

# Towards urban-rural sustainable cooperation: Models and policy implication

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## ABSTRACT

In the process of urbanization, many developing countries have had, or are being confronted with severe imbalance between urban and rural development, which causes serious un-sustainability. To address these challenges, this paper designs models to explore an 'urban-rural sustainable cooperation' pattern, with the idea of realizing 'green poverty reduction' in rural areas. Firstly, the infinitely repeated game model with trigger strategy is employed to prove the feasibility of establishing long-term urban-rural cooperation mode, with two conditions of low time preference rate and high efficiency of utilizing resource. Then this paper further discusses four requirements to enhance the accomplishment of green poverty reduction by cost-benefit analysis model: high antipollution costs afterwards, low time preference rate, the society's urgent need for environmental restoration, and high output gains without destroying environment. Lastly, this paper puts forward targeted policy proposals accordingly for relieving urban-rural imbalance problems in developing countries.

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## 1. Introduction

### 1.1. Research Background

Globally, the support from rural areas to cities is almost universal in the early stage of economic development, and most countries have undergone a period featuring ongoing industrialization and urbanization, when free resources were supplied to industry by agriculture and to cities by rural areas (Schultz, 1978). Many developing countries undertake a biased policy against rural areas in the process of industrialization (Wang and Li, 2003). For example, most of energy resources, like coal and gas, are located in remote poor rural areas, and governments allow over-exploitation of these energy resources in rural areas with unreasonable compensation to facilitate urban economic development. Moreover, due to scarcity of energy resources, cities are always put into first priority in energy resources consumption, leaving nearly no access to these resources to rural areas.

The experiences of many developed countries suggest that

during the transition from dualistic economy to industrialized economy, industry must help agriculture when it gets on a certain stage, and cities are supposed to assist rural areas by means of technical and financial support or compensation (Olson, 1985, 1990; Anderson and Hayami, 1986). However, many developing countries have been or are being confronted with dual polarization of urban and rural areas due to lacking support or improper compensation in the course of industrialization and urbanization (Bates, 1981; Krueger et al., 1991, 1992; Lipton, 1977). That is, urbanization has been boosted by large resource support from rural area, especially natural resources (for example, energy and food), however urbanization benefits were not fairly shared, even worse rural areas have to bear huge economic, social and environmental pressure (for instance, sickness, air pollution and climate change) due to uncompensated over-exploitation of resources (Ji and Chen, 2017; Kelly-Reif and Wing, 2016). All these have severely impaired programs of poverty reduction at global scale.

Rural poverty and rural environmental problems are inseparably interconnected (Sandhu and Sandhu, 2014). Recognition of the interrelationships between the recession in the global environment and the collapse of rural communities is essential (Kindie et al., 2014), and progressing environmental and development

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policies in isolation will lead to ineffectual or deleterious natural and rural systems management (Beeton and Lynch, 2012). As the livelihood of rural poverty population is mostly dependent on basic environment services<sup>1</sup>(Ji and Long, 2016), the reduction of critical natural resources and the deterioration of environment will put the poor population in more desperate situation. On the one hand, poverty areas are relatively weak in financial technology and mechanism to tackle environmental degradation, and cannot afford the loss of critical environment services; on another hand, poverty areas are always highly relevant to environmentally fragile regions (Thondhlana and Muchapondwa, 2014). According to the statistics by the Ministry of Environmental Protection of China in 2005, 95% of China's absolute poverty population lives in remote areas where the environment is extremely fragile. Globally, among the 1.3 billion people living in environmental fragile areas, nearly half can be classified as rural poverty population (World Bank, 2002). Compared with cities and developed regions, the residential livelihood and local economy of rural areas is more dependent on basic environmental services (Christie et al., 2012), thus rural areas are finally stuck into the vicious loop where people's response to survival crisis leads to deterioration of the environment, and the deterioration of environment will further intensify the survival crisis. This is the 'development trap' for most rural poverty areas; to escape this trap, rural poverty areas need to blaze a sustainable development path more urgently than cities and developed regions. Instead, public resource allocation is often biased against the rural population in many developing countries. Since a vast majority of the poor live in rural areas (Ravallion, 2002), the bias is highlighted as one of the pivotal institutional factors contributing to poverty (Shifa, 2013).

Rural areas are closely interconnected with the city evolution. Urban and rural areas have their interests interrelated (Murata, 2002), sharing will and woe together. The intensifying imbalance between urban and rural development will inevitably pose threats to the sustainable development of the whole economy and society of a country. On the one hand, urban and rural areas are actually interdependent (Kalantaridis, 2010; Torreggiani et al., 2012). For example, during the two periods of 1959–1962 and 1966–1976, China's urban development was twice stuck in stagnancy due to the recession of rural economy; while in early 1950s and after 1980s, with the upturns in rural economy, the urban development also became more flourishing. The rise of rural areas will benefit the lasting prosperity of cities; and the fall of rural areas certainly cannot ensure the continued urban growth (Ji, 2015). On the other hand, the lagging rural areas will naturally restrain the whole socioeconomic development. Suryahadi et al. (2009) used evidence from Indonesia and found that rural agriculture growth strongly reduced poverty in rural areas. To improve farmers' income, to develop agriculture and to gradually narrow the urban-rural income gap will definitely become a key breakthrough in stimulating the domestic demand and will exert immeasurable impetus to socioeconomic development in a nation.

Pushing rural poverty reduction and improving rural environment, enhancing the common development of urban and rural areas, and gradually eliminating the imbalance between urban and rural, are significant to sustainable development, so that for many dual economies it is essential to explore a new urban-rural cooperation mode to address the dual polarization phenomenon.

## 1.2. Literature review and the objectives of this paper

Nowadays, more and more scholars have paid their attention to clarifying the relationship between rural issues and economic development. In particular, some studies stressed the importance of the rural and agricultural issues. Hazell (1992) indicated the important role of agricultural insurance in developing countries. Christiaensen et al. (2011) took an empirical perspective and proved the evolving role of agriculture in poverty reduction. Cao and Birchenall (2013) examined the important role of agricultural productivity in China's post-reform economic growth and sectoral reallocation. Some scholars focused on the perspective of dualistic economy and urban-rural integration. Todd (1979) found that urban spill-overs are key agents in transmitting development impulses from urban centers into rural hinterlands. Yuki (2007) analyzed different qualitative natures of urbanization across countries. Fergusson (2013) showed the persistency of the dual economy and its impact on the rural. Shifa (2013) indicated that, in many developing countries, public resource allocation is often biased against the rural population, and the bias is highlighted as one of the most important institutional factors contributing to poverty since a vast majority of the poor live in rural areas. Most studies tried to reveal the relationship from the point of view of 'imbalanced development between agricultural industry and industrial industry'. Rozelle and Boisvert (1995) concluded that unbalanced growth can partially be explained by the way economic incentives induce individuals in rural areas to move resources towards the rural industrial sector and away from agriculture. Picard and Zeng (2005) discussed a model where industry hires labor from local agricultural sector. Even in nowadays developed country like France, Duvernoy et al. (2018) found that characteristics of urban growth play a key role to keep sustainability of land development in both urban and rural areas.

Some studies tried to carry out the research on the imbalance problem between urban and rural areas, while mainly regarding it as an extension of 'industry-agriculture imbalance' (Cai, 2006; Hong, 2007). Industry-agriculture interplay is certainly an important form, but not the whole story. The urban-rural interplay should cover a wider range, in more diversified forms, including culture, education, and environmental injustice (Arnaiz-Schmitz et al., 2018; Li et al., 2018; Hugo, 2017; Peou, 2016; Rao and Ye, 2016; Kelly-Reif and Wing, 2016; Hou et al., 2015). This paper puts emphasis on environmental perspective, particularly caring about issues of rural poverty and rural environmental degradation. This is consistent with the idea of 'Green Economy'<sup>2</sup> initially proposed by Pearce et al. (1989) and recently raised in the United Nations Environment Programme (UNEP, 2011). Rural areas are faced with serious challenges in green economic transition, due to the internal systematic restrictions by weak economic foundation, backward technological levels and fragile living conditions. Midmore and Whittaker (2000) have suggested that within the rural context, economics can make a valuable contribution to the design and achievement of sustainable ways of living. From their own side, rural areas should actively strive for more financial and technological support from government and cities, and meanwhile the government and cities should support or compensate rural areas aiming at cultivating green economy, and help rural areas to achieve long-lasting and sustainable green growth, so as to relieve rural areas from the predicament where poverty and environmental problem coexist, and to realize the so-called 'Green Poverty Reduction'. Green rural development mode

<sup>1</sup> According to Costanza et al. (1997) as well as Campbell and Brown (2012), this paper also refers to natural resources (for instance, coal, wood, water) and services (such as gas regulation, climate regulation, waste treatment) together as environment services for simplicity.

<sup>2</sup> Green Economy is a new economic form forced by the varied un-sustainability that global economic development is faced with in post-industrial era (Pearce et al., 1989).

and green rural poverty reduction will become important means of ensuring the sustainable economic and social development in developing countries. Therefore, it is essential to explore a new mode for urban-rural interplay with emphasis on sustainability and poverty reduction.

According to our literature research by far, however, very few researchers have discussed urban-rural interplay from perspectives of long-term urban-rural cooperation and green poverty reduction, and the theoretical analysis based on modelling is even less frequent. As mentioned at the end of 1.1 *Research Background* part, in order to solve urban-rural imbalance problems, a long-term urban-rural cooperation mode must be established, and the mode must be progressed in a sustainable way, with emphasis on both economic development and environmental protection. Therefore, this paper seeks to prove the possibility and feasibility of urban-rural sustainable cooperation, and explore policies and mechanisms to establish such a new urban-rural cooperation mode in developing countries. The remainder of this paper will be structured as follows: part 2, the methods and results part, introduces the models to theoretically prove the possibility and rationality of urban-rural sustainable cooperation. This part first employs infinitely repeated game model with trigger strategy to prove the feasibility of establishing a long-term urban-rural cooperation mode; then further discusses four requirements to enhance the accomplishment of developing green poverty reduction by cost-benefit analysis model; finally, combining the above two models, establishes urban-rural sustainable cooperation mode and derives optimal urban-to-rural compensation amount. Part 3 summarizes previous results and puts forward targeted policy proposals aiming at solving urban-rural imbalance problems, by enhancing long-term urban-rural sustainable cooperation mode in developing countries.

## 2. Methods and results

First of all, it needs to be realized that in addition to institutional barriers and policy bias, the lack or incompleteness of incentive and restraint mechanisms as well led to cities' insufficient compensation to rural areas. To realize urban-rural cooperation, any radical, externally forcing, or purely regulatory policy is likely to fail. Caffyn and Dahlstrom (2005) argued that there are benefits to be gained by taking an integrated urban-rural approach to regional development and by focusing on interdependencies and commonalities rather than on differences. Thus, to solve the problem, urban and rural areas should be regarded as an interactive entirety, instead of two unrelated individuals (Ward and Brown, 2009). In order to promote the cities' compensation to rural areas, a point where both cities and rural areas can benefit, should be confirmed before establishing a long-term mechanism for the cooperation and co-development between urban and rural areas. In the meantime, cities' compensation to rural areas must be progressed in a more sustainable way, and rural areas must put emphasis on both economic development and environmental protection. Therefore, a voluntary urban-rural cooperation mode needs to be justified.

Suppose that both urban and rural areas are rational, and that they have equal status.<sup>3</sup> This prerequisite implies that both urban and rural areas can make choices freely and voluntarily to maximize their own benefits. This assumption has both theoretic and

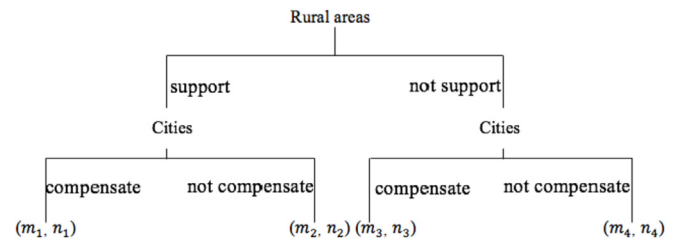


Fig. 1. The repeated stage in the infinitely game between cities and rural areas.

practical foundations. According to the 'Quantity Paradox Theory',<sup>4</sup> nowadays there are fewer rural residents, so they have more power to influence policies than before (Olson, 1965). Also, when the number of rural residents declines, the relation between the nation and rural areas will change, that is, the 'city preference' policy will disappear (Anderson, 1995). In addition, urban development still requires resources support from rural areas today, particularly in the form of energy resource, water and food supply. Thus, rural areas actually have the power to argue for equal status, and can help eliminate the priority of urban areas and abolish the 'city-preference' policy through the 'exit reaction'.<sup>5</sup> All these provide solid foundation for establishing and realizing the model.

In the following, two models would be proposed first, in order to justify the rationality and feasibility of urban-rural cooperation, and developing green poverty reduction, respectively.

### 2.1. Infinitely repeated game model with trigger strategy: it is possible to establish long-term urban-rural cooperation mode with mutual benefits

To solve urban-rural imbalance problems, this paper chooses the model of Infinitely Repeated Game with Trigger Strategy to prove the possibility of long-term urban-rural cooperation. This model is capable of well describing the images of long term urban-rural cooperation, and the trigger strategy is consistent with the 'exit reaction' mentioned above. Thus, this model is appreciated for the merits of both reasonability and feasibility. The relation between cities and rural areas can be described as a game, where rural areas have two options, to support cities with resources or not to, and cities also have two options, to compensate or not to. Thus there would be four combined strategies and outcomes, where  $m_i$  and  $n_j$  represent the rural income and urban income of each outcome respectively, as shown in Fig. 1.

The first outcome that rural areas choose to support and cities choose to compensate, that is, the cooperation outcome  $(m_1, n_1)$ , is the goal of the paper. However, if the game is finite or there is not any restriction, the dominant strategy of rural areas is not to support, and that of cities is not to compensate, then the last outcome of non-cooperation  $(m_4, n_4)$ , the Nash equilibrium, would be reached finally. Actually, in the present society, rural areas are forced to choose to support cities first, so it is understandable that cities will choose not to compensate. Therefore, in order to reach the cooperation outcome, infinitely game is required, and it means that urban-rural cooperation must be long-term. In addition, this cooperation must be carried out voluntarily and equally. Based on

<sup>3</sup> The assumption about equal status requires equal access to information and education, which may seem not very realistic. However, this assumption is used in order to run the model in a simple and straightforward way. If relaxing this assumption, there may exist some gap between urban and rural benefits in the final outcome, while the main conclusion and the mode of urban-rural sustainable cooperation should still be able to be established.

<sup>4</sup> The 'Quantity Paradox Theory' indicates that, more rural residents have less influential power to policy, since there are higher communication costs and free rider phenomenon among them (Olson, 1965).

<sup>5</sup> The concept of 'Exit' was first proposed by Hirschman (1970). It can be understood as a reaction when rural residents cannot bear the 'city preference' policy. The irrational behavior of migrating into cities causing 'urban diseases' is actually an 'exit' reaction (Todaro, 1969).

these prerequisites, it is possible to reach and keep the cooperation outcome with trigger strategy. In game theory, trigger strategy is that, once one cheats, the other one will stop cooperating immediately and will never cooperate. Trigger strategy here, is that cities and rural areas both make commitments to keeping the cooperation outcome, then once one cheats, then the non-cooperation outcome will be kept forever. More specifically, for rural areas, they originally have the incentive to choose not to support if cities keep commitment and choose to compensate. But once rural areas do not support and violate the cooperation, both cities and rural areas will keep the non-cooperation outcome forever. Thus, in order to encourage rural areas to keep to cooperation, the benefit of keeping promise must be larger than violating it. As shown in [Appendix A](#), this can be satisfied 1) when people put less preference on current value and care more about long-term benefit, and 2) when there is higher technology and efficiency of utilizing resource. Therefore, this model of Infinitely Repeated Game with Trigger Strategy provides solid theoretical foundation for realizing long-term cooperation between cities and rural areas.

## 2.2. Cost-benefit analysis model: how to achieve green poverty reduction

In conventional assessments, there is trade-off between economic development and environmental protection. Particularly in poor areas, since income is scarcer than natural resources, the marginal utility of unit resource is regarded as smaller than that of unit income. Therefore, economic developments always enjoy a priority regardless of the consequent pollution problems. And this is the reason why the phenomenon of 'damage first, restoration later', and 'improper compensation' are prevalent. However, in recent years, environmental pollution has brought threats on economic development and human health, and people have come to realize the potential value of the environment, natural resources and other environment services-. This paper will take the value of all environment services into consideration,<sup>6</sup> and then build a cost-benefit analysis model on this basis, in order to prove the possibility and rationality to achieve green poverty reduction.

This section uses cost-benefit analysis method, to compare the net value of developing economy protecting the environment and the net value of developing economy at the expense of the environment. As shown in [Appendix B](#), to reduce poverty without destroying environment will be a rational choice, when the extra economic benefit by destroying environment instead of protecting environment is less than the environment value and the cost of afterwards environmental restoration. To be more specific, rural areas gain larger incentive to reduce poverty in a green way, when:

- 1) cost of afterwards environmental restoration is higher,
- 2) discounting rate is smaller, that is, people put less preference to current value,
- 3) it is more urgent to require the environmental protection,
- 4) output gain on the basis of the environment protection is higher.

## 3. Conclusions and policy implications

### 3.1. Conclusions

In the early even current stage of industrialization and

urbanization among developing countries, it is common that rural areas give numerous support to urban areas. However, rural areas have not received sufficient proper compensation, and this long existing imbalanced interplay between urban and rural leads to various serious problems like rural poverty and environmental destruction, which have potential hazards in the whole economic and environmental development. In order to meet these challenges, a new mode of urban-rural sustainable cooperation must be established. This paper seeks to prove the possibility and feasibility of this new mode, and accordingly explore relevant policies and mechanisms to realize the mode.

First, the paper employed the model of Infinitely Repeated Game with Trigger Strategy, uncovering that: when people hold low time preference rate and there is high efficiency of utilizing resource, it is possible to realize the long-term urban-rural cooperation with mutual benefit. This model implies the importance of sufficient urban-to-rural compensation and equal status of urban and rural areas.

Then, the cost-benefit analysis model is used in this study to verify the rationality and feasibility of achieving green poverty reduction: when the extra economic growth at the cost of environmental degradation is less than the environment value and the cost of afterwards environmental restoration, it is more rational for rural areas to choose green development path. In addition, this paper carried out detailed discussion on the requirements for promoting green poverty reduction, and discovered that rural areas would be given more incentives to choose green development path when it meets the following four requirements: 1) cost of afterwards environmental restoration is high; 2) people put less preference to current value; 3) the society has more urgent need in environmental restoration; 4) the output gains based on environmental conservation are higher.

In conclusion, to relieve the observed long-term imbalance between urban and rural, and the serious rural poverty as well as rural environmental degradation due to insufficient and even improper urban-to-rural compensation, this paper proposes a new mode of urban-rural sustainable cooperation and proves its possibility and feasibility by modelling. According to the models developed in the paper, cities can take diversified forms of compensation to help rural areas realize green poverty reduction, and cities can get profit from the investment and sustainable resource support from rural areas, achieving urban-rural sustainable cooperation and co-development. More specific relevant policies and mechanisms according to the models are proposed in the following part.

### 3.2. Policy implication

Based on above conclusions, the following proposals aiming to promote urban-rural sustainable cooperation and thus relieving urban-rural imbalance in developing countries are put forward.

Firstly, the role of market mechanisms should be addressed in promoting the sustainable cooperation between urban and rural areas. For a long time, whether in developed market economies or transition economies, people have usually regarded problems related to the environment and natural resources as the consequence of 'market failure', and tended to overly depend on government behavior. In fact, most environmental problems are caused by lack of binding or incentive power, so are the problems occurring in urban-rural cooperation. In order to realize the urban-rural sustainable cooperation promoting green poverty reduction, the role of market mechanism should not be neglected or misread. Therefore, first, it is necessary to clarify the property rights of the rural environment and resources, so as to make the rural environment and resources truly become the capital used for the wellbeing of the rural residents. Second, the resource allocation

<sup>6</sup> Though environmental economists are increasingly divided on the question of using money to value nature ([Kallis et al., 2013](#)), this paper only emphasizes that environment and resources have values, and the form of the value does not matter so much.



function of the market should be strengthened to establish a pricing system able to reflect the scarcity of environment services, for one thing, to ensure the reasonable benefit for the rural areas when selling or transferring the environment services to achieve higher rural income level, and for another to increase the cost for cities to overexploit or damage the rural environment, to push the internalization of social and environmental externalities, and to increase the cities' utilization efficiency of the rural resources, so that the whole society will form the expectations that environmental treatment and environmental restoration cost will keep increasing, and the development mode of 'damage first, restoration later' and improper urban-rural compensation will gradually vanish. Third, it is recommended to further promote the marketization mechanism of eco-compensation to avoid the problems of low compensation standard, unsustainable financial support, technical obstacles of evaluation of environmental services derived in government directed eco-compensation. Establishing a market connecting all stakeholders to realize direct market transaction of environmental services which are with specific market prices. The mechanism of carbon trading market is recommended to support the design of eco-compensation's marketization.

Secondly, the government should better perform the duties as 'public service provider'. First, the government should keep improving the relevant law and regulations, as well as the supervision and management mechanisms, to provide sufficient legal safeguards for the rural areas' property and rights, and to raise the price for cities to randomly overexploit, or even grab and damage the rural environment and resources. Second, the government ought to encourage the innovative forms of urban-to-rural compensation besides financial aid, such as support in talent, technology, mechanism and culture, so as to create diversified compensation channels suiting local conditions, and to improve the effectiveness of compensation on the premise of protecting the rural environment, and reducing the pollution and destruction. Meanwhile, the government should replace the current unified GDP-oriented assessment system with diversified multi-level assessment mechanism, and underline the assessment on achievements of poverty reduction and environmental protection. Third, to promote eco-compensation through market, government should design fiscal policies such as tax incentives, fiscal interest subsidies, investment subsidies etc. to support the establishment of eco-compensation marketization mechanism. Last but not the least, the government should provide highly efficient education and propaganda services. Notwithstanding that it is not easy to alter people's time preference rate, the government and public opinion should still stick to education and propaganda, in order to raise people's awareness of the value of environment services and deepen their understanding of sustainable development. Thus people will increasingly value the environmental quality and attach more importance to long-term benefit and inter-generation equity, and their preference to current value will be unconsciously transformed, so as to strengthen the appeal of the society, particularly rural areas, for environmental protection and antipollution. The participation of rural areas into sharing the urbanization fruits calls for the whole society to make efforts to forsake prejudices and break down consciousness barriers. A fair, respectful and inclusive society is of great importance to promoting rural areas to share the urbanization fruits.

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## Appendix

### A. Infinitely repeated game model with trigger strategy

In order to make the discussion more explicit, suppose further that in each repeated stage of game:

- The normal incomes of cities and rural areas (no cooperation) are represented by  $GDP$  and  $gdp$ .
- Rural areas can choose to support cities by providing resources valued  $a$ , or choose not to.
- After obtaining resources valued  $a$  from rural areas, city income will increase, and the growth amount has a linear positive correlation on the  $a$  value. Use  $f(a)$  to represent this amount, and  $f(a) = A*a$ , where  $A \geq 1$  which represents technology and efficiency or resource utilization.
- Cities can choose to compensate rural areas, or choose not to. If cities compensate, we require the amount  $t$  to satisfy that  $f(a) \geq t \geq a$ .
- When rural areas receive compensation valued of  $t$ , their income  $gdp$  will also increase. Suppose that the growth amount also has a linear positive correlation on the amount of compensation. Use  $g(a)$  to represent this growth, and  $g(a) = B*t$ , where  $B \geq 1$  which represents technology and efficiency or resource utilization.

Based on these suppositions, as shown in Fig. 1, rural areas have two options, to support cities with resources or not to, and cities also have two options, to compensate or not to. Therefore, the combinations of strategies and results are:

- When rural areas support and cities compensate, rural income is  $m_1$ , and urban income is  $n_1$ .
- When rural areas support but cities do not compensate, rural income is  $m_2$ , and urban income is  $n_2$ .
- When rural areas do not support but cities compensate, rural income is  $m_3$ , and urban income is  $n_3$ .
- When rural areas do not support and cities do not compensate, rural income is  $m_4$ , and urban income is  $n_4$ .

With above suppositions and strategy combinations, the following relations are obtained:

$$m_1 = gdp - a + g(a) = gdp - a + B*t, \quad (A1)$$

$$m_2 = gdp - a, \quad (A2)$$

$$m_3 = gdp + g(a) = gdp + B*t, \quad (A3)$$

$$m_4 = gdp, \quad (A4)$$

$$n_1 = GDP + f(a) - t = GDP + A*a - t, \quad (A5)$$

$$n_2 = GDP + f(a) = GDP + A*a, \quad (A6)$$

$$n_3 = GDP - p*f(a) = GDP - p*A*a, \quad (A7)$$

$$n_4 = GDP. \quad (A8)$$

It is obvious that:

$$m_3 > m_1 > m_4 > m_2, \quad n_2 > n_1 > n_4 > n_3 \quad (A9)$$

The goal is to achieve result 1. Trigger strategy here, is that cities

and rural areas both make commitments to keeping result 1, then once one cheats, then result 4 will be kept forever. Thus, in order to encourage rural areas to keep to cooperation, the benefit of keeping promise<sup>7</sup> must be larger than violating it. That is,

$$\frac{(1+\mu)m_1}{\mu} \geq m_3 + \frac{m_4}{\mu}, \quad (\text{A10})$$

where,  $\mu$  is discounting rate. So it is required that,

$$\mu \leq \frac{m_1 - m_4}{m_3 - m_1} = \frac{B^*t - a}{a}. \quad (\text{A11})$$

In the same way, for cities to keep cooperation, it is required that,

$$\mu \leq \frac{n_1 - n_4}{n_2 - n_1} = \frac{A^*a - t}{t}. \quad (\text{A12})$$

Therefore, the long-term urban-rural cooperation mode can be achieved when equations (A11) and (A12) are satisfied, that is, 1) smaller discounting rate  $\mu$ , 2) higher technology and efficiency of resource utilization  $A$  and  $B$ .

### B. Cost-benefit analysis model

First, suppose that the value of unit environment service with high quality is  $v_1$ , the production cost is  $c_1$ , the value of output is  $v_2$ , then the total amount of the value of both income and the environment services represented by  $\pi_1$  is that:

$$\pi_1 = v_1 + v_2 - c_1. \quad (\text{A13})$$

If rural areas develop their economy at the expense of this unit environment service with high quality, with the same production cost  $c_1$ , the value of income represented by  $v_3$  is normally larger than  $v_2$ . Suppose that with increasing income while deteriorating environment and lavishing natural resources, in  $n$  years for example, rural areas become aware of the significance of the environment and natural resources, and start to treat pollution. For comparison, suppose that this unit environment services could be recovered as  $n$  years ago with same value  $v_1$ , and the afterwards antipollution cost is  $c_2$ . So the true benefit of rural areas represented by  $\pi_2$  is that:

$$\pi_2 = v_3 - c_1 - \frac{c_2}{(1+\mu)^n} + \frac{v_1}{(1+\mu)^n}. \quad (\text{A14})$$

Compare  $\pi_1$  and  $\pi_2$ , it is obtained that,

$$\pi_1 - \pi_2 = v_2 - v_3 + \frac{c_2}{(1+\mu)^n} + \left( v_1 - \frac{v_1}{(1+\mu)^n} \right). \quad (\text{A15})$$

When equation (A15) is above zero, to reduce poverty without destroying environment will be a rational choice. This happens when afterwards environmental restoration  $c_2$  is higher, discounting rate  $\mu$  is smaller,  $n$  is smaller, and output gain on the basis of the environment protection  $v_2$  is higher.

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<sup>7</sup> For simplicity of discussion, we use  $m_1$  to represent output value of rural areas in result 1 in each repeated stage of the game. Actually, the true output value in result 1 will increase as the game plays, making condition (10) easier to hold. Same for urban areas.

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