)} + 1\theta L_r + (1-\theta) L_p/L_r$, and the growth rate of total GDP, denoted by g_{GDP}, is given by:

$$g_{GDP} = \frac{\dot{A}_m}{A_m} = \frac{\epsilon-1}{\epsilon}\left(\frac{\theta L_r + (1-\theta)L_p}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1}\right)^{\alpha}, \tag{42}$$

and the Gini coefficient in the urban region is zero, whereas the Gini coefficient in the rural region is:

$$GINI_r = \frac{(1-\theta)\left((L_r/L_p)-1\right)\left[\theta(L_r/L_p)-\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1-\theta)\right]\left[\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right]}{\left[(1-\theta)+\theta(L_r/L_p)\right]\left[(L_r/L_p)+(1-\theta)\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((L_r/L_p)-1\right)\right]},$$

and $\Omega = L^*$, where L^* is given by (38).

Proof. See the Appendix. ■

On this BGP, the value added of the two sectors grows at the same speed as total GDP, and there is no structural change (labor reallocation across the two sectors). Observe that when price demand elasticity ϵ increases, value-added share and employment share of the non-agriculture sector both increase $((\partial \eta m/\partial \epsilon) > 0, (\partial Nm/\partial \epsilon) > 0)$, so does the GDP growth rate $((\partial g_{GDP}/\partial \epsilon))$. Moreover, when α increases, value-added share and employment share of the non-agriculture sector both become larger $((\partial \eta m/\partial \alpha) > 0, (\partial Nm/\partial \alpha) > 0)$. Notice that η_m is independent of θ, L_p and L_r on the BGP, but the opposite is true in Scenario I in the static model. Both N_m and g_{GDP} increase with θ and L_p, whereas an increase in L_r reduces N_m but increases g_{GDP}.

Lemma 1 implies that the BGP (on which $\Omega = L^*$ holds) characterized in the last proposition is unstable. The following proposition characterizes what happens off the BGP:

P6. Suppose (39) is true. When $\Omega(0) < L^*$ holds, the economy will keep industrializing, GDP will grow monotonically, and the economy will converge to an asymptotic steady state (referred as asymptotic steady state 2 henceforth), in which all households consume both agriculture (negligible) and non-agriculture goods and the following is true:

$$\begin{aligned} \dot{A}_m &= A_m\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}, \\ \dot{A}_a &= 0, \end{aligned} \tag{43}$$

$$g_{GDP} = \left[\theta L_r + (1-\theta)L_p\right]^{\alpha},$$

$$\eta_m = N_m = 1.$$

When $\Omega(0) > L^*$ holds, the economy will keep de-industrializing, GDP will grow monotonically, and the economy will converge to the agrarian steady state (referred as agrarian steady state 3 henceforth), in which all households consume agriculture goods only and the following is true:

$$\begin{aligned} \dot{A}_m &= 0, \\ \dot{A}_a &= A_a\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}, \\ g_{GDP} &= \tfrac{\epsilon-1}{\epsilon}\left[\theta L_r + (1-\theta)L_p\right]^{\alpha} \\ \eta_m &= N_m = 0. \end{aligned} \tag{44}$$

Proof. Using (31), (36), (32), (33) and Lemma 1. Note that both A_a and A_m will always weakly increase and at least one of them strictly increases any time, so GDP will keep increasing strictly. ■

Observe that the GDP growth rate is highest in steady state 2, second highest in steady state 3 and lowest in steady state 1. Suppose $\Omega \in [L_p, L^*)$ initially. The economy starts with Scenario I characterized in the static model, in which rich households consume both agriculture and non-agriculture goods and poor households only consume agriculture goods. Then Ω monotonically decreases over time, labor continuously moves from the agriculture sector into the non-agriculture sector and the value-added share of the non-agriculture sector keeps increasing. When $\Omega < L_p$, poor households also consume both agriculture and non-agriculture goods. This industrialization process lasts forever, converging to the asymptotic steady state (steady state 3), in which all people work in the non-agriculture sector and no agriculture goods will be consumed. Suppose, on the other hand, $\Omega \in (L^*, L_r)$ holds initially. Then de-industralization will take place continuously till the economy reaches steady state 3, in which every household only consumes agriculture goods and nobody works in the non-agriculture sector.

How does the rural Gini coefficient change over time? Suppose (39) is true and $\theta < (1/2)$. When $\theta \in (0, (1/[(\epsilon-1/\epsilon)]^{(1/\alpha)}+2))$, Figure 4 applies. That is, when $\Omega(0) < L^*$, the rural Gini coefficient monotonically decreases as Ω declines over time till Ω reaches $(1-\theta)L_p$, after which the rural Gini coefficient is always zero. When $\Omega(0) > L^*$, the rural Gini coefficient monotonically increases over time till Ω reaches L_r, after which the rural Gini coefficient remains constant at the level given by (5). When $\theta \in ((1/[(\epsilon-1/\epsilon)]^{(1/\alpha)}+2), (1/2))$, Figure 5 applies. Moreover, $\tilde{L} \equiv (1-\theta/\theta)\sqrt{L_p L_r} > L^*$ if and only if $1+[(\epsilon-1/\epsilon)]^{(1/\alpha)}(1/\theta) \leqslant L_r/L_p < H$, where:

$$H \equiv \frac{\left[\left([(\epsilon-1/\epsilon)]^{(1/\alpha)}+1\right)(1-\theta/\theta)+\sqrt{\left[\left([(\epsilon-1/\epsilon)]^{(1/\alpha)}+1\right)(1-\theta/\theta)\right]^2+4[(\epsilon-1/\epsilon)]^{(1/\alpha)}(1/\theta-1)}\right]^2}{4}. \tag{45}$$

In that case, $\Omega(0) \in (L^*, \tilde{L})$, the rural Gini coefficient first strictly increases over time till it reaches the maximum level $(\sqrt{L_r}-\sqrt{L_p}/\sqrt{L_r}+\sqrt{L_p})$ when $\Omega = \tilde{L}$, after which the rural Gini coefficient declines over time till Ω reaches L_r, after which the rural Gini remains constant at level given by (5). Similar analyses can be made when $(L_r/L_p) \geqslant H$ or when $\theta \geqslant (1/2)$. Please refer to the Appendix for more details of the proof.

We can easily obtain the following two propositions when (39) is not satisfied:

P7. Suppose (39) is violated, that is, $L_p < L_r < [1+[(\epsilon-1/\epsilon)]^{(1/\alpha)}(1/\theta)]L_p$. There exists a steady state, in which all households consume both agriculture and non-agriculture goods and:

$$\Omega = L^{**},$$
$$L_m = \theta L_r + (1-\theta)L_p - L^{**},$$
$$L_a = L^{**},$$

and the value-added share of the non-agriculture sector η_m is still given by (41), and the employment share is given by:

$$N_m = \begin{cases} \dfrac{[((\epsilon-1)/\epsilon)]^{(1/\alpha)} - \theta((L_r/L_p)-1)}{1+[((\epsilon-1)/\epsilon)]^{(1/\alpha)}}, & \text{if } L^{**} \leqslant (1-\theta)L_p \\ \dfrac{[((\epsilon-1)/\epsilon)]^{(1/\alpha)}}{1+[((\epsilon-1)/\epsilon)]^{(1/\alpha)}} \dfrac{\theta L_r + (1/\alpha)L_p}{L_r}, & \text{if } L^{**} \in \left((1-\theta)L_p, L_p\right) \end{cases},$$

and the growth rate of total GDP is given by (42), where L^{**} is given by (40).

Proof. Similar to that of *P5*. ■

Observe further that $L^{**} \leqslant (1-\theta)L_p$ if and only if the human capital endowment is sufficiently close between a rich household and a poor household, or, more precisely:

$$L_p < L_r \leqslant \left[((\epsilon-1)/\epsilon)\right]^{(1/\alpha)}(1-\theta/\theta)L_p,$$

which is possible only when $\theta < \eta_m$ given by (41).

This steady state is also unstable and any deviation from it would result in continuous industrialization till almost no agriculture is produced or continuous de-industralization till only agriculture is produced, depending on whether $\Omega < L^{**}$ or $\Omega > L^{**}$. It is formally stated in the following proposition:

P8. Suppose (39) is violated, that is, $L_p < L_r < [1+[(\epsilon-1/\epsilon)]^{(1/\alpha)}(1/\theta)]L_p$. When $\Omega < L^{**}$ holds initially, the economy will converge to asymptotic steady state 2 characterized in *P6*. When $\Omega > L^{**}$ holds initially, the economy will converge to agrarian steady state 3 characterized in *P6*.

Proof. Similar to that of *P6*. ■

How the rural Gini coefficient changes over time can be analyzed analogously and is skipped here.

Is the Laissez-faire market equilibrium Pareto-efficient or socially optimal? We turn to this question now.

Redistributive policy

First, consider the static case. It turns out that when not every household can afford to consume the non-agriculture consumption, the aggregate GDP can be improved by appropriate redistributive policies. More precisely, we have the following proposition:

P9. In the static economy, when $\theta L_r + L_p(1-\theta) \geqslant \Omega > L_p$, the aggregate GDP can be raised to the level:

$$Y' = A_m\left[\theta L_r + (1-\theta)L_p + \frac{1}{\epsilon-1}\Omega\right],$$

by using the following redistributive policy: each rich household has to pay a lump-sum tax equal to $((1-\theta)[\Omega-L_p]W/\theta)$, and all the tax revenues are equally transferred to all poor households in a lump-sum fashion. When $\theta L_r + L_p(1-\theta) < \Omega$, the total GDP can be raised to the level:

$$\frac{\epsilon}{\epsilon-1}A_m\Omega^{(1/\epsilon)}\left[\theta L_r+(1-\theta)L_p\right]^{(\epsilon-1/\epsilon)},$$

by imposing a lump-sum tax $(1-\theta)(L_r-L_p)\ W$ on each rich household and equally redistributing to all poor households in a lump-sum way.

Proof. See the Appendix. ■

We emphasize that these redistributive policies are valid only when they are expected by the public before production, otherwise it has no impact on GDP. The intuition behind the GDP-enhancing redistributive policies is that when the constraint $c_m \geqslant 0$ becomes binding for some household, it is equivalent to a binding borrowing constraint that prevents firms with relatively high marginal productivity form producing at a higher level. Note that the marginal productivity of agricultural labor is diminishing and also higher than that of non-agriculture labor when $c_m \geqslant 0$ is binding, but the poor households cannot afford enough agriculture goods. By redistributing income from rich to poor households, the aggregate demand for agriculture goods increases, so more labor is allocated into the agricultural sector to meet the demand, which improves resource allocation and hence increases aggregate GDP. Obviously, when $\Omega \leqslant L_p$, the demand for agriculture goods is fully satiated, and $c_m \geqslant 0$ is no longer binding because all the remaining income is spent on the non-agriculture goods, the technology of which is of constant returns to scale, so redistributive policies would not improve GDP.

In short, the redistributive policies are can enhance GDP because it effectively enhances the aggregate demand. An equivalent policy intervention is that the government collects the all the tax revenues in the same way as specified in the previous proposition and spend all the revenues to purchase agriculture goods as public expenditure. This Keynesian expansionary fiscal policy with a balanced government budget turns out to have a multiplier larger than unity whenever $\Omega > L_p$.

When $\theta L_r + L_p(1-\theta) \geqslant \Omega > L_p$, the before-redistribution rural Gini coefficient is given by:

$$GINI_r = \frac{\theta(1-\theta)\left(1-\left(L_p/L_r\right)\right)\Omega}{\left[L_p+\theta\left(\Omega-L_p\right)\right]\left[1-\theta+\theta\left(\Omega/L_r\right)\right]},$$

according to *P4*, and the employment share of the agriculture sector is $1-\theta+\theta(\Omega/L_r)$ according to *P3*. The post-redistribution rural Gini coefficient is given by:

$$GINI_r' = \frac{\left(\Omega-L_p/L_r\right)\left[\left(\theta L_r+(1-\theta)L_p-\Omega/\theta\right)\right]}{\left[1+\left(\Omega-L_p/L_r\right)\right]\left[\left(\epsilon\Omega/\epsilon-1\right)\left(L_r+\Omega-L_p/L_r\right)+\left(\Omega-L_p/L_r\right)\left(\theta L_r+(1-\theta)L_p-\Omega/\theta\right)\right]},$$

and the employment share of the agriculture sector is $(1-\theta)(1+(\Omega-L_p/L_r))$, which is larger than that before the redistribution. Among all the rural workers, there are $1-\theta$ workers with low human capital and $((1-\theta)[\Omega-L_p]/L_r)$ workers with high human capital. When $\theta L_r + L_p(1-\theta) < \Omega$, the post-redistribution rural Gini coefficient is zero.

In the dynamic case, recall that the GDP growth rate in the asymptotic steady state 2 is higher than any other steady state. When $L_r > \Omega > L_p$, the redistributive policies prescribed in *P9* encourage workers to move into the agriculture sector to boost the instantaneous aggregate GDP; however, (36) implies that such redistributive policies would result in GDP loss in the future because these policies dynamically increase Ω and push the economy away from the asymptotic steady state 2. Consequently, there is a

trade-off between current GDP and future GDP when policy makers decide labor allocation across sectors.

Whereas it is difficult to characterize the precise dynamic optimal policies for the general case due to the non-linear transitional dynamics, it is nevertheless useful to examine a few special cases. To sharpen the result, suppose $u(c)$ in (35) takes the functional form of CRRA as follows:

$$u(c) = \frac{c^{1-(1/\sigma)}-1}{1-(1/\sigma)},$$

where σ is the inter-temporal elasticity of substitution. Consider the following two policies:

(1) Policy A: an infinitely high tax rate is imposed on the consumption of agriculture permanently; and

(2) Policy B: a prohibitive tax is permanently imposed on production of non-agriculture goods and a lump-sum tax $(1-\theta)(L_r-L_p)\ W$ is imposed on each rich household and then equally redistributed to all poor households in a lump-sum way every time point, so that all households have equal consumption of agriculture after redistribution.

Observe that under Policy A, the economy is always in steady state 2 as described in *P6*, and the GDP is:

$$Y_A(t) = A_m(0)\cdot\left[\theta L_r+(1-\theta)L_p\right]e^{\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}\cdot t}, \forall t\in[0,\ \infty).$$

In contrast, under Policy B, the economy is always in the steady state 3 as described in *P6* and the GDP is:

$$Y_B(t) = \frac{\epsilon}{\epsilon-1}A_a(0)^{(\epsilon-1/\epsilon)}\left[\theta L_r+(1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}e^{\epsilon-1/\epsilon\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}\cdot t}, \forall t\in[0,\ \infty).$$

So Policy A always yields a higher GDP growth rate than Policy B. Moreover, define:

$$\Omega_1 \equiv \left[\frac{\rho-(\epsilon-1/\epsilon)\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}{\rho-\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}\right]^{(\sigma\epsilon/\sigma-1)}\left(\frac{L_r}{(\epsilon/\epsilon-1)\left[\theta L_r+(1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}}\right)^{\epsilon},$$

$$\Omega_2 \equiv \left[\frac{\rho-(\epsilon-1/\epsilon)\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}{\rho-\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}\right]^{(\sigma\epsilon/\sigma-1)}\left(\frac{L_p}{(\epsilon/\epsilon-1)\left[\theta L_r+(1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}}\right)^{\varepsilon},$$

where the time discount rate ρ is assumed sufficiently large to exclude explosive growth:

$$\rho-\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}\left(1-\frac{1}{\sigma}\right)>0.$$

It can be shown that the following is true (please refer to the Appendix for proofs):

P10. When $\Omega(0)<\Omega_2$, every household is strictly better off under Policy A than under Policy B. When $\Omega(0)\in(\Omega_2,\ \Omega_1)$, every rich household is strictly better off under Policy A than under Policy B but the opposite is true for each poor household. When $\Omega(0)>\Omega_1$, every household is strictly worse off under Policy A than under Policy B. When $\Omega(0)=\Omega_2$, every poor household feels indifferent between the two policies but every rich household strictly prefers Policy A. When $\Omega(0)=\Omega_1$, every rich household feels indifferent between the two policies but every poor household strictly prefers Policy B.

This example suggests that at which steady state the welfare of a household is higher depends on the level of initial productivities $\Omega(0)$, not necessarily the steady state that yields the higher GDP growth rate. In general, a high enough A_m or a low enough A_a would in general make Policy A more favorable than Policy B. Moreover, households with different human capital endowment may have different preferences over policies.

Suppose (39) holds and $\Omega(0)$ is equal to L^*, given by (38), so from time 0, the economy is always at the steady state characterized in *P5*:

P11. A rich household is strictly better off under Policy A than in the Laissez-faire market equilibrium.

If and only if the inter-temporal elasticity satisfies $\sigma \in (\sigma^*,1)$, where σ^* is uniquely determined by:

$$\log \frac{1+\left(1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)\right)(\epsilon-1)}{\left(1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)\right)(\epsilon-1)} = \frac{\sigma^2}{1-\sigma}\log\left[\frac{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1}{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}}\right],$$

and:

$$\frac{1}{1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)} \geqslant \frac{L_p}{L_r} > \frac{1-(\epsilon-1)\left(\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\left[\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\right]^{(\sigma^2/\sigma-1)}-1\right]}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}((1/\theta)-1)}. \quad (46)$$

Please refer to the Appendix to see the proof. This example suggests that inter-temporal elasticity of substitution σ, initial productivities $\Omega(0)$, and human capital heterogeneity (L_p/L_r) could be all important in determining whether a household is better off in a Laissez-faire market equilibrium or in a steady state under policy interventions. In this specific example, if $\sigma \leqslant \sigma^*$ or $\sigma \geqslant 1$, the Laissez-faire market equilibrium characterized in *P5* delivers a higher welfare level to the rich households than Policy A, even though the latter achieves full industrialization and attains a higher growth rate of GDP. Furthermore, based on the previous discussion, when $L^* < \Omega_2$, rich households are better off under Policy A than Policy B, so the Laissez-faire equilibrium when $\Omega(0) = L^*$ is better than Policy B in terms of the welfare of rich households. This example shows that when human capital endowment becomes too heterogeneous in the sense that (L_p/L_r) is sufficiently small so that the second inequality is violated in (46), Policy A also makes rich households worse off than in the Laissez-faire market equilibrium. Similar analyses can be made on the welfare of poor households and the steady state characterized in *P7*.

Conclusion

In this paper, we develop a simple dynamic model of (de)industrialization and income distribution to analytically characterize how these two dynamic processes interact with each other and what they imply for aggregate GDP growth, the evolution of rural income distribution as well as welfare. Redistributive policies are shown to be sometimes useful to improve GDP via structural change. The high tractability of the model mainly comes from the new non-homothetic utility function introduced in this paper. Several avenues for future research seem appealing. One is to extend the model to an open economy to allow for international trade. Another possibility is to allow human capital to change endogenously. Yet another direction is to explore quantitative implications of this theoretical model, which presumably requires introducing certain additional relevant frictions to match data.

Notes

1. The analytical convenience of this quasi-linear utility function in the structural change models is also demonstrated when allowing for multiple production factors, non-competitive market structures, input-output linkages across sectors and international trade; see Li *et al.* (2016) and Lin and Wang (2018).
2. For more discussions on the role of non-homothetic preferences, see Boppart (2014) and Matsuyama and Ushchev (2018).

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Further reading

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Appendix

Proof of *P1*

Proof. The Gini coefficient is defined mathematically based on the Lorenz curve, which plots the proportion of the total income of the population (y-axis) that is cumulatively earned by the bottom x% of the population, see Figure A1.

The line at 45° thus represents perfect equality of incomes. The Gini coefficient can then be thought of as the ratio of the area that lies between the line of equality and the Lorenz curve (marked A in the diagram) over the total area under the line of equality (marked A and B in the diagram), i.e. Gini $= A/(A + B)$.

In *P1*, area A is a triangle, the area of which is given by:

$$A = \frac{1}{2}\left[(1-\theta) - \frac{(1-\theta)L_p W}{(1-\theta)L_p W + \theta L_r W}\right] = \frac{1}{2}(1-\theta)\theta\frac{(L_r - L_p)}{(1-\theta)L_p + \theta L_r},$$

and the area of $(A + B)$ is 1/2, so we obtain the Gini coefficient as $(1-\theta)\theta((L_r-L_p)/(1-\theta)L_p+\theta L_r)$. ■

As a useful rule, the Gini coefficient for this two-group situation is equal to the population proportion of the low-income group minus the income proportion of the low-income group.

Proof of (19)

Proof. Use the rule mentioned in the proof of *P1*; the Gini coefficient in the rural region is equal to the population proportion of the low-income group minus the income proportion of the low-income group, that is:

$$\frac{1-\theta}{\theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r\right)+1-\theta} - \frac{(1-\theta)L_p W}{(1-\theta)L_p W + \theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r\right)L_r W}$$

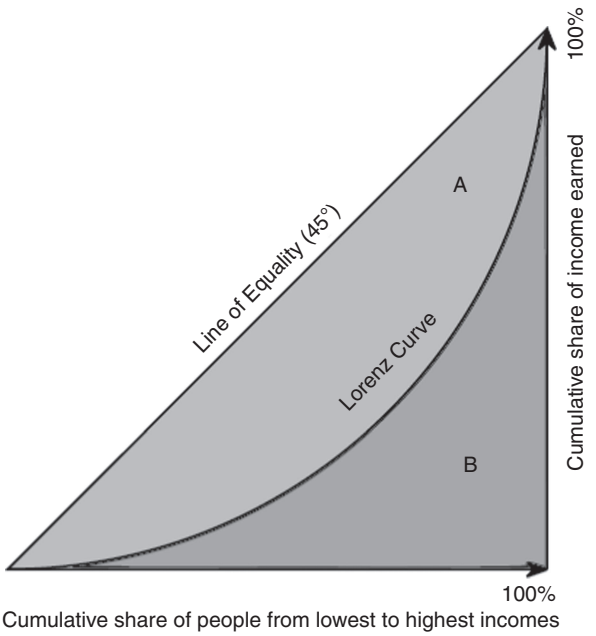

Figure A1.
The cumulatively earned proportion of the total income of the population

$$= \frac{1-\theta}{\theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r\right)+1-\theta} - \frac{(1-\theta)L_p}{(1-\theta)L_p+\theta A_a^{\epsilon-1}A_m^{-\epsilon}}$$

$$= \frac{(1-\theta)\theta A_a^{\epsilon-1}A_m^{-\epsilon}\left(1-\left(L_p/L_r\right)\right)}{\left(\theta\left(A_a^{\epsilon-1}A_m^{-\epsilon}/L_r\right)+1-\theta\right)\left[(1-\theta)L_p+\theta A_a^{\epsilon-1}A_m^{-\epsilon}\right]}.$$

■

Proof of how $GINI_r$ in (34) changes with Ω

Proof. When $\Omega \in [L_p, L_r)$, we have:

$$GINI_r = \frac{\theta(1-\theta)\left(1-\left(L_p/L_r\right)\right)\Omega}{\left[L_p+\theta\left(\Omega-L_p\right)\right]\left[1-\theta+\theta\left(\Omega/L_r\right)\right]},$$

which strictly increases with Ω for any $\Omega \in \left(L_p, \left(1-\theta/\theta\right)\sqrt{L_pL_r}\right)$.

$$L_p < \frac{1-\theta}{\theta}\sqrt{L_pL_r} \Leftrightarrow L_r > \left(\frac{\theta}{1-\theta}\right)^2 L_p,$$

which is true if and only if $\theta \leqslant 1/2$ or $L_r > ((\theta/1-\theta))^2\, Lp$ when $\theta > 1/2$.

Observe that:

$$\frac{1-\theta}{\theta}\sqrt{L_pL_r} \leqslant L_r \Leftrightarrow L_r \geqslant \left(\frac{1-\theta}{\theta}\right)^2 L_p,$$

which is always true if $\theta \geqslant 1/2$. When $\theta < 1/2$, it requires $L_r \geqslant ((1-\theta/\theta))^2 L_p$.

So when $\theta < 1/2$, we have $L_p < (1-\theta/\theta)\sqrt{L_pL_r}$. In this case, if we further have $L_r \geqslant ((1-\theta/\theta))^2 L_p$, then $(1-\theta/\theta)\sqrt{L_pL_r} \leqslant L_r$, so $GINI_r$ increases with Ω when $\Omega \in (L_p, (1-\theta/\theta)\sqrt{L_pL_r})$ and decreases with Ω when $\Omega \in ((1-\theta/\theta)\sqrt{L_pL_r}, L_r]$. If $L_r \leqslant ((1-\theta/\theta))^2 L_p$, then $(1-\theta/\theta)\sqrt{L_pL_r} \geqslant L_r$, so $GINI_r$ increases with Ω when $\Omega \in (L_p, L_r]$.

When $\theta > 1/2$, we always have $(1-\theta/\theta)\sqrt{L_pL_r} < L_r$. In this case, $L_p < (1-\theta/\theta)\sqrt{L_pL_r}$ holds only when $L_r > ((\theta/1-\theta))^2 L_p$, so $GINI_r$ increases with Ω when $\Omega \in (L_p, (1-\theta/\theta)\sqrt{L_pL_r})$ and decreases with Ω when $\Omega \in ((1-\theta/\theta)\sqrt{L_pL_r}, L_r]$. When $L_r \leqslant ((\theta/1-\theta))^2 L_p$, $GINI_r$ decreases with Ω when $\Omega \in (L_p, L_r]$.

When $\theta = 1/2$, $L_p < (1-\theta/\theta)\sqrt{L_pL_r}$ is always true. $GINI_r$ increases with Ω when $\Omega \in (L_p, (1-\theta/\theta)\sqrt{L_pL_r})$ and decreases with Ω when $\Omega \in ((1-\theta/\theta)\sqrt{L_pL_r}, L_r]$.

When $\Omega = (1-\theta/\theta)\sqrt{L_pL_r}$, the rural region achieves the maximum inequality with Gini coefficient $GINI_r = (\sqrt{L_r}-\sqrt{L_p}/\sqrt{L_r}+\sqrt{L_p})$.

When $\Omega \notin [L_p, L_r)$, we can do the analysis in a similar way. ■

Proof for how rural Gini changes over time

Proof. Suppose $\theta < (1/2)$ and (39) is true. Recall Figure 5 refers to the case when $L_r \leqslant ((1-\theta/\theta))^2 L_p$ and $\theta < (1/2)$. Since:

$$\left[1+\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\frac{1}{\theta}\right]L_p \leqslant \left(\frac{1-\theta}{\theta}\right)^2 L_p \Leftrightarrow \theta \leqslant \frac{1}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+2},$$

so when $\theta \leqslant (1/[(\epsilon-1/\epsilon)]^{(1/\alpha)}+2)$, Figure 4 applies under (39). So if $\Omega(0) < L^*$, the rural Gini coefficient monotonically decreases over time. If $\Omega(0) > L^*$, the rural Gini coefficient monotonically

increases over time. When $\theta \in ((1/[(\epsilon-1/\epsilon)]^{(1/\alpha)}+2),(1/2))$, we have:

$$L_r \geqslant \left[1+\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\frac{1}{\theta}\right]L_p > \left(\frac{1-\theta}{\theta}\right)^2 L_p,$$

so Figure 5 applies.

Now we show that $\tilde{L} \equiv (1-\theta/\theta)\sqrt{L_p L_r} > L^*$ if and only if:

$$1+\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\frac{1}{\theta} \leqslant \frac{L_r}{L_p} < H, \tag{A1}$$

where H is given by (45):

$$\begin{aligned}
\tilde{L} > L^* &\Leftrightarrow \frac{1-\theta}{\theta}\sqrt{L_p L_r} > \frac{L_r - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((1/\theta)-1\right)L_p}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1} \\
&\Leftrightarrow \frac{L_r}{L_p} - \left(\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}+1\right)\frac{1-\theta}{\theta}\sqrt{\frac{L_r}{L_p}} - \left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\left(\frac{1}{\theta}-1\right) < 0 \\
&\Leftrightarrow \sqrt{1+\left[\frac{\epsilon-1}{\epsilon}\right]^{(1/\alpha)}\frac{1}{\theta}} \leqslant \sqrt{\frac{L_r}{L_p}} < \sqrt{H},
\end{aligned}$$

where the first inequality in the last line is from (39). We can verify that $1+[(\epsilon-1/\epsilon)]^{(1/\alpha)}(1/\theta) < H$ always holds when $\theta \in (0,(1/2))$.

So if $\Omega(0) < L^*$, the rural Gini coefficient strictly decrease over time as Ω continuously decreases, till Ω reaches $(1-\theta)L_p$, after which the rural Gini coefficient is always zero. If $\Omega(0) \in (L^*, \tilde{L})$, the rural Gini coefficient first strictly increases till it reaches the maximum value when $\Omega = \tilde{L}$, after which the rural Gini coefficient strictly decreases till $\Omega = L_r$, after which it remains constant at the level given by (5). ■

Proof of *P9*

When the following is true:

$$\theta L_r + L_p(1-\theta) \geqslant A_a^{\epsilon-1}A_m^{-\epsilon},$$

let:

$$\begin{aligned}
T &= (1-\theta)\left[\left(\frac{A_a}{A_m}\right)^{\epsilon} - A_a L_p\right]\frac{W}{A_a} \\
&\theta\left[WL_r - \left(\frac{A_a}{A_m}\right)^{\epsilon}\frac{W}{A_a}\right] - (1-\theta)\left[\left(\frac{A_a}{A_m}\right)^{\epsilon} - A_a L_p\right]\frac{W}{A_a} > 0 \\
&\theta\left[A_a L_r - \left(\frac{A_a}{A_m}\right)^{\epsilon}\right] - (1-\theta)\left[\left(\frac{A_a}{A_m}\right)^{\epsilon} - A_a L_p\right] > 0.
\end{aligned}$$

It can be shown that all poor people can afford to consume $((A_a/A_m))^{\epsilon}$ amount of agriculture goods and the total output of agriculture good is $((A_a/A_m))^{\epsilon}$, so the total effective labor to produce agriculture is $A_a^{\epsilon-1}A_m^{-\epsilon}$, and the total expenditure on non-ag is:

$$\begin{aligned}
&\theta\left[WL_r - \left(\frac{A_a}{A_m}\right)^{\epsilon}\frac{W}{A_a}\right] - T + T - (1-\theta)\left[\left(\frac{A_a}{A_m}\right)^{\epsilon} - A_a L_p\right]\frac{W}{A_a} \\
&= \frac{W}{A_a}\left\{\theta\left[A_a L_r - \left(\frac{A_a}{A_m}\right)^{\epsilon}\right] - (1-\theta)\left[\left(\frac{A_a}{A_m}\right)^{\epsilon} - A_a L_p\right]\right\} = \frac{W}{A_a}\left[\theta A_a L_r + (1-\theta)A_a L_p - \left(\frac{A_a}{A_m}\right)^{\epsilon}\right],
\end{aligned}$$

which is solely produced by rich people. The total GDP is given by:

$$\theta\left[\frac{WL_r-(T/\theta)}{p_m}+\frac{1}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1}\right]+(1-\theta)\left[\frac{WL_p+(T/1-\theta)}{p_m}+\frac{1}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1}\right]$$

$$=A_m\left[\theta L_r+(1-\theta)L_p\right]+\frac{1}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1},$$

which is strictly larger than that before the redistribution. Moreover, the non-ag employment share is given by:

$$N_m=\theta+(1-\theta)\frac{L_p}{L_r}-\frac{A_a^{\epsilon-1}A_m^{-\epsilon}}{L_r},$$

which is smaller than before.

When:

$$\theta L_r+L_p(1-\theta)<A_a^{\epsilon-1}A_m^{-\epsilon}<L_r,$$

we could let:

$$T=\theta L_rW-\theta\left(\frac{A_a}{A_m}\right)^{\epsilon}\frac{W}{A_a},$$

and transfer them equally to a subset of poor households with a measure equal to:

$$\frac{\theta L_rW-\theta\left((A_a/A_m)\right)^{\epsilon}(W/A_a)}{\left[\left((A_a/A_m)\right)^{\epsilon}-A_aL_p\right](W/A_a)}=\theta\frac{L_r-\left((A_a/A_m)\right)^{\epsilon}(1/A_a)}{\left((A_a/A_m)\right)^{\epsilon}(1/A_a)-L_p}=\theta\frac{L_r-\Omega}{\Omega-L_p},$$

and the remaining poor households with a measure equal to:

$$1-\theta-\theta\frac{L_r-\Omega}{\Omega-L_p},$$

will stay with their original consumption. The post-distribution GDP is:

$$\left(\theta+\theta\frac{L_r-\Omega}{\Omega-L_p}\right)\frac{\epsilon}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1}+\left(1-\theta-\theta\frac{L_r-\Omega}{\Omega-L_p}\right)\frac{\epsilon}{\epsilon-1}(A_aL_p)^{(\epsilon-1/\epsilon)}$$

$$=\theta\left(\frac{L_r-L_p}{\Omega-L_p}\right)\frac{\epsilon}{\epsilon-1}\left(\frac{A_a}{A_m}\right)^{\epsilon-1}+\left(1-\theta-\theta\frac{L_r-\Omega}{\Omega-L_p}\right)\frac{\epsilon}{\epsilon-1}(A_aL_p)^{(\epsilon-1/\epsilon)}$$

$$=\frac{\epsilon}{\epsilon-1}A_m\Omega^{(1/\epsilon)}\left[\theta\left(\frac{L_r-L_p}{\Omega-L_p}\right)\Omega^{(\epsilon-1/\epsilon)}+\left(1-\theta\left(\frac{L_r-L_p}{\Omega-L_p}\right)\right)L_p{}^{(\epsilon-1/\epsilon)}\right].$$

Note that:

$$\theta\left(\frac{L_r-L_p}{\Omega-L_p}\right)\Omega+\left(1-\theta\left(\frac{L_r-L_p}{\Omega-L_p}\right)\right)L_p$$

$$=\theta\left(L_r-L_p\right)+L_p.$$

Note that the before-distribution GDP is:

$$\frac{\epsilon}{\epsilon-1}A_m\Omega^{(1/\epsilon)}\left[\theta\Omega^{-(1/\epsilon)}\frac{\epsilon-1}{\epsilon}L_r-\theta\frac{\epsilon-1}{\epsilon}\Omega^{(\epsilon-1/\epsilon)}+\theta\Omega^{(\epsilon-1/\epsilon)}+(1-\theta)L_p{}^{(\epsilon-1/\epsilon)}\right],$$

so:

$$\left(\frac{L_r-L_p}{\Omega-L_p}\right)\Omega^{(\epsilon-1/\epsilon)}-\left(\frac{L_r-\Omega}{\Omega-L_p}\right)L_p{}^{(\epsilon-1/\epsilon)}>\Omega^{-(1/\epsilon)}\frac{\epsilon-1}{\epsilon}L_r+\frac{1}{\epsilon}\Omega^{(\epsilon-1/\epsilon)}$$

$$\frac{\Omega^{(\epsilon-1/\epsilon)}-L_p{}^{(\epsilon-1/\epsilon)}}{\Omega-L_p}>\Omega^{-(1/\epsilon)}\frac{\epsilon-1}{\epsilon},$$

which is true because the right-hand side is the slope of curve $y=x^{(\epsilon-1/\epsilon)}$ at point $x=\Omega$ on the x–y space while the left-hand side is larger.

Proof of *P10* and *P11*

Proof. Consider the following policy: an infinitely high tax rate is imposed on the consumption of agriculture permanently. In this case:

$$Y(t)=A_m(t)\cdot\left[\theta L_r+(1-\theta)L_p\right],$$

where:

$$\dot{A}_m=A_m\left[\theta L_r+(1-\theta)L_p\right]^{\alpha},$$

so aggregate GDP at any time t is given by:

$$Y(t)=A_m(0)\cdot\left[\theta L_r+(1-\theta)L_p\right]e^{\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}t},$$

and the total discounted welfare of a rich household is:

$$\begin{aligned}&\int_0^{\infty}\frac{\left[A_m(0)L_re^{\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}t}\right]^{1-(1/\sigma)}-1}{1-(1/\sigma)}e^{-\rho t}dt\\&=\int_0^{\infty}\frac{(A_m(0)L_r)^{(1-(1/\sigma))}e^{\left\{\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))-\rho\right\}t}-e^{-\rho t}}{1-(1/\sigma)}dt\\&=\frac{1}{1-(1/\sigma)}\left[\frac{(A_m(0)L_r)^{1-(1/\sigma)}}{\rho-\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}-(1/\rho)\right],\end{aligned}$$

and the total welfare of a poor household is:

$$\frac{1}{1-(1/\sigma)}\left[\frac{\left(A_m(0)L_p\right)^{1-(1/\sigma)}}{\rho-\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}-(1/\rho)\right].$$

Consider another extreme policy, which permanently prohibits production of non-agriculture goods and imposing a lmup-sum tax $(1-\theta)(L_r-L_p)W$ on each rich household and equally redistributing to all poor households in a lump-sum way every time point, then GDP at time t is given by:

$$Y(t)=\frac{\epsilon}{\epsilon-1}A_a(t)^{(\epsilon-1/\epsilon)}\left[\theta L_r+(1-\theta)L_p\right]^{(\epsilon-1/\epsilon)},$$

where:

$$\dot{A}_a = A_a\left[\theta L_r + (1-\theta)L_p\right]^{\alpha},$$

so:

$$\begin{aligned} Y(t) &= Y(0)e^{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}t} \\ &= \frac{\epsilon}{\epsilon-1}A_a(0)^{(\epsilon-1/\epsilon)}\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}e^{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}t}, \end{aligned}$$

and the total welfare of a rich household and a poor household will be equal, given by:

$$\begin{aligned} &\int_0^{\infty} \frac{\left[Y(0)e^{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}t}\right]^{1-(1/\sigma)} - 1}{1-(1/\sigma)} e^{-\rho t}dt \\ &= \int_0^{\infty} \frac{(Y(0))^{(1-(1/\sigma))}e^{\left\{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))-\rho\right\}t} - e^{-\rho t}}{1-(1/\sigma)}dt \\ &= \frac{1}{1-(1/\sigma)}\left[\frac{\left[(\epsilon/\epsilon-1)A_a(0)^{(\epsilon-1/\epsilon)}\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}\right]^{1-(1/\sigma)}}{\rho-(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} - \frac{1}{\rho}\right], \end{aligned}$$

Compare the welfare of a rich household in the first policy with the welfare of a household in the second policy:

$$\begin{aligned} &\frac{1}{1-(1/\sigma)}\left[\frac{(A_m(0)L_r)^{1-(1/\sigma)}}{\rho-\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} - \frac{1}{\rho}\right] \\ &-\frac{1}{1-(1/\sigma)}\left[\frac{\left[(\epsilon/\epsilon-1)A_a(0)^{(\epsilon-1/\epsilon)}\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}\right]^{1-(1/\sigma)}}{\rho-(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} - \frac{1}{\rho}\right] \\ &= \frac{1}{1-(1/\sigma)}\left[\frac{(A_m(0)L_r)^{1-(1/\sigma)}}{\rho-\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} - \frac{\left[(\epsilon/\epsilon-1)A_a(0)^{(\epsilon-1/\epsilon)}\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}\right]^{1-(1/\sigma)}}{\rho-(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}\right]. \end{aligned}$$

We can show that it is strictly positive if and only if when $\Omega(0) < \Omega_1$; a poor household's welfare in the first policy is higher than that of a household in the second policy if and only if $\Omega(0) < \Omega_2$, where $\Omega_2 < \Omega_1$.

When $\Omega(0) < \Omega_2$, every household is strictly better off under Policy A than under Policy B. When $\Omega(0) \in (\Omega_2, \Omega_1)$, every rich household is strictly better off under Policy A than under Policy B but the opposite is true for each poor household. When $\Omega(0) > \Omega_1$, every household is strictly worse off under Policy A than under Policy B. When $\Omega(0) = \Omega_2$, every poor household feels indifferent between the two policies but every rich household strictly prefers Policy A. When $\Omega(0) = \Omega_1$, every rich household feels indifferent between the two policies but every poor household strictly prefers Policy B:

$$\Omega_1 \equiv \left[\frac{\rho-(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}{\rho-\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}\right]^{(\sigma\epsilon/\sigma-1)}\left(\frac{L_r}{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}}\right)^{\epsilon}$$

$$\Omega_2 \equiv \left[\frac{\rho-(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}{\rho-\left[\theta L_r + (1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))}\right]^{(\sigma\epsilon/\sigma-1)}\left(\frac{L_p}{(\epsilon-1/\epsilon)\left[\theta L_r + (1-\theta)L_p\right]^{(\epsilon-1/\epsilon)}}\right)^{\epsilon}.$$

By comparison, the Laissez-faire market equilibrium in the steady state described in *P5*, the welfare of a rich household is given by:

$$c_r = A_m L_r + (1/\epsilon - 1)\left(\frac{A_a}{A_m}\right)^{\epsilon-1} = A_m\left[L_r + (1/\epsilon - 1)\Omega\right],$$

$$g_{GDP} = \frac{\dot{A}_m}{A_m} = \left[\frac{\left((\epsilon - 1/\epsilon)\right)^{(1/\alpha)}}{\left((\epsilon - 1/\epsilon)\right)^{(1/\alpha)} + 1}\left[\theta L_r + (1-\theta)L_p\right]\right]^{\alpha},$$

$$\int_0^{\infty} \frac{\left[A_m(0)\left[L_r + (1/\epsilon - 1)\Omega\right]e^{\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}t}\right]^{1-(1/\alpha)} - 1}{1-(1/\alpha)} e^{-\rho t}dt$$

$$= \int_0^{\infty} \frac{\left(A_m(0)\left[L_r + (1/\epsilon - 1)\Omega\right]\right)^{(1-(1/\alpha))} e^{\left\{\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}(1-(1/\alpha))-\rho\right\}t} - e^{-\rho t}}{1-(1/\alpha)} dt$$

$$= \frac{1}{1-(1/\alpha)}\left[\frac{\left(A_m(0)\left[L_r + (1/\epsilon - 1)\Omega^*\right]\right)^{1-(1/\alpha)}}{\rho - \left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}(1-(1/\alpha))} - \frac{1}{\rho}\right],$$

and the total welfare of a poor household is:

$$c_r = \frac{\epsilon}{\epsilon - 1}\left(A_a L_p\right)^{(\epsilon-1/\epsilon)} = A_m \frac{\epsilon}{\epsilon - 1} L_p^{(\epsilon-1/\epsilon)}\Omega^{(1/\epsilon)}.$$

The total welfare is:

$$\frac{1}{1-(1/\sigma)}\left[\frac{\left(A_m(0)(\epsilon/\epsilon - 1)L_p^{(\epsilon-1/\epsilon)}\Omega^{(1/\epsilon)}\right)^{1-(1/\sigma)}}{\rho - \left[\left(\left((\epsilon-1/\epsilon)\right)(1/\sigma)/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}(1-(1/\sigma))} - \frac{1}{\rho}\right].$$

A rich household is strictly better off in policy 1 than in Laissez-faire steady state in *P5* if and only if:

$$\frac{1}{1-(1/\sigma)}\left[\frac{(A_m(0)L_r)^{1-(1/\sigma)}}{\rho - \left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} - \frac{\left(A_m(0)\left[L_r + (1/\epsilon - 1)\left(L_r - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}((1/\theta)-1)L_p/\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\right]\right)^{1-(1/\sigma)}}{\rho - \left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}(1-(1/\sigma))}\right] > 0.$$

When $(1/1-(1/\sigma)) > 0$, it becomes:

$$\frac{1}{\rho - \left[\theta L_r+(1-\theta)L_p\right]^{\alpha}(1-(1/\sigma))} > \frac{\left(\left[1 + (1/\epsilon - 1)\left(1 - \left[(\epsilon-1/\epsilon)\right]^{(1/\sigma)}((1/\theta)-1)(L_p/L_r)/\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\right]\right)^{1-(1/\sigma)}}{\rho - \left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}(1-(1/\sigma))},$$

which is never possible.

When $(1/1-(1/\sigma)) < 0$, it becomes:

$$\frac{1}{\rho + \left[\theta L_r+(1-\theta)L_p\right]^{\alpha}((1/\sigma)-1)} < \frac{\left(\left[1 + (1/\epsilon - 1)\left(1 - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}((1/\theta)-1)(L_p/L_r)/\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\right]\right)^{1-(1/\sigma)}}{\rho + \left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\left[\theta L_r+(1-\theta)L_p\right]\right]^{\alpha}((1/\sigma)-1)},$$

which is reduced to:

$$\rho < \frac{\left[\theta L_r+(1-\theta)L_p\right]^{\alpha}((1/\sigma)-1)\left[\left[1 + (1/\epsilon - 1)\left(1 - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}((1/\theta)-1)(L_p/L_r)/\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\right]^{1-(1/\sigma)} - \left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\right]^{\sigma}\right]}{1 - \left[1 + (1/\epsilon - 1)\left(1 - \left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}((1/\theta)-1)(L_p/L_r)/\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\right]^{1-(1/\sigma)}},$$

which only requires that:

$$\left[1+\frac{1}{\epsilon-1}\frac{1-\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((1/\theta)-1\right)(L_p/L_r)}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1}\right]^{(\sigma-1/\sigma)} > \left[\frac{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}}{\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1}\right]^{\sigma},$$

which can be further simplified to:

$$\frac{1-(\epsilon-1)\left(\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\left[\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\right]^{(\sigma^2/\sigma-1)}-1\right]}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((1/\theta)-1\right)} < \frac{L_p}{L_r}.$$

Together with (39), we must have:

$$\frac{1}{\left[1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)\right]} \geqslant \frac{L_p}{L_r} > \frac{1-(\epsilon-1)\left(\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}+1\right)\left[\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1\right)\right]^{(\sigma^2/\sigma-1)}-1\right]}{\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}\left((1/\theta)-1\right)},$$

which further requires:

$$\frac{\log\left(1+\left(1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)\right)(\epsilon-1)/\left(1+\left[(\epsilon-1/\epsilon)\right]^{(1/\alpha)}(1/\theta)\right)(\epsilon-1)\right)}{\log\left[\left(\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}+1/\left((\epsilon-1/\epsilon)\right)^{(1/\alpha)}\right)\right]} < \frac{\sigma^2}{1-\sigma},$$

since the left-hand side is strictly positive and right-hand side is a strictly increasing function of σ for $\sigma \in [0, 1)$ with value from 0 to ∞, so there must exist a unique $\sigma^* \in (0, 1)$ such that the above inequality is true if and only if $\sigma \in (\sigma^*, 1)$. ■

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Mechanization services, farm productivity and institutional innovation in China

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Abstract

Purpose – The purpose of this paper is to investigate the impact of mechanization services on farm productivity in Northern China from an empirical perspective, with the aim to identify the underlying market and institutional barriers.

Design/methodology/approach – The authors apply the regression method with the control of village fixed effects to examining the relationship between capital–labor ratio, mechanization service ratio and farm productivity, using the panel data collected in 2013 and 2015 by CCAP.

Findings – Mechanization services improve farm productivity through substituting labor, but it may generate a less positive impact on farms who do not have self-owned capital equipment.

Originality/value – It is the first study to investigate how mechanization services affect farm productivity for grain producers in Northern China.

Keywords Total factor productivity, Farm survey, Mechanization service, Small household farms

Paper type Research paper

1. Introduction

The past four decades have witnessed a significant change in China's agricultural development and rural transformation, underlying which a rapid growth in agricultural productivity plays an important role. Between 1978 and 2008, agricultural total factor productivity (TFP) of the crop and livestock industry in China has grown at the rate of 2.4 percent a year, which is around twice of the world average for the same period of time (Fuglie and Rada, 2015; Sheng *et al.*, 2019). The rapid increase in agricultural productivity offsets negative effects of constrained supply of inputs and adverse seasonal conditions and contributes to improve China's food security. Since the late 1970s, the real gross output value of Chinese agriculture has grown at an average rate of 5.4 percent a year, while annual growth of total input was 2.5 percent a year (Huang and Rozelle, 2018), and agricultural production becomes more diversified. Increased agricultural productivity

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has also helped to release rural labor, facilitating rapid urbanization and industrialization in China. Since the early 1990s, there has been a strong rise in off-farm employment, providing additional labor supply to support the industrialization process and urban development (Meng and Zhang, 2010).

While accomplishments are impressive, agricultural productivity growth in China shows a slowing-down pattern since 2008. Over the past decade, the estimated agricultural TFP has fallen at the rate of 1.2 percent a year, which has been much lower than its historical trend (Sheng *et al.*, 2019). Underlying such a change in agricultural productivity growth, there are both previous remained issues and newly emerged challenges. For example, overuse of fertiliser and crop chemicals has gradually caused land degradation and slowed the yield growth of major crops (Zhang *et al.*, 2013; Lu *et al.*, 2015), while changing climate conditions also threaten agricultural productivity growth.

Other than those constraints listed above, a more critical issue is that small farm size (in terms of land area operated), as a consequence of the "equalitarianism" in land allocation system in history (Chen, 2018), has restricted farmers from utilizing labor-augmented techniques (such as precision seeding and micro-spray irrigation) (Sheng and Chancellor, 2018). Although over the last four decades, the farmland institutional reform in China has focused on "stabilizing the land property rights" and "promote the farmland transfer" (Luo, 2018), the farm size still small. Estimates based on annual rural household surveys by the Chinese Ministry of Agriculture and Rural Affairs (MARA) show that the average size of farms in China declined from 0.73 hectare in the early 1980s to 0.57 hectare in 2003. As most of these small household farms rely on labor-intensive technologies (Huang, 2013; Han, 2015), rising wages and rural labor shortages have caused them to lose competitiveness and profitability in market (Shi, 2018). Farmer input choice between labor and capital is likely to smooth the non-linear farm size–productivity relationship (Sheng *et al.*, 2019).

Mechanization services, including plant and machinery hire and technical/management services, have long been regarded as a complementary to self-owned machinery in agricultural production of OECD countries. Between 1973 and 2011, the proportion of expenditure on plant and machinery hire in total intermediate costs of the US farm sectors have increased by 40 percent. A similar growing trend was also observed in Australia and Canada as well as in the EU countries. For decades, farms in OECD countries gradually increase the percentage usage of mechanization services to save the sunk costs associated with investing in newly invented capital equipment, which become more expensive over time. This helps to facilitate the diffusion of technologies embodied, in particular for those professional farms which hope to increase asset liquidity and shorten investment cycles. Although mechanization services also become popular recently in China, little is known about whether and how mechanization services may change the way of production of small household farms. In particular, one would like to know whether small household farms could increase their productivity performance through outsourcing plant and machinery services.

To answer these questions, this paper examines the impact of mechisation services on production efficiency of small household farms from an empirical perspective, by using the farm-level panel data in Northern China collected by China Centre for Agricultural Policy (CCAP), Peking University, in 2013 and 2015. With the control of the village fixed effects, we show that switching toward capital-intensive technology tends to improve small household farms' TFP and profitability but not the yield. In this sense, mechanization services play a similar role in affecting farmers' productivity performance as self-owned investment and will significantly improve the productivity performance of those farms with no equipment. However, we also show that majority mechanization service providers provide only basic capital services to substitute labor, which is different from what we have observed in OECD countries, and thus it becomes a barrier to the development of modern agricultural production.

This implies that there could be some market failure that restricts high-quality mechanization services to be provided, calling for additional institutional arrangements.

The remainder of the paper organizes as below. Section 2 first describes the farm survey data used in this paper, followed by a brief discussion on the relationship between institutional arrangement, farm size and the development of mechanization services in China in Section 3. Section 4 provides the model specification. Section 5 presents the analytical results on how mechanization services may affect household farms' yield, profits and TFP relative to self-owned investment in machinery. Section 6 makes the concluding remarks.

2. Data source and variable description

The data sets used in this paper come from a two-wave repetitive farm survey conducted by CCAP, Peking University, in 2013 and 2015. This survey focuses on collecting the farm-level and the plot-level data on agricultural production and household consumption in two major cropping regions in Northern China: Northeast and North China.

In terms of survey methodology, we employed a stratified random sampling approach to choose household farms in two provinces (including Heilongjiang and Jilin) in Northeast and two provinces (including Shandong and Henan) in North China in 2013 and traced these selected samples in 2015. Two rice-dominated counties and two maize-dominated counties were randomly selected from each province in Northeast China, while three counties, mainly producing wheat and maize, were randomly chosen from each province in North China. We then randomly chose two towns in every selected county and two villages in every sample township. In total, ten household farms were selected as follow: we divided all household farms in each village into two groups, small and large farms, and chose seven household farms from the small farm group and three household farms from the large farm group randomly. If the large farm households were less than three, then we added the number of small farm households to make up a total of ten household farms from every village.

We surveyed 560 households in 2013 in Northeast and North China, and got 506 tracked-samples and 57 new samples in 2015. Because farmers could grow more than one crop for each year and the production of different crop may need different inputs and production technology, we treat the production of each type of crop as separate observation. So we got 1,494 observations from sampled households. We eliminated 110 observations in total, due to incomplete data, outliers and other statistical problems. Following this procedure, the total number of observations is 1,384, and 728 in 2013, 656 in 2015 (Figure 1).

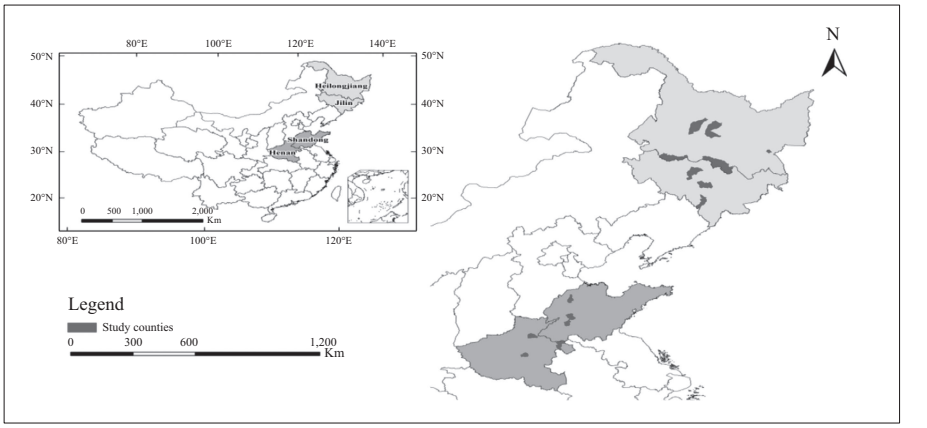


Figure 1.
Geographical distribution of sample farms in Northern China: 2013, 2015

To examine the impact of mechanization services on farm productivity, we define seven variables at the farm level. These variables include crop yield, benefit-cost ratio, LnTFP index, capital–labor ratio, the ratio of custom service over self-owned capital, a dummy variable used to identify household farms which do not own capital equipment but use custom services as capital inputs.

The crop yield is defined as total output of major grain crops (i.e. maize, wheat and rice) produced by each farm divided by the sowing area of the same grain crop each year. The benefit-cost ratio is defined as total value of the main grain crops (estimated by multiplying total output by the farm-gate price of the corresponding crop) divided by the total production costs which include land rent, labor costs, capital service costs (including both self-owned and custom services) and intermediate inputs such as fertilizers and chemicals. The farm-level TFP is defined as the residual that gross output minus the contributions of each input It is estimated by using the regression method based on the assumption of a Cobb–Douglas production function.

The capital–labor ratio is defined as real total costs related to the use of capital equipment (including the opportunity costs of using self-owned machinery and the costs of using custom services) divided by the total number of hours worked. The ratio of custom service over self-owned capital is then defined as the area of land cropped using the customized service divided by the area using the own machinery. To be noted, for those who own no capital equipment, there will be no value for this variable. We assume that, under this situation, the ratio of custom service over self-owned capital takes the value of zero. Finally, a dummy variable is used to identify household farms which do not own capital equipment but use custom services as inputs, and it takes 1 if the hypothesis is true and 0 otherwise.

Other variables used in the paper also include the intermediate input, the share of land adjoining, the share of land irrigated, the share of high-quality land, the share of farmers who aged over 65, the share of nonfarm labor, farmers' education, the share of male farming labor, family wealth and so on[1]. Table I provides the descriptive statistics for major variables.

Variable	Obs	NE&NC Mean	SD
Yield of wheat (t/ha)	405	7.3	1.0
Yield of maize (t/ha)	679	8.2	2.1
Yield of rice (t/ha)	300	7.5	1.6
The LnTFP index	1,384	−5.5	0.32
Benefit-cost ratio	1,384	1.2	0.2
Capital–labor ratio	1,384	2.7	3.6
The ratio of custom service over self-owned capital	1,384	1.7	2.9
Dummy for only using custom service (0 = No; 1 = Yes)	1,384	0.4	0.5
Intermediate input (yuan/ha)	1,384	291.8	90.2
The share of high-quality land (%)	1,384	28.4	41.1
The share of land irrigated (%)	1,384	84.8	35.5
The share of land adjoining (%)	1,384	11.2	26.6
The mean age of farming labor (%)	1,384	49.3	8.9
The maximum of farmer's education year	1,384	8.5	2.5
The share of nonfarm labor (%)	1,384	61.0	34.1
Family wealth (1,000 yuan)	1,384	202.9	270.3
Farmers only do manual work	15	–	–
Farmers only use self-owned capital	179	–	–
Farmers only use custom service	552	–	–
Farmers use self-owned capital and custom service	638	–	–
In 2013	728		
In 2015	656		

Note: The total number of observations is 1,384, and 728 in 2013, 656 in 2015
Source: Authors' estimation by using the CCAP farm survey data

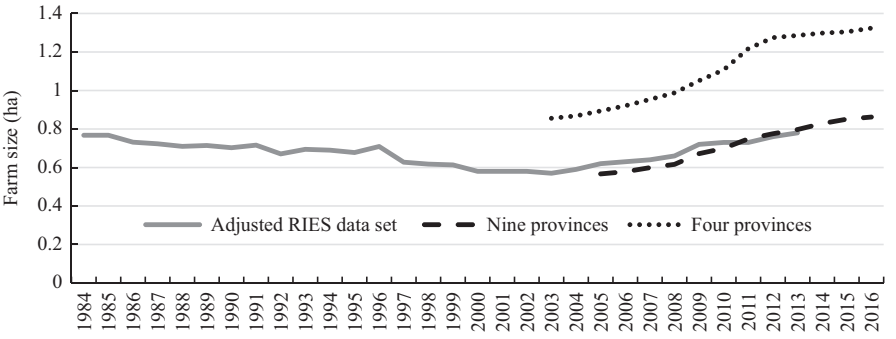
Table I.
A descriptive statistics on key variables

3. Farm size, institutional arrangement and custom services in China

Agricultural productivity in China was heavily influenced by institutional innovation and its induced technological adoption over the past four decades. For the decade immediately after the implementation of household responsibility (HRS) reform 1978–1984, farm productivity in China experienced rapid growth. Between 1978 and 1985, the annual farm TFP for rice, wheat and maize grew at the rate of 6.9 percent a year, 7.3 percent a year and 5.6 percent a year, respectively, which were around twice of that for the USA and four times of the world average TFP over the same period of time (Huang and Rozelle, 1996; Jin *et al.*, 2002; Jin and Deininger, 2009). Efficiency gain obtained from incentiveness change, when the HRS reform dismantled the people's communes and contracted cultivated land to individual households equally, accounted for around 30–50 percent of output rise (Fan, 1991; Lin, 1992; Huang and Rozelle, 2018) and around 90 percent of TFP growth (Jin *et al.*, 2002).

Although the HRS reform succeeded to promote farm productivity growth through stabilizing farmers' control of income from land contract rights (e.g. extending tenureship from 15 to 30 years), equitable distribution of land between farmers leads to the small-size farm issue (or the land fragmentation problem). Figure 2 shows that average farm size (in terms of land owned) declined from 0.73 hectare in 1984 to 0.57 hectare in 2004. Although ongoing land reforms, such as township land right transfers and "San-Quan-Fen-Zhi," facilitate land consolidation throughout the country since the mid-2000s (Huang and Ding, 2016), it is not until recent years that average land size of household farms does not reach its pre-reform level. Even for cropping farms in Northern China which experienced much quicker land consolidation than other places in recent years, majority grain farms still hold land areas less than 3 hectares (Figure 3).

It is widely believed that small household farms could make use of labor-intensive technology to achieve a high yield (or land productivity) (Sen, 1962, 1966). But, comparing to capital-intensive technology, labor-intensive technology has disadvantage in improving labor productivity (or income per capita), and nor does it good to improve farm TFP and profit (Fuglie and Rada, 2015). In particular when labor costs rise as off-farm wage and employment increase over time, continuing to use labor-intensive technology may incur additional costs for agricultural production and thus become a bottleneck for farm productivity and profit growth[2]. As such, how to increase farm-level mechanization level and to facilitate their switching from



Notes: RIES is a nationally representative survey with an average sample of about 60,000 rural households each year. Adjusted RIES data set are estimated farm size excluding households living in rural but either fully rent out or gave up their land or lost land due to land acquisition by Huang and Ding (2016). The average farm size of nine provinces and four provinces are authors' estimates based on data from CCAP survey. The nine provinces include Heilongjiang, Jilin, Shandong, Henan, Shanxi, Zhejiang, Sichuan, Hubei and Guangdong. These four provinces include Heilongjiang, Jilin, Shandong and Henan

Figure 2.
The average farm size in China, 1984–2016

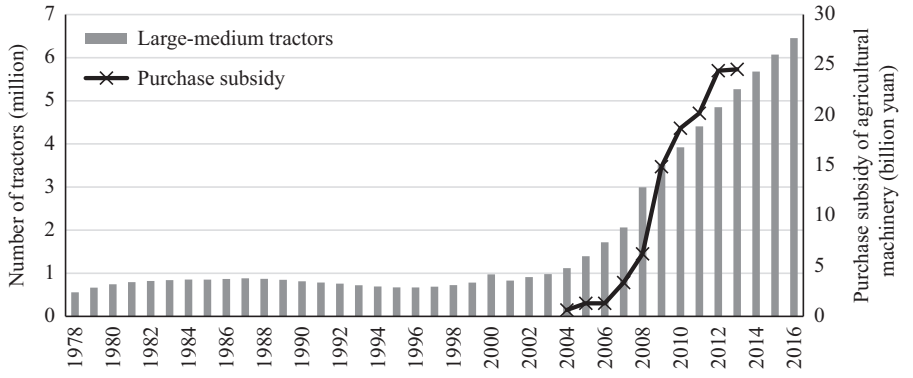
Source: Authors' estimates based on data from CCAP survey

Figure 3. The distribution of farm size in Northern China, 2003–2015

labor-intensive technology to capital-intensive technology becomes an essential question for policy makers to break through the bottleneck.

Theoretically, small-sized household farms are unlikely to make capital investment than their larger counterparts. On one hand, small household farms' willingness and ability to invest are restricted by their lesser financial capacity. On the other hand, there is a limited scope for small household farms to obtain gains from increasing returns to scale. Since making an investment in capital equipment will incur a large amount of sunk costs that small-sized household farms are unwilling and unable to afford, small-sized household farms could not maintain productivity growth through investing their own capital equipment to substitute labor as their large counterparts.

Figure 4 shows that the change of capital stock in the Chinese agricultural industry and its components over the past four decades, by using the number and total power of tractors at the industry level as indicators. Although total power of tractors has increased from 3.5 to 44.7 kilowatts between 1978 and 2016 (with an annual growth rate of 6 percent a year), the share of large- and medium-sized tractors in the total (or the structure of capital stock) does not increase relative to that of small-sized tractors until the early 2000s when land consolidation started between farms. Since large and medium size tractors are usually more



Sources: National Bureau of Statistics of China, China Agricultural Machinery Industry Yearbook (1986–2017)

Figure 4. The number of agricultural tractors and the purchase subsidy of agricultural machinery in China, 1978–2016

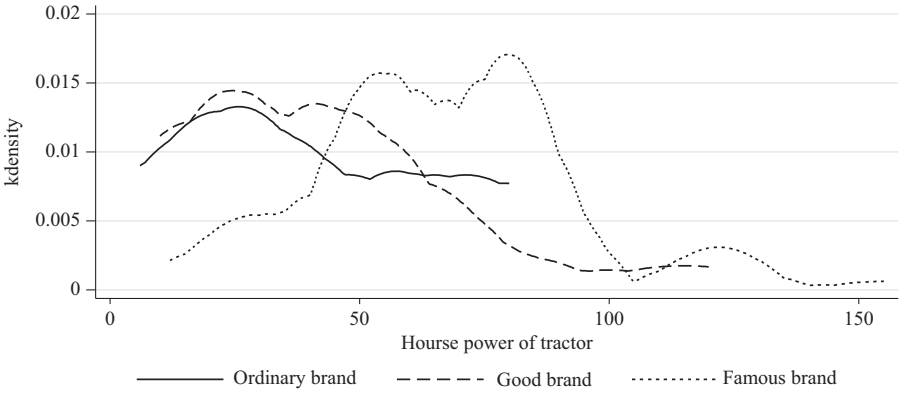


Figure 5.
The relationship between machinery power and capital service quality (brand), 2015

Source: Authors' estimation by using the CCAP farm survey data

efficient than small-sized tractors in agricultural production (as is shown in Figure 5), such a change in the structure of capital stock over time is generally consistent with the change of average household farm size, reflecting the possible negative impact of small farm size on capital investment and technology adoption.

Although facing the farm size constraint, small household farms in Northern China have significantly improved the capital-equipment level by using mechanization services as a substitute for self-owned capital. Due to statistics from the China MARA, there are total 263.7m household farms in 2016 among which 42.3m made investment in capital machinery accounting for only 12.0 percent[3]. However, more than 72 percent of arable land is ploughed and 53 percent harvested by using capital equipment, and some of them are even very large and efficient machinery. This is mainly because that there is a rapid development of agricultural mechanization service market, providing mechanization services to household farms with relatively lower costs to meet their need for employing capital equipment in production.

Figure 6 shows an increasing of mechanization service over the past three decades. Driven by increasing demand over time, the proportion of service providers that start customer service have increased significantly, in particular after 2000.

The proportion of villages that employ mechanization services have the similar developing trend. By 2015, except for some remote mountainous areas, 91 percent of villages in China could get access to mechanization services.

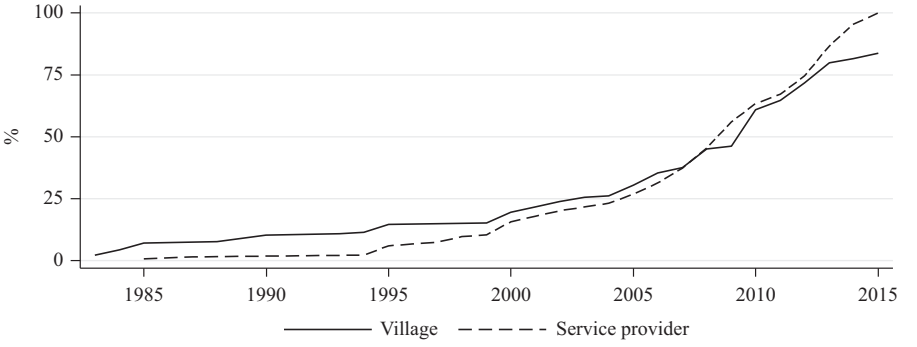
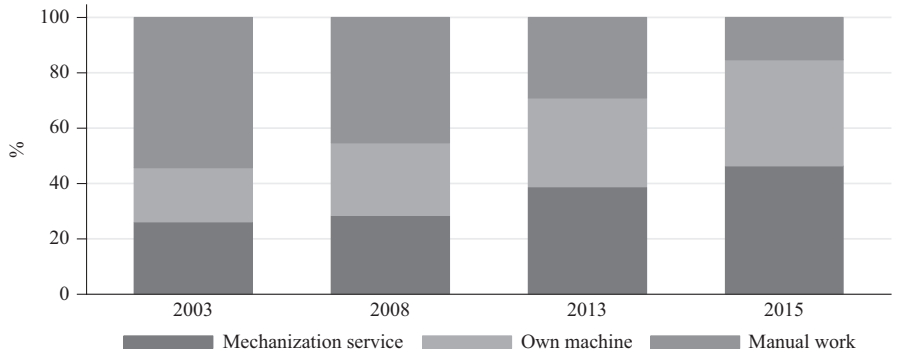


Figure 6.
The proportion of villages start to employ mechanization services and provider start to provide service in China, 1983–2015

Source: Authors' estimates based on data from CCAP survey

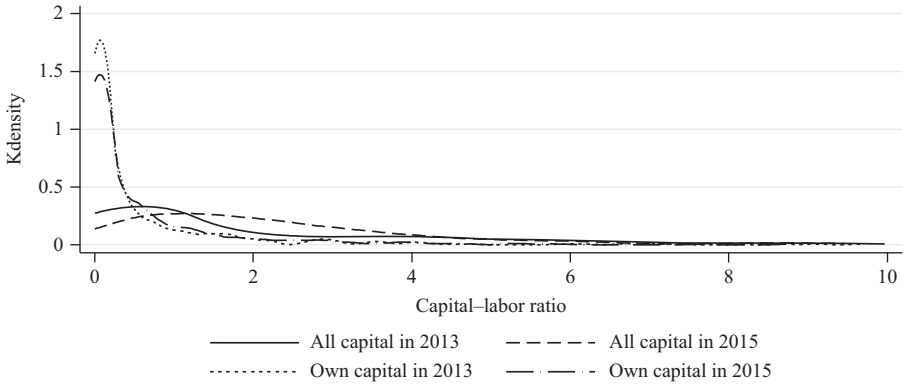
In addition to increased geographical coverage, the importance of mechanization services in farm production, in particular for grain production in Northern China, also increases over time. As is shown in Figure 7, the mechanization level for major crop production (including maize, wheat and rice) in Northeast and North China increased from 40 percent in 2003 to more than 80 percent in 2015, among which custom services accounted for more than half of this growth.

Figure 8 further compares the distribution of capital–labor ratios for household farms focusing on stable crop production in Northern China with and without considering mechanization services between 2013 and 2015. When we only consider farm self-owned capital equipment, the kernel density of estimated capital–labor ratio between farms does not change much. However, when we include capital services that farmers obtained from hiring mechanization services, the kernel density of estimated capital–labor ratio between farms shift to the right significantly. A Kolmogorov–Smirnov test (Hazewinkel, 2001) of equality of the two distributions between 2013 and 2015 is conducted. The test values for the case without considering custom services and the case with considering custom services are 728 and 656, respectively, which fail to reject at 10 percent level and reject at 1 percent level. This suggests that mechanization services nowadays have become one of the most important ways that household farms use to increase their capital-equipment levels.



Source: Authors' estimates based on data from CCAP survey

Figure 7.
The mechanization level of major crops in Northern China, 2003–2015



Source: Authors' estimates based on data from CCAP survey

Figure 8.
Changes in the distribution of capital–labor ratios for staple crop production in Northern China, 2013 and 2015

4. Model specification and data collection

Although mechanization services helped to improve the capital–labor ratio of household farms in China, little is known about whether they have positively contributed to farm productivity and profit performance. To answer this question, we propose a simple empirical model specification to examine the linkage between capital equipment, mechanization service and farm productivity/profit.

Specifically, we assume that farm productivity performance is a linear (log-linear) function of its capital–labor ratio and source of capital service in use such that:

$$y_{ijt} = \alpha_0 + \alpha_1 KL_{ijt} + \alpha_2 CSRto_{ijt} + \alpha_3 Dummy_CS_{ijt} + \delta X_{ijt} + u_j + T_t + \varepsilon_{ijt}, \quad (1)$$

where y_{ijt} denotes household farms' productivity measure which include crop yield, LnTFP index and benefit-cost ratio; KL_{ijt} refers to capital–labor ratio at the farm level; $CSRto_{ijt}$ refers to the ratio of custom services over self-owned machinery; $Dummy_CS_{ijt}$ denotes the dummy for those farms only using custom services. X_{ijt} is a vector which includes all other controlled variables such as logarithm of total intermediate inputs per hectare, soil quality (percentage of high-quality land), percentage of land irrigated, percentage of plots adjoining, farmers' average age and education, percentage of nonfarm employment, family's wealth. In addition, we also include dummy variables to control the village fixed effects (u_j) and time-specific effects (T_t).

Based on Equation (1), three hypotheses tests are established. First, a positive (negative) coefficient in front of KL_{ijt} suggests that increasing capital investment to substitute labor tends to improve (decrease) household farms' productivity performance. Second, a positive (negative) coefficient in front of $CSRto_{ijt}$ suggests that custom services are more superior (inferior) than self-owned capital equipment in providing capital services, when the capital–labor ratio is well controlled. Third, a positive (negative) coefficient in front of $Dummy_CS_{ijt}$ suggests that using custom services will increase (decrease) the productivity performance of farms owning no capital equipment.

We can estimate Equation (1) by using the general least square (GLS) method with the control of the village fixed effects to all samples, as well as the sub-samples regrouped by three different commodities, namely rice, wheat and maize. For each exercise, we choose different productivity performance indicators as dependent variables for the regression so that we can distinguish between different effects of custom services on different productivity indicators. The estimation results obtained from different scenarios will provide robustness check for each other. Finally, we also account for the county-level cluster effects in all regressions to reduce the heterochasticity between household farms clustered in the same county.

Figure 9 provides the apparent relationship between capital–labor ratio and three farm productivity performance indicators, measured respectively by using yield, TFP and cost-benefit ratio.

Overall, grain farms' productivity in Northern China is generally increasing with capital–labor ratio. This result is stable even when we split our sample by enterprises, by data sets for different regions and by time or using different productivity performance indicators (i.e. crop yield, the LnTFP index and benefit-cost ratio), which indicates that switching from labor-intensive technology to capital-intensive technology will help to improve household farms' productivity. Moreover, since custom services are important sources for household farms to get access to capital services, it is in no doubt that there is a positive relationship between custom services and household farms' productivity performance. Although the scattered relationship is informative, we still need to use more thorough regression analysis to examine the relationship between custom services and household farms' productivity performance.

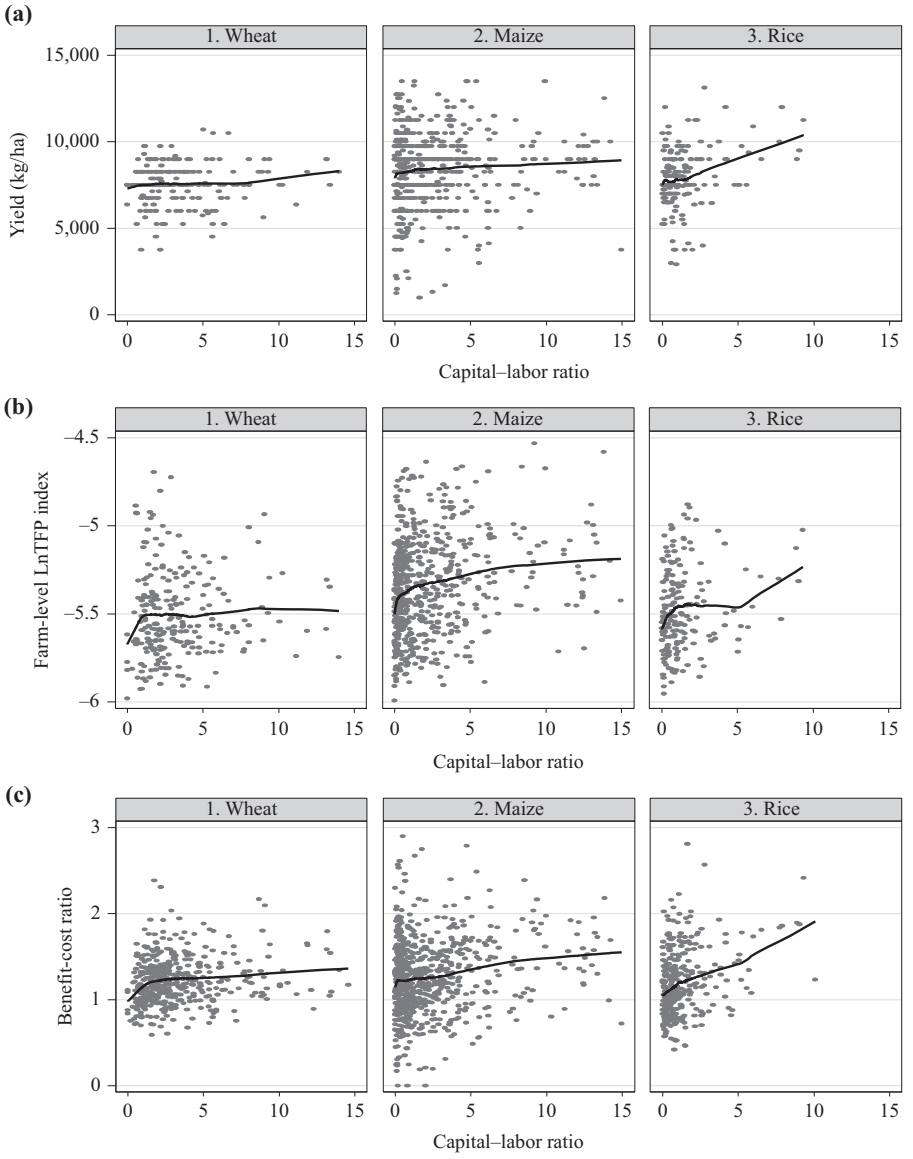


Figure 9.
The relationship between yield and capital–labor ratio in Northeast and North China: 2013, 2015

Notes: (a) Crop yield vs capital–labor ratio; (b) the LnTFP index vs capital–labor ratio; (c) benefit-cost ratio vs capital–labor ratio

5. Empirical results: impact of custom services on household farms productivity

Using the farm-level panel data for North and Northest China in 2013 and 2015, we examine the relationship between three farm productivity performance indicators (including crop yield, the LnTFP index and benefit-cost ratio) and mechanization services, with the control of intermediate inputs, other farm characteristics and farming practice. The estimation

results obtained from using the aggregate dataset and the data sets by commodities are presented in Tables II and III.

5.1 Household farms' productivity, capital–labor ratio and custom services

Table II provides the estimated relationship between farms productivity performance indicators (including crop yield, the LnTFP index and benefit-cost ratio) and their capital–labor ratio, the mechanization service to self-owned capital ratio and the dummy for farms only using mechanization services.

With the control of intermediate inputs, farm characteristics and other farming practices (as well as the village fixed effects and the time-specific effect), we show that the estimated coefficients in front of capital–labor ratio in the regressions of crop yield, farm LnTFP index and the benefit-cost ratio are all positive and significant for the farm TFP and the benefit-cost ratio regressions at the 10 and 1 percent levels, respectively. This implies that using more capital equipment to substitute labor tends to increase household farm productivity and profitability, although this may not significantly increase crop yield. A possible explanation on the insignificant relationship between crop yield and capital–labor ratio is that labor-intensive technology has the same efficiency as capital-intensive technology for household farms to improve crop yield, but capital-intensive technology could save more other inputs and thus improve farm TFP performance and profitability in total.

Moreover, for those household farms that use both self-owned capital equipment and mechanization services, farm TFP and profit performance are independent of the choice between these two ways to improve their capital–labor ratio. As is shown in Table II, the estimated coefficients in front of mechanization services to self-owned capital ratio, $CSRto_{ijt}$, are insignificant at 10 percent level throughout all three regressions when we control farm capital–labor ratio. This implies that: there is no difference in productivity performance for household farms to choose between making investment in self-own capital equipment and using the mechanization services hired from the market, when they have the same level of capital-equipment per capita. In other words, mechanization services are prefect substitutes for self-own capital equipment and provide no additional benefits to household farms than

	Crop yield	LnTFP index	Benefit-cost ratio
Capital–labor ratio	0.002 (0.002)	0.004* (0.002)	0.007*** (0.003)
CSRto	0.002 (0.003)	−0.004 (0.003)	−0.001 (0.005)
Dummy_CS	−0.036 (0.024)	−0.059*** (0.019)	−0.072** (0.036)
Intermediate input	−0.041* (0.024)	−0.268*** (0.032)	−0.494*** (0.047)
The share of high-quality land	0.0004** (0.0002)	0.0001 (0.0002)	0.0004 (0.0002)
The share of land irrigated	0.002** (0.001)	−0.0002 (0.001)	0.001 (0.0001)
The share of land adjoining	0.00003 (0.0002)	0.001** (0.0002)	0.0001 (0.0003)
The mean age of farming labor	0.001 (0.001)	−0.001 (0.001)	0.001 (0.001)
Farmers' education	0.002 (0.003)	0.003 (0.003)	0.008* (0.005)
The share of nonfarm labor	0.0003 (0.0003)	0.0002 (0.0003)	0.001 (0.001)
Family wealth	0.004 (0.008)	0.009 (0.009)	0.001 (0.011)
Dummy for year 2015	0.107*** (0.027)	0.087*** (0.031)	0.028 (0.035)
Dummy for wheat	−0.037 (0.030)	−0.118*** (0.017)	0.080 (0.031)
Dummy for rice	−0.203** (0.078)	−0.109 (0.084)	0.066 (0.087)
Dummy for village	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes
Constant	0.002 (0.002)	0.004* (0.002)	0.005*** (0.002)
Number of observations	1,369	1,369	1,369

Notes: Standard errors in parentheses. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively

Table II.
Estimated relationship between capital–labor ratio, custom service and farm-level productivity

	LnTFP index			Benefit-cost ratio		
	Wheat	Maize	Rice	Wheat	Maize	Rice
Capital–labor ratio	0.009*** (0.003)	0.003 (0.000)	0.013 (0.011)	0.015*** (0.002)	0.005 (0.005)	0.035*** (0.013)
CSRto	−0.004 (0.005)	0.001 (0.003)	−0.000 (0.008)	0.00002 (0.006)	−0.002 (0.008)	−0.009 (0.014)
Dummy_CS	−0.059 (0.036)	−0.038 (0.027)	−0.111*** (0.020)	−0.041 (0.054)	−0.080* (0.050)	−0.104* (0.052)
Intermediate input	−0.177*** (0.045)	−0.240*** (0.042)	−0.307*** (0.048)	−0.351*** (0.062)	−0.545*** (0.058)	−0.500*** (0.106)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Dummy for village	Yes	Yes	Yes	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes	Yes	Yes	Yes
Dummy for year 2015	0.009*** (0.003)	0.003 (0.003)	0.013 (0.011)	0.181*** (0.046)	−0.123*** (0.057)	0.152*** (0.066)
Constant	−4.414*** (0.252)	−3.941*** (0.223)	−2.617*** (0.300)	2.865*** (0.308)	4.273*** (0.344)	5.082*** (0.476)
Number of observations	405	667	300	405	667	300

Notes: Standard errors in parentheses. "NE&NC" means use the data surveyed in NE&NC, "Wheat" means only use the data about wheat, "Maize" means only use the data about maize, "Rice" means only use the data about rice. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively

Table III.
Estimated relationship between capital–labor ratio, custom service, intermediate input and LnTFP index

increasing their capital–labor ratio. Such a finding is interesting as it is quite different from what we have observed in OECD countries, where mechanization services are more superior to self-owned machinery in quality, and thus generate additional productivity gains for farms using mechanization services by promoting their adoption of the embodied technology. It suggests that household farms gain little benefits from the channel of technological progress and technology diffusion by using mechanization services in China.

Finally, for majority of household farms that have no self-owned capital equipment, using mechanization services tends to result in a weakly worse productivity performance. As mentioned before, the positive and significant coefficient in front of capital–labor ratio suggests that the household farms that using mechanization services as the only source of capital equipment will improve their productivity and profitability through increasing capital–labor ratio. However, when combining the estimated coefficients in front of the dummy for farms using only mechanization services as the supply of capital equipment, $Dummy_CS_{ijt}$, and the estimated coefficients in front of $CSRto_{ijt}$, we show that the synthetic coefficients are negative and significant at 1 percent level (Table II). This implies: when compared to those also using self-owned capital equipment, household farms only using mechanization services could have a relatively lower productivity and profit performance. In other words, there is something wrong in practice with the mechanization service market that prevents household farms from directly using mechisation services to improve capital–labor ratio.

The above regression results are generally consistent with the finding for rice and maize farms when we split the sample by commodities (Table III)[4].

5.2 Household farms choices between self-own machinery and mechanization services

Section 4.1 specifies an important channel through which mechanization services may affect household farm productivity and profitability in Northern China: employing mechanization services enable household farms to increase their capital–labor ratio for capital-intensive technology. This makes perfect sense: When labor costs increase, household farms used to adopt labor-intensive technology are forced to adopt capital-intensive technology for efficiency and profit improvement. As mechanization services substitute for self-owned machinery, household farms can hire capital equipment to increase the capital–labor ratio when making investment in self-owned capital is not feasible. Moreover, since mechanization services could become a vehicle for embodied technology and save sunk costs for small household farms to adopt capital-intensive technology (from a theoretical perspective), we are expecting to see that they will grow more quickly than investment in self-own machinery to meet the increasing demand of household farms for capital services.

However, such a prediction is not consistent with the practice. In our sample of grain household farms in Northern China, both mechanization services and investment in self-owned capital have been increasing at the similar speed over time as farms switching from labor-intensive technology to capital-intensive technology (Table IV). In particular, when land consolation and machinery subsidy policies increase household farms' affordability to make their own capital investment, more investment in self-owned capital is used to substitute mechanization services. Such a phenomenon could be linked to our finding of the additional negative impact of using mechanization services by household farms owning no capital equipment on their productivity and profitability performance. This is a worrying issue as majority of household farms in China will rely on using mechanization services to meet their capital demand. In 2016, the total number of household farms in China was 263.4m, among which there are around 87.7 percent having no self-owned capital equipment (Table IV).

To further investigate the underlying driver of negative impact of mechanization services on farm productivity, we distinguish between two types of mechanization service

	Rural household (million)	Total number (million)	Professional (%)	The original 200,000–500,000 (%)	The original value over 500,000 (%)
1999	239.7	–	–	–	–
2000	237.7	–	–	–	–
2001	247.4	28.5	11.2	–	–
2002	254.2	29.4	11.2	–	–
2003	247.9	30.5	11.8	–	–
2004	248.4	32.0	11.3	–	–
2005	248.4	33.6	11.4	–	–
2006	252.5	34.7	11.1	–	–
2007	253.5	36.3	11.0	–	–
2008	253.9	38.3	11.0	0.9	0.09
2009	254.0	39.4	11.3	0.9	0.09
2010	254.2	40.6	11.9	1.0	0.1
2011	260.4	41.1	12.4	1.0	0.1
2012	259.8	41.9	12.4	1.0	0.1
2013	261.9	42.4	12.4	1.1	0.1
2014	262.2	42.9	12.2	1.17	0.2
2015	263.7	43.4	12.1	1.22	0.2
2016	263.7	42.3	12.0	1.25	0.2

Sources: National Statistical Bureau, China Agricultural Machinery Industry Yearbook (2002–2017); National Statistical Bureau, China Yearbook (2000–2017)

Table IV. The number of rural household with self-owned machinery in China, 2001-2015

providers (namely, service organizations and household providers) in different production stages between 2013 and 2015. Table V shows that: for the two most important production stages: ploughing and harvesting, household providers dominate professional organizations in providing mechanization services. In 2015, household providers provided mechanization services to serve 54.9 percent of total ploughing areas and 42.3 percent of total harvesting area throughout the country, which were around five and four times of those provided by professional organizations. Since household providers usually do not provide professional services (as they only own one or two pieces of machinery), it is not surprising that household farms with no self-own machinery may benefit less from hiring such custom services, which are with relatively low quality (Figure 10 and Table VI).

Number of provider (million)		Average service area(ha)		Estimated total service area (million ha)		The percentage of estimated service area to sowing area (%)	
		Plough	Harvest	Plough	Harvest	Plough	Harvest
Household providers							
2013	5.26	18.59	14.7	97.7	77.4	59.4	47.0
2014	5.24	16.45	11.8	86.1	61.6	52.0	37.2
2015	5.25	17.42	13.4	91.4	70.4	54.9	42.3
Professional organizations							
2013	0.17	93.95	114.7	15.8	19.3	9.6	11.7
2014	0.18	91.23	103.5	16.0	18.1	9.7	11.0
2015	0.18	104.05	118.0	19.0	21.5	11.4	12.9

Sources: Authors' estimates based on data from CCAP survey and National Statistical Bureau, China Yearbook (2000–2017)

Table V. The number of service providers and service area in China, 2013–2015

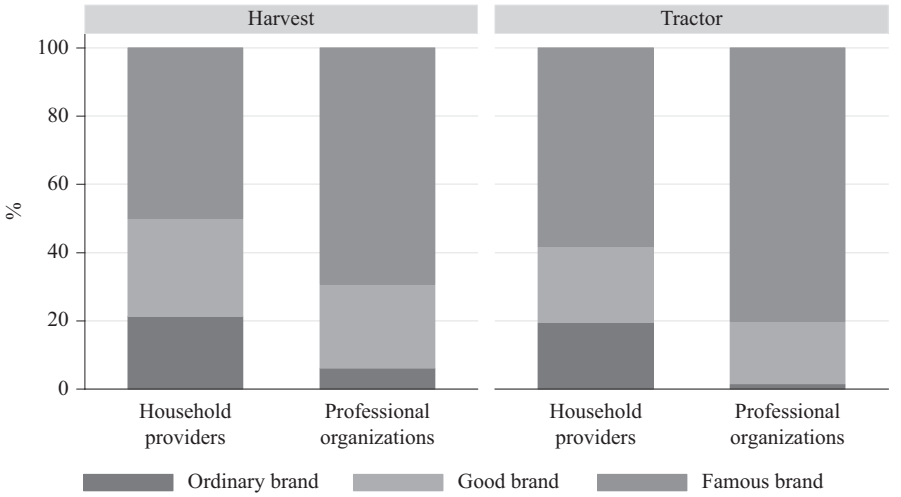


Figure 10.
Comparing quality of machinery owned by household providers and professional organizations, 2015

Sources: Authors' estimates based on data from CCAP

	Household providers			Professional organizations		
	2013	2014	2015	2013	2014	2015
Tractor	1.2	1.3	1.3	5.1	7.5	8.1
Rotary cultivator	0.8	1.1	1.3	3.3	3.8	4.4
Combine	0.8	0.8	0.9	1.6	2	2.5
Ridger	0.1	0.1	0.1	0.7	1.1	1.3
Subsoiler	0.04	0.04	0.03	0.2	0.2	0.3
No-tillage planter	0	0	0.02	0.4	0.5	0.8
Rice transplanter	0.3	0.3	0.3	1.8	2	2.2
Straw returning machine	0.3	0.3	0.3	0.7	0.9	1
Irrigation and drainage machine	0.02	0.02	0.1	0.2	0.2	0.2
Thresher	0.1	0.1	0.1	0.2	0.2	0.3
Dryer	0.02	0.02	0.02	0.1	0.2	0.4
Planter and sower	0.2	0.2	0.2	0.7	0.8	1.1
Spraying machine	0.1	0.1	0.2	0.5	0.8	1.1
Straw baling machine	0	0	0	0.1	0.1	0.2
Stubble cleaner	0.1	0.1	0.1	0.4	0.8	0.9
Agricultural vehicle	0.8	0.7	0.8	1.6	1.6	1.7
Other machines	0.1	0.2	0.2	0.4	0.5	0.8

Table VI.
The average number of machines of different service providers, 2013–2015

Sources: Authors' estimates based on data from CCAP

6. Concluding remarks

It is widely believed that mechanization services can help to improve small household farms' productivity and profitability, through facilitating technology adoption and saving sunk costs for capital investment. For decades, mechanization services have been widely adopted by small household farms in China, as a substitute for capital investment in self-owned equipment, for improving agricultural mechanization level. However, it is not known whether and how mechanization services affect household farm productivity and profitability in China.

This paper uses a two-wave farm survey data in 2013 and 2015 to examine the impact of mechanization services on farm productivity and profitability for grain production in Northern China. We show that mechanization services improve farm productivity and profitability mainly through increasing their capacity to use capital to substitute labor but may not necessarily improve crop yield.

Moreover, we show that household farms that use mechanization services as the only source of capital equipment may benefit less compared to those own their own machinery. This provides useful policy insights calling for additional institutional arrangements to promote the future development of custom service market to address bottlenecks.

Notes

1. A detailed definition of those variables are available in Appendix 1.
2. In addition, household farms could not get access to advanced technology embodied in and associated with the use of plant and machinery, when they are not being properly equipped.
3. Among those household farms who own capital machinery, there are only 0.61 and 0.08m household farms owning capital machinery with the original investment value (at the current price) more than 200 thousand and 500 thousand respectively, which account for 1.3 and 0.2 percent of total number of farms.
4. We also conduct a robustness check by using dummy variables to examine the relative difference in productivity between farms only using self-owned capital equipment, using both self-owned capital and hired machinery and using only mechanization services. The results are shown in Appendix 2, which show the similar results.

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Appendix 1. Definition of control variables

Variable	Describe
Yield	Total output (quantity) of major grain crops (i.e. maize, wheat and rice) divided by the sowing area of the same grain crop each year (kg/ha)
Benefit-cost ratio	Total value of the main grain crops (estimated by multiplying total output by its farm-gate price) divided by the total production cost which include land rent, labor costs, capital service costs (including both self-owned and custom services) and intermediate inputs such as fertilizers and chemicals
The LnTFP index	Use the regression method based on the assumption of household farms using a Cobb–Douglas production technology, and get the logarithm value of residual that gross output minus the contributions of each input
Capital–labor ratio (KL)	Real total costs related to use capital equipment (including the opportunity costs of using self-owned machinery and the costs of using custom services) divided by the total number of hours worked
The ratio of custom service over self-owned capital (CSRto)	Land cropping area used by custom services dividing by that used by self-owned machinery
Dummy for only using custom service (Dummy_CS)	Dummy variable is used to identify household farms which do not own capital equipment but use custom services as inputs (0 = No; 1 = YES)
Intermediate input	Intermediate input such as fertilizers and chemicals (yuan)
The share of high-quality land	The share of high-quality land (%)
The share of land irrigated	The share of land irrigated (%)
The share of land adjoining	The share of linkaged plots (%)
The mean age of farming labor	The share of who aged over 65 (%)
Farmers' education	The maximum of education year of the farming labor (num. per family)
The share of nonfarm labor	The share of nonfarm labor (%)
The share of male farming labor	Share of male farming labor (%)
Family wealth	The total present value of housing, electrical appliances and machinery of family (1,000 yuan)
Time	Dummy for year 2015 (0 = No; 1 = Yes)
Maize	Dummy for maize (0 = No; 1 = Yes)
Rice	Dummy for rice (0 = No; 1 = Yes)

Table AI. Variable name and description

Appendix 2. Retained sample and deleted sample

	Sample retained			Sample deleted			Difference	
	Obs	Mean	SD	Obs	Mean	SD	*t*-value	Probability
Yield of rice (t/ha)	1,384	7.8	1.8	110	8.6	3.1	0.05	0.9
The growth rate of farm-level LnTFP	1,384	−5.5	0.3	110	−5.3	0.4	−2.0	0.04
Benefit-cost ratio	1,384	0.6	0.2	110	0.8	0.3	−6.4	0.0
Capital–labor ratio	1,384	2.7	3.6	110	10.1	17.7	−11.4	0.0
The ratio of custom service over self-owned capital	1,384	1.7	2.9	110	1.9	3.7	−0.2	0.9
Intermediate input (yuan/ha)	1,384	292.1	90.5	110	266.5	113.1	2.6	0.0

Note: *t*-test made by choosing "sample deleted" as the reference

Table AII. Comparison of retained sample and deleted sample

Total sample	1,494
Incomplete data	35
Abnormal value of variable	40
Abnormal value of multivariate cross analysis	35
Retained sample	1,384

Table AIII. Sample deleted method

Appendix 3. Robust estimation with dummies for farmers' categories

	Yield	LnTFP index	Benefit-cost ratio
Capital–labor ratio	0.002 (0.002)	0.004* (0.002)	0.005*** (0.002)
Dummy for only have own machine	0.046 (0.081)	0.099* (0.055)	0.099** (0.042)
Dummy for only use custom service	−0.011 (0.071)	0.027 (0.063)	0.028 (0.042)
Dummy for have own machine and custom service	0.030 (0.074)	0.066 (0.061)	0.055 (0.041)
Intermediate input	−0.042* (0.024)	−0.268*** (0.032)	−0.216*** (0.019)
The share of high-quality land	0.001** (0.0002)	0.0002 (0.0002)	0.0002 (0.0001)
The share of land irrigated	0.002** (0.0009)	−0.0001 (0.001)	0.001* (0.0004)
The share of land adjoining	5.49E-05 (0.0003)	0.001** (0.0002)	0.0001 (0.0001)
The mean age of farming labor	0.001 (0.001)	−0.002* (0.001)	0.0004 (0.001)
Farmers' education	0.002 (0.003)	0.003 (0.003)	0.004* (0.002)
The share of nonfarm labor	0.0002 (0.0002)	0.0001 (0.0003)	0.0002 (0.0002)
Family wealth	0.004 (0.007)	0.008 (0.009)	−0.001 (0.004)
Dummy for year 2015	0.109*** (0.027)	0.088*** (0.031)	0.022 (0.017)
Dummy for wheat	−0.034 (0.030)	−0.120*** (0.017)	0.028* (0.016)
Dummy for rice	−0.209*** (0.077)	−0.122 (0.083)	0.012 (0.042)
Dummy for village	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes
Constant	9.110*** (0.162)	−3.746*** (0.211)	1.787*** (0.116)
Observation	1,384	1,384	1,384

Table AIV.
Estimation results for robustness check

Notes: Standard errors in parentheses. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively

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Targeted poverty reduction under new structure

A perspective from mental health of older adults in rural China

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Abstract

Purpose – The purpose of this paper is to investigate the impact of social capital on the mental health of older adults in rural China. The authors also examine potential heterogeneous effects and two possible pathways from social capital increase to mental health improvement.

Design/methodology/approach – Based on a panel data of China Health and Retirement Longitudinal Study, this paper employs a fixed effect model to examine the impact of social capital on health. A two-stage instrumental variable approach is adopted to alleviate the issue of endogeneity.

Findings – Results demonstrate that social capital has improved the mental health of older adults in rural China significantly. The beneficial effect is stronger for female, people with lower income, aged people and mainly observed in the central and western regions. Social capital affects the mental health of rural older adults through raising the awareness of healthy behavior and lowering the searching cost of health-related information.

Practical implications – Social capital plays a vital role in improving the mental health of older adults in rural China and is necessary for the construction of beautiful countryside in China. The authority should increase the investment in both the hard and soft infrastructure to improve the mental health of rural residents and narrow the inequality in health status.

Originality/value – This study enriches the empirical literature on the relationship between social capital and mental health by providing new evidence from China. Also, we choose the social activities and communications of individuals to construct a standardized index for social capital, which can better capture the social capital at the individual level.

Keywords Mental health, Social capital, Rural China, Older adults, New structural economics

Paper type Research paper

1. Introduction

Since the reform and opening-up, the regional structure of factor endowments, particularly in labor resources, has changed dramatically in China as the rapid development of urbanization and continuous upgrading of industrial structural. Manufacturing and service sectors absorbed massive labor forces from the agricultural sector, especially young adults in the rural area, which makes the phenomenon of migrant workers become prevalent and older adults become the primary labor supply in rural areas (Figure 1). This trend lowers the opportunity for older adults to be attended and results in "empty nester" phenomenon in many rural areas.

Up to the end of 2017, there are 0.24bn people aged 60 and above in China, accounting for 17.3 percent of the total population. Old people are at a higher risk of having mental illnesses such as dementia and depression due to their deteriorating physiological functions.

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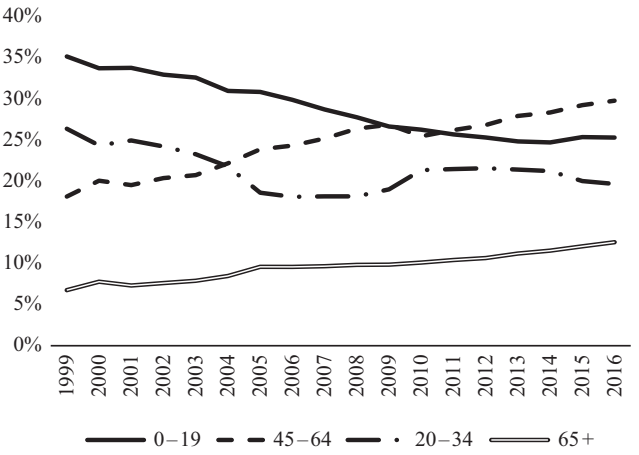

Figure 1.
Rural population by age groups

The World Health Organization reports that older adults with mental health problems, such as loneliness, self-doubt and depression, tend to have symptoms of incapacitation (Lei *et al.*, 2014). Meanwhile, mental illness is the leading cause of suicide (Zhang *et al.*, 2010), and nearly half of suicides in China have serious issues of mental health. The rural older adults' suicide caused by mental issues, like Geriatric depression, is continuously striking the public perceptions of ageing society. The mental health of this population needs to be concerned due to its direct association with the development and stabilization of rural society. The targeted poverty reduction under the new structure should not only focus on material poverty but also spiritual impoverishment.

China's medical sector is still underdeveloped, and the social security system is not comprehensive yet, manifested by a considerable shortage of medical services in mental health. The enormous aged population is expected to bring huge burden to the medical and social security systems. Before the urban–rural dual structure being completely eliminated, the older adults are not only the primary labor supply of rural areas but also solid support and an important family foundation for the migrant workers in urban areas. Problems regarding rural older adults' health have to be appropriately addressed to guarantee the maximization of benefits under the current structure of factor endowments in China. However, the negative externalities, caused by industrial upgrading, on the agricultural sector cannot be addressed spontaneously and adequately by the market, which calls for a facilitating government to coordinate and assist (Lin, 2011).

Research on developed economies shows that sufficient social capital plays a vital role in enhancing the living quality and maintaining psychological soundness for older adults (Hamano *et al.*, 2010; Johnson *et al.*, 2017; Fiorillo and Sabatini, 2015). As proposed by Putnam (2000), no field linked to social capital such closely as health. From this perspective, social capital could be a complement to existing medical and social security systems in improving residents' mental health. On the other hand, social capital, as an important component of soft infrastructure, should be fully considered by the authority in promoting regional economic growth (Lin, 2012). However, there is little literature on the relationship between social capital and older adults' mental health in rural areas. Also, developing countries are quite different from developed countries regarding social institutions, economic development status and other aspects. Thus, it awaits further empirical investigation on whether the relationship between social capital and mental health still holds in developing countries.

Therefore, this study explores the impact of social capital on the mental health of older adults in rural China, the largest developing country, by using the China Health and Retirement Longitudinal Study (CHARLS) data. This work adds to the literature in the following ways. First, this study enriches the empirical literature on the relationship between social capital and the mental health of rural older adults by providing new evidence from China. A non-balanced panel data is constructed based on a large micro-level tracking survey data, which can alleviate the heterogeneity issue generally seen in cross-section data which are widely used in existing literature. Second, we choose the social activities and communications of individuals to construct a standardized index for social capital, which can better capture the social capital at the individual level. Third, we further examined whether the social capital has different impacts on residents' mental health according to their gender, income levels, age and regions, which reflects a more comprehensive relationship between social capital and mental health. During the transition of realizing healthy aged-care, it is essential to make the utmost of social capital this kind of informal institution as additional measures in a traditional and *guanxi*-dominant society of China. This paper could further address the problem on the providing for the aged in rural China.

The rest of the paper is organized as follows. Section 2 is a literature review for this field. Section 3 introduces the data used, variables specified, and the empirical design. Empirical results are presented in Section 4, while Section 5 concludes the paper and provides some discussions.

2. Literature review

Most of the literature on residents' health is based on the theory of the demand for health (Grossman, 1972) to explore the determinants of health from dimensions like age, gender, marriage status, income level and social support, etc. (Zhao, 2006; Cutler and Lleras-Muney, 2010; Rocco *et al.*, 2014; Lei *et al.*, 2014; Qin *et al.*, 2018). However, it is rarely seen in the literature whether social capital affects residents' mental health. Existing literature on social capital and mental health problem can be summarized as three kinds of views.

The first kind of view is that social capital could improve mental health status. Hamano *et al.* (2010) investigated the relationship between social trust in the neighborhood and mental health, after considering potential individual confounders, by using a multilevel method. He found that cognitive and structural social capital may influence the mental health of Japanese. Forsman *et al.* (2012) shed light on the positive relationship between structural and cognitive social capital and depression in later life. Nielsen *et al.* (2015) focused on adolescents and found that social trust could alleviate mental health problems. Landstedt *et al.* (2016) believe that involvement in social networks promotes mental health and may have different meanings and consequences across gender. Hollard and Sene (2016) found a positive promoting effect of social capital on mental health. Johnson *et al.* (2017) investigated the migration data of Sweden and found that social capital explained mental health inequalities between immigrants. They also highlighted that social capital could effectively mediate psychological distresses of immigrant groups. Kazemi *et al.* (2017) proposed that the improvement in social engagement and public trust could significantly promote the state of mental health in families with disabled members.

The second kind of view believes that social capital has adverse effects on mental health. Yu *et al.* (2008) suggest that the collective-level interaction between members of society amplifies some members' psychological burden and therefore leads to a decrease in the level of mental health. Mitchell and Lagory (2010) found that while bridging social capital displays a small inverse relationship with distress, bonding social capital appears to increase an individual's level of mental distress in an impoverished community. Bae (2015)

pointed out that the social capital obtained from non-spouse family members does not positively, even might negatively, influence health status.

The third kind of view suggests that social capital is not correlated with mental health. Ziersch *et al.* (2005) found that trust and reciprocity do not necessarily affect health. Veenstra *et al.* (2005) show that the participation of government and non-government organizations does not affect subjective senses of health and depression at all. Wang *et al.* (2013) argued that current evidence is not sufficient to conclude that structural social capital could improve the mental health of older adults. Xue and Liu (2012) used the older adults' sample of China Family Panel Studies data in 2012 to investigate the impact of social capital on health and found that the organizational involvement has no significant impact on older adults' health.

These studies provide valuable references for this paper, while there are still some problems wait to be resolved. Existing literature generally has relatively limited sample coverage, and empirical studies based on panel data are rarely seen. Few scholars dealt with the problem of endogeneity in the variable of social capital appropriately, which might lead to biases in the estimation. Therefore, this study adopts a panel data from the CHARLS in the year 2011, 2013 and 2015 to evaluate the impact of social capital on the mental health of rural residents. The mental health status is measured by the Centre for Epidemiological Studies Depression (CES-D) Scale. Various regression techniques are employed to alleviate the potential problem of endogeneity and individual heterogeneity. We also analyze sub-samples to explore whether the social capital affects health conditions of different groups differently.

3. Empirical design

3.1 Data issues

The data in this study are drawn from CHARLS database which is collected by the National School of Development of Peking University through conducting a nationwide field survey every two years since 2011. This survey covers 150 counties, 450 villages and about 17,000 people in 10,000 families. This paper constructed a non-balanced panel data by using the tracking survey data in the year 2011, 2013 and 2015, which has 4,642, 4,645 and 3,378 observations, respectively.

3.2 Variable specifications

3.2.1 Dependent variable: mental health. We use the simplified version of the CES-D Scale (Radloff, 1977) to measure whether the respondent is positive and optimistic, or anxious and depressed. This scale is widely applied in studies on mental health (Zimmerman and Katon, 2005; Lei *et al.*, 2014; Qin *et al.*, 2018). Lei *et al.* (2014) verified the credibility and validity of the simplified CES-D Scale by using CHARLS data and proved that the scale is applicable to studies on Chinese population. The simplified CES-D Scale requires the respondent to choose from following four option to tell how often they have felt or behaved this way during the past week[1]: rarely or none of the time (less than 1 day); some or a little of the time (1–2 days); occasionally or a moderate amount of time (3–4 days); and most or all of the time (5–7 days). The four options correspond to 1, 2, 3 and 4 scores, respectively, while the fifth and eighth questions have the inverse order, namely, 4, 3, 2 and 1 score, respectively. The CES-D Scale is just the summation of these scores which ranges from 10–40 scores, with the higher scores indicating more depression symptoms and worse mental health status. People with 20 scores or above is generally believed to have a poor mental health and a tendency to be depressed (Andresen *et al.*, 1994). Thus, a negative coefficient would indicate an improvement in mental health, which has to be noticed when analyzing the results.

3.2.2 Key variable: social capital. Social capital includes cognitive social capital and structural social capital. The cognitive social capital is not involved in the CHARLS questionnaire, this study therefore only considers individual structural social capital. Considering rural China is an acquaintance society, and social trust is relatively high, social communication and engagement are good choices to represent individual social capital for rural older adults.

The social capital variable is mainly based on the question "Did you participate in the following social activities in the past one month?" Stock trading and online surfing are excluded from the ten social activities since these two are not highly correlated with social engagement and therefore cannot reflect social capital properly. The remaining eight social activities such as interacted with friends, played Ma-jong, played chess, played cards, went to community club or took part in a community-related organization are considered in this study. Dummy variables are created for these activities, which take value one if participated in the activity, otherwise, take value zero. We add up these dummy variables and then standardize them to represent residents' social capital (Ronconi *et al.*, 2012), with a higher value indicating more social capital.

3.2.3 Control variables. Many factors could affect health status, and most scholars believe that factors like age, gender, marriage status, income level and social security system would influence rural residents' health (Grossman, 1972; Cutler and Lleras-Muney, 2010; Rocco *et al.*, 2014). We also include these factors as control variables to reduce potential biases. Control variables could be divided into three categories. The first category is the individual characteristics, namely, age, gender, marriage status, education attainment and whether retired. The second category is the social and economic factors. This study mainly controlled the dummy variable for medical insurance, average family income, family size, family medical expenses in the last year and family expenses on health maintenance in the last year. In addition, it has been proved that lifestyle has a significant impact on health (Cockerham, 2009; House, 2002). This study incorporated three lifestyle indicators, namely, smoke or not, drink or not and sound sleep or not. Sound sleep is considerably important to mental health. Table I shows the definition and some descriptive statistics of main variables used in our analysis.

Variables	Specifications	Mean	SD
Health	CES-D score	18.618	5.360
SC	Social capital	0.784	0.923
Gender	Male = 1, female = 0	0.492	0.500
Age	Age	60.924	9.891
Marriage	Married = 1, otherwise = 0	0.776	0.417
Education	Illiteracy = 0, primary school graduated or partially = 1, junior high school graduated = 2, senior high school graduated = 3	0.563	0.812
Retire	Retired = 1, not retired = 0	0.021	0.143
Insurance	Has medical insurance = 1, has no medical insurance = 0	0.936	0.245
lnwage	Average family income (10,000)	1.720	37.927
Size	Family size	3.946	2.121
Hospital	Family medical expenses in the last year	0.231	0.818
Protect	Family expenses on health maintenance in the last year	0.019	0.115
Smoking	Smoking = 1, not smoking = 0	0.300	0.458
Drink	Drink = 1, no drink = 0	0.346	0.476
Sleep	Take value 1 if sleeping time is 6–9 h, otherwise 0	0.616	0.486

Table I.
Variable specifications and descriptive statistics

3.3 Empirical model

To investigate the relationship between social capital and health status, we construct an empirical model as follows:

$$\text{Health}_{it} = \alpha_i + \beta_1 \text{SC}_{it} + Z_{it}\theta + \mu_{it}, \quad (1)$$

where Health_{it} is the mental health status of the ith observation in year t. Similarly, SC_{it} is the social capital possessed by the ith observation in year t. Z_{it} represents a group of control variables and μ_{it} is the stochastic error term. The coefficient β_1 is the interest of this paper and indicates the impact of social capital on mental health. The Hausman test is applied to determine which model is more appropriate, namely, the fixed effects model or the random effects model. The pooled regression model is reported as well to make a comparison.

The potential endogeneity of social capital could be attributed to two reasons. First, omitted variable bias. Unobservable characteristics of individual or community affect the social capital and mental health simultaneously. Second, reverse causality. The mental health might reversely affect older adults' participation in social activities, and therefore determine the level of social capital. We introduce the instrumental variable (IV) method to eliminate the problem of endogeneity and identify the pure effect of social capital on health. The IV employed in this study is the mean of other community members' social capital. We argue that the mean value can reflect the activeness of other community members in participating in social activities, which is highly correlated with individual social capital. Meanwhile, the activeness of other community members does not correlate with individual health status. Therefore, this measurement satisfied the essential feature of IV.

The p-value of the DWH test is smaller than 0.05, showing that the model has the problem of endogeneity and IV method is applicable. The F-value in the first stage regression is 727.55, which is way higher than the critical value 10, indicating the high correlation between the IV and the endogenous independent variable. The Cragg-Donald Wald F statistic is 727.548, which also suggests that there is no problem of weak instruments (Stock and Yogo, 2005).

4. Empirical results and discussion

4.1 Impact of social capital on health: full sample

In columns 1 to 3 of Table II, estimations from the pooled regression, the fixed effect panel regression and the IV regression are reported. The Hausman test indicates the fixed effect model is preferred.

Results show that the coefficient of social capital is relatively small and only significant at 10 percent level, but the coefficient increases from −0.142 to −1.213 and is significant at 1 percent level once the endogeneity was controlled. Therefore, if the problem of endogeneity was not carefully dealt with, the impact of social capital on health conditions will be highly underestimated. The self-selection behavior of rural older adults possibly could explain this result. Rural residents with poorer health conditions are more likely to improve their mental health condition via social activities, which leads to underestimation.

From control variables, we can see that the health status of the male is generally better than that of the female. Educational attainment is not significant in improving older adults' mental health, which might be due to the overall low level of educational attainment in rural areas. Married older adults have better mental health status than those are not married. Income level also positively influence mental health status. Medical insurance plays a significant role in improving mental health. Family size positively contributes to better mental health status. A higher medical expense in the last year is associated with worse mental health status. Regarding lifestyle, sound sleep is positively correlated with better mental health status, while smoking is detrimental to mental health.

Variables	(1) Pooled	(2) Fixed effect	(3) IV
Social capital	−0.403*** (0.047)	−0.142* (0.081)	−1.213*** (0.206)
Gender	−0.958*** (0.128)	−2.943 (2.107)	−1.037*** (0.131)
Age	−0.006 (0.006)	−0.156*** (0.038)	−0.017*** (0.006)
Education	0.011 (0.060)	−0.017 (0.098)	0.039 (0.061)
Marriage	−0.823*** (0.130)	−0.226 (0.445)	−0.820*** (0.131)
Retire	−0.399 (0.320)	−0.471 (0.494)	−0.227 (0.327)
Insurance	−0.536*** (0.186)	−0.276 (0.291)	−0.472** (0.189)
lnwage	−0.216*** (0.025)	−0.056 (0.043)	−0.197*** (0.026)
Size	−0.225*** (0.022)	−0.332*** (0.036)	−0.233*** (0.023)
Hospital	0.100* (0.056)	−0.030 (0.085)	0.111** (0.057)
Protect	0.362 (0.394)	0.515 (0.602)	0.428 (0.400)
Smoke	0.268** (0.127)	−0.060 (0.370)	0.323** (0.129)
Drink	−0.236** (0.110)	0.218 (0.223)	−0.138 (0.114)
Sleep	−1.913*** (0.096)	−0.782*** (0.162)	−1.879*** (0.098)
Constant	22.191*** (0.456)	31.650*** (2.706)	22.788*** (0.483)
Observations	12,569	12,569	12,569

Notes: Figures in parentheses are standard errors. *,**,***Significant at 10, 5 and 1 percent levels, respectively

Table II. Baseline regression results

4.2 Heterogeneous effects of social capital on mental health

4.2.1 Income level differences. There has been a debate on whether social capital is a kind of capital for the poor. This study further investigates whether the impacts of social capital on health are significantly different across different income levels by dividing the sample equally into three groups, namely, the low-income group, the middle-income group and the high-income group. From Table III it can be seen that the coefficient of social capital decreases as the increase of income level and is significant in all three cases. This reflects that social capital benefits the low-income group much more than the high-income group regarding mental health. This observation supports the argument that social capital is a kind of capital for the poor. The possible reasons are as follows. First, the lower income group has a higher rate of return on social capital. The high-income group generally has more social capital than the low-income group, and therefore the marginal return on social capital tends to be lower. Second, for the high-income group, the impact of income on mental health possesses a dominant position, while for lower income group, the lack of income and factors such as poor social security system and insufficient medical resources also constrained the influence of income on mental health. Therefore, the social capital stands out in improving mental health for the poor. Third, the time cost of the low-income group is lower than the high-income group. The low-income group has more time to spend on casual and exercise activities but less physical capital in comparison to the high-income group. Therefore, social capital plays a much more critical role in improving the mental health for the low-income group who are more likely to rely on social capital.

Variables	(1) Low income	(2) Middle income	(3) High income
SC	−1.653*** (0.378)	−1.456*** (0.388)	−0.755** (0.301)
Other control variables	Yes	Yes	Yes
Observations	4,366	4,019	4,184

Note: **,***Significant at 5 and 1 percent levels, respectively

Table III. Regression results by income levels

4.2.2 Gender differences. Existing literature demonstrates that mental health has significant gender differences (Weissman *et al.*, 1993; Qin *et al.*, 2018). Thus, we divide the sample by gender to examine whether the impact of social capital is different across gender. Columns 1 and 2 in Table IV show that the impact of social capital on females is stronger than that of males regarding mental health. Potential reasons are, first, different marginal effects across gender. As the average social capital index of females is much lower than that of males, the marginal effect for females' health is greater as the increase of social capital. Second, females in China's rural area undertake more housework and therefore have less opportunity to participate in social activities. Then, the beneficial effects of social capital on mental health for females are much more prominent at each level in comparison to the counterpart. Third, females generally underestimate their mental health status as they may consider more factors than males when answering questions due to different perceptions on indicators for health status.

4.2.3 Regional differences. There is considerable regional heterogeneity across regions in China, this study, therefore, explores whether the impact of social capital is different across regions. From Table IV, the impact of social capital for residents in central and eastern areas is quite significant, at 1 percent level, while for the eastern area it is not significant. This finding indicates that social capital plays a relatively limited role in more developed areas but a significant role in the less developed area.

4.2.4 Age differences. We further divide our sample into two age groups by setting the dividing line as 65 and 60 years old, respectively. We aim to identify whether the impact of social capital is higher for aged people. Results in Table V show that, even though the coefficients of separate regressions are not directly comparable, the impact of social capital on the aged group is generally higher. The potential reason is that the aged group has fewer opportunities to participate in social activities, then the marginal effect of social capital tends to be higher than the younger group.

4.3 Robustness tests

To ensure the reliability of our estimations, we conduct the following robustness tests.

4.3.1 Alternative indicators for mental health. We dichotomize the CES-D score into a dummy variable by setting the critical value as 20 (Andresen *et al.*, 1994). If the CES-D score equals to 20 or above, it will be considered as depression and take value 1, otherwise 0.

Table IV.
Regression results by gender and by region

	By gender		By regions		
Variables	Male (1)	Female (2)	East (3)	Central (4)	West (5)
SC	−0.931*** (0.284)	−1.454*** (0.296)	0.363 (0.373)	−1.808*** (0.358)	−1.747*** (0.393)
Other control variables	Yes	Yes	Yes	Yes	Yes
Observations	6,180	6,389	3,930	3,931	4,708

Note: ***Significant at 1 percent level

Table V.
Regression results by age groups

Variables	(1) Below 65	(2) Above 65	(3) Below 60	(4) Above 60
SC	−1.088*** (0.215)	−1.664*** (0.527)	−1.022*** (0.239)	−1.492*** (0.357)
Other control variables	Yes	Yes	Yes	Yes
Observations	8,262	4,307	5,961	6,608

Note: ***Significant at 1 percent level

IV-probit model is employed since ordinary IV regression is not applicable to this binary variable. We also adopt another health indicator, namely, self-assessed health to check the robustness. Self-assessed health, as a comprehensive indicator, is an overall assessment of health status by the interviewees themselves and reflects both physical and mental health status. Regression results are in Table VI.

4.3.2 Group by the poverty line. According to China's poverty line set in 2011 (average annual income per person at 2,300 RMB), we divide the total sample into families below the poverty line and families above the poverty line to investigate the impact of social capital across groups with different income levels. It is found that social capital is more beneficial to health for families below the poverty line (Table VI).

4.3.3 Change the sample range. To eliminate the bias caused by the measurement error or outliers, we remove the relatively older and relatively younger rural residents in the sample, namely, the 1 percent from both ends of the age variable to test the robustness (Table VI).

Through various ways to check the robustness, our main conclusions are not affected. Therefore, it can be concluded that social capital could improve the mental health of rural older adults.

4.4 Mechanism of social capital on mental health

We also want to investigate the pathways through which the social capital could affect mental health. The social capital may improve personal mental health through better access to information on a healthy living, more exercises or more frequent use of medical resources led by peer pressure and alike factors. Due to the availability of data, this study mainly focuses on the use of medical services and exercise activities to discuss the potential pathways.

Potential pathways are measured by three dummy variables according to three questions in the questionnaire, namely, whether you took a physical examination in the last two years, whether you checked blood pressure in the last year and whether you do exercise frequently. We regress the three dummy variables on the level of social capital and other control variables and found that a higher level of social capital is associated with a higher frequency in using medical services and doing exercises. Therefore, the social capital benefits personal mental health by raising the awareness of healthy behavior and lowering the searching cost of health-related information (Table VII).

	Health		Poverty line		Age
	Dummy	Self-assessed	Above	Below	Winsorized
Variables	(1)	(2)	(3)	(4)	(5)
SC	0.104*** (0.012)	0.057*** (0.010)	−0.885*** (0.296)	−1.518*** (0.276)	−1.219*** (0.207)
Other control variables	Yes	Yes	Yes	Yes	Yes
Observations	12,569	12,569	4,418	8,151	12,316

Note: ***Significant at 1 percent level

Table VI. Robustness check

Variables	(1) Physical examination	(2) Blood pressure	(3) Exercise
SC	0.032*** (0.004)	0.010*** (0.003)	0.006** (0.003)
Other control variables	Yes	Yes	Yes
Observations	12,569	12,569	12,551

Note: **,***Significant at 5 and 1 percent levels, respectively

Table VII. Mechanism analysis

5. Conclusions and implications

As the progressing of urbanization and industrial upgrading in China, the structure of factor endowments has changed dramatically, particularly in rural areas in terms of labor resources. Under this new structure, a facilitating government is required to appropriately address the mental health issues of rural older adults as the negative externalities cannot be internalized by the market alone. Therefore, this study appeals that the targeted poverty reduction under the new structure should not only focus on material poverty but also spiritual impoverishment.

Based on the CHARLS data in the year of 2011, 2013 and 2015, this study investigates the impact of social capital on the mental health of rural older adults and also its heterogeneous effects by sub-samples. Results show that, after the control of endogeneity by the IV method, social capital plays a positive role in improving rural residents' mental health. In addition, we also demonstrate that the promoting effects of social capital on health are significantly different across gender, income level, age, and regions. Particularly, females enjoy more benefits from social capital than males in terms of mental health, social capital effectively improves the mental health of the low-income group, aged people, and the impact is mainly observed in central and western areas.

Policy implications of this study are manifold. First, authorities should be aware of the positive role of social capital and fully utilize this information institution in public health to accelerate the process of building a healthy aged-care system in the health China strategy. Second, to facilitate the formation of social capital, local governments should provide necessary infrastructures for residents' social activities, such as building more relevant spaces and facilities as well as raising the awareness of the whole community to accumulate social capital. Third, a facilitating government should implement pertinent policies for cultivating social capital across different population and areas. For example, more attention should be paid to aged female residents with lower income in central and western regions. In addition, local governments should give play to the Community Council, the Women's Federation and related support groups in forming social capital. Relevant communities and associations should be established to provide a pleasant environment for older adults to make contributions under the new structure.

Note

1. Ten specific questions: I was bothered by things that do not usually bother me; I had trouble keeping my mind on what I was doing; I felt depressed; I felt everything I did was an effort; I felt hopeful about the future; I felt fearful; my sleep was restless; I was happy; I felt lonely; and I could not get "going."

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