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Analysis of Forest Carbon Sequestration Attributes

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Abstract: ***Forest carbon sequestration is an important tool to address global climate change. Forest carbon sequestration has great potential to reduce CO_2 emissions compared to other measures, with the unique advantages of rapid results, low cost, and other comprehensive benefits. It is essential to understand and analyze the attributes and develop trade in forest carbon sequestration for this measure to be effective. In this study, the three attributes of forest carbon sequestration were analyzed from the perspectives of nature, economy and society. The relationships between the natural, economic and social attributes of forest carbon sequestration were discussed.***

Keywords: Forest carbon sequestration; Economic attribute; Natural attribute; Social attribute.

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1. Introduction

Forests provide habitats for organisms, sustain biodiversity, and function in carbon sequestration. It is widely recognized that forests play an important role in the global carbon cycle by sequestering and storing carbon and facilitating the substitution of biomass fuels for fossil fuels. It is this role of forests in climate change that has influenced participants of the Kyoto Protocol to allow countries to include carbon sequestered in forests in a country's emission requirements (Stainback and Alavalapati, 2002). Forest carbon sequestration refers to the process, activity, or mechanism of reducing CO_2 in the atmosphere through photosynthesis and storing it in the body and soil as biomass (Carbon Sink Foundation, 2013). Forest carbon sequestration has three attributes: nature, economy, and society, and there are mutually restrictive relationships between them. Based on existing literature, we focused on gaining new insight in order to contribute to the understanding of forest sequestration in two significant ways. First, our study was based on a comprehensive theoretical framework which considered three sets of attributes with a number of factors in each set. Second, we focused on the interaction and influence between the three attributes to provide useful insight into methods to increase production of carbon sequestration and to develop carbon sequestration trade.

2. Natural Attribute of Forest Carbon Sequestration

2.1 The Significance of Carbon Sequestration

Forests are largest carbon storage systems in terrestrial ecosystems and more attention has been paid to their carbon sequestration in recent years. In 2015, the total global forest area was approximately 4 billion hectares, with a forest volume of 531 billion cubic meters, and an average volume of 129 cubic meters per hectare of forest (FAO, 2016). In 2010, the total carbon reserves of the global forest reached 6,524 million tons, of which forest biomass, dead wood and leaf litter, and forest soil carbon reserves were 2,888 million tons, 719 billion tons, and 2,917 billion tons, respectively. The carbon storage of forest per hectare reached 161.8 tons, of which the forest biomass per hectare, dead wood and litter, and the carbon reserves of forest soil were 71.6 tons, 17.8 tons, and 72.3 tons, respectively (FAO, 2010). In the course of natural growth, the effective carbon sequestration in forests will increase if there is no interference from external factors.

The carbon sequestration effect of a forest is more significant than for other vegetation. Trees have developed roots and a larger leaf area index, which provide significant advantages for photosynthesis. Compared to other terrestrial ecosystems, such as grassland and farmland, forest consumption, absorption, fixation, and storage of CO_2 can be greater. For example, based on the same sized area, the carbon sequestration capacity of a forest ecosystem is 1.9-5 times that of farmland (Ji, 2012).

2.2 Double Characteristics of Carbon Sequestration and Carbon Source

Forests have dual characteristics of carbon sequestration and carbon sources. On the one hand, actively growing trees process, absorb, and fix CO_2 in the atmosphere by photosynthesis. On the other hand, the respiration of forest plants, and the oxidization and decomposition of humus, dead branches, and deciduous leaves will release a certain amount of CO_2 into the atmosphere (Figure 1). Large-scale fires, diseases and pests, deforestation, and processing and waste disposal of forest products will release fixed CO_2 to the atmosphere.

In the global carbon balance, tropical forests play a major role in carbon sources, mainly because they are subjected to destruction, logging, and degradation (Derwiler, 1988; Oliver, 1998). Research shows that after the conversion of woodland into farmland, carbon loss is generally between 0-60%, and may reach 75%. The amount of forest carbon sequestration depends on the size of the forest area. The FAO's 2015 Forest Resource Assessment report shows that between 1990 and 2015, although the number of forest areas in different regions of the world varied in different periods, the overall global forest area decreased, with an average decrease of 0.13% per year (Table 1).

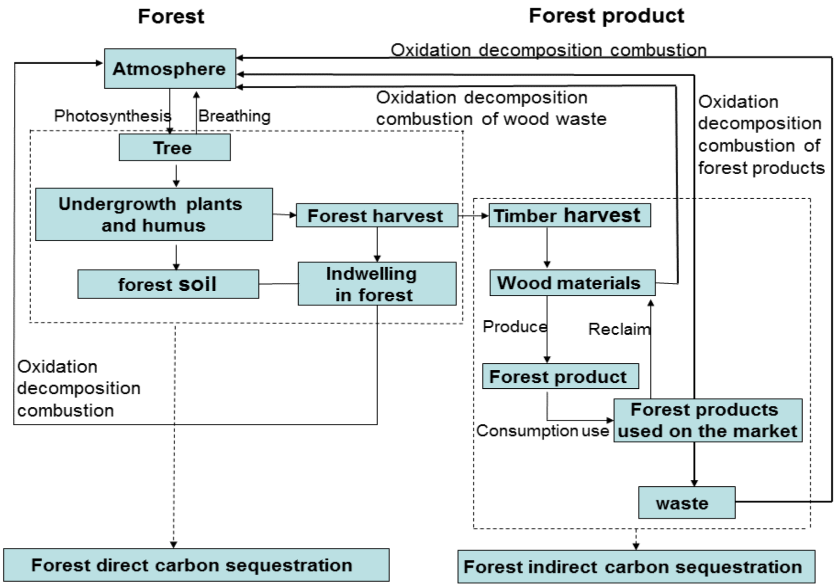

Figure 1: Carbon cycle and carbon sequestration in forests

Table 1: Changes of global and regional forest areas between 1990 and 2015

Regional	Quantity change (1000 HA / year)			Annual rate of change%
	1990-2000	2000-2010	2010-2015	1990-2015
Africa	-4 067	-3 414	-2 800	-0.49
Asia	-595	2 235	800	0.17
Europe	877	676	400	0.08
North America and Central America	-289	-10	100	-0.01
Oceania	-41	-700	300	-0.08
South America	-4 213	-3 997	-2 000	-0.40
Whole world	-6 327	-5 211	-1 650	-0.13

Source: From FAO's 2010 Forest Resource Assessment report and 2015 Global Forest Resources Assessment report.

This strongly suggests that the world's forests are currently the net source of CO_2 in the world because of the decrease in total forest area. The FAO report pointed out that over the past 25 years (1990-2015), global forest biomass carbon reserves have been reduced by nearly 110 million tons, mainly due to the conversion of woodland to agricultural and other man-made uses, and to a lesser degree, to forest degradation (FAO,2016). Of course, the area of forests in Asia and Europe has increased in general over the past 25 years, and forests have shown the nature of carbon sequestration.

Because CO_2 absorbed by actively growing forest will be eventually reemitted into the atmosphere through various mechanisms, there are schools of thought, which argue that carbon sequestration can delay the accumulation of greenhouse gases but cannot eventually reduce the emissions of greenhouse gases permanently. We believe that the size of forest carbon sequestration and carbon source will ultimately depend on forest management activities. Forest management can be strengthened in the following ways. First, through rigorous development of afforestation and reforestation activities, a degraded ecosystem can be restored, and the sustainable development of a forest can be promoted, leading to increased carbon reserves in land vegetation and soil. Second, by reducing deforestation, strengthening forest fire prevention, pest control, improving cutting methods, increasing the longevity of wood products, and improving the efficiency of wood utilization, damage to original forest can be avoided, which will have the effect of reducing the loss of carbon to the atmosphere in a forest ecosystem. Third, carbon substitution can be promoted, using durable wood forest products instead of energy intensive building materials such as cement and steel, and by strengthening the development and utilization of energy from forestry biomass. As long as forest management activities are improved and scientific and rational use of forest resources are made, forests can continue to play the important role of carbon sinks and carbon pools for a long time. Forests in the northern hemisphere (especially temperate zone and boreal forests) may predominantly play the role of CO_2 sinks (Kauppi, 1992).

2.3 Diversity of Forest Carbon Sequestration

Forest carbon sequestration can be divided into two types: direct carbon sequestration and indirect carbon sequestration. The direct carbon sequestration of forests refers to the direct fixation of CO_2 by photosynthesis into the forest carbon pool, including carbon sequestration in trees, understory plants, humus, and forest soil. Indirect carbon sequestration is the fixation of CO_2 into forest products, including carbon sequestration of forest products and other materials to save energy for the production of these materials and reduce the emission of CO_2.

(1) Carbon sequestration in trees

CO_2 is an important raw material for forest growth. In the growth process, trees absorb CO_2 from the atmosphere by photosynthesis, convert it into organic matter, and release a large amount of oxygen into the atmosphere. The storage of 1 ton of standing wood needs to absorb 1.63 tons of CO_2. Each 1 cubic meter increase of timber will absorb 1 ton of CO_2 (Li, 2007). Of course, during tree growth it is also necessary to release CO_2 and absorb oxygen to maintain normal growth and respiration; however, ultimately, the amount of CO_2 absorbed by photosynthesis of trees is far greater than the amount of CO_2 released by respiration.

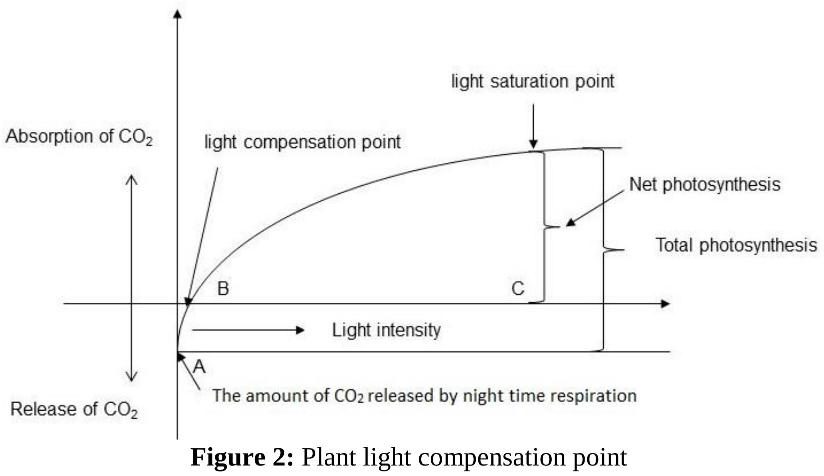

Figure 2: Plant light compensation point

As shown in Figure 2, the curve of A and B points represents the photosynthesis curve of a plant and the transverse axis indicates the intensity of light. The longitudinal axis is positive for CO_2 absorption, and the negative direction indicates the release of CO_2. The B point is called the light compensation point. At this point, the amount of CO_2 absorbed by plant photosynthesis is equal to that of CO_2 released by respiration; the organic matter formed and consumed is equal, and plants cannot accumulate dry matter. A plant can grow normally only when the light intensity is above the light compensation point. The BC section in the map indicates that net photosynthesis of plants will increase with increasing light intensity. Under the light compensation point, the respiration of plants will exceed that of photosynthesis; organic matter for carbon sequestration is accumulated, and stored as carbon sources. The light compensation point will change with temperature, tree species and leaf age.

The final net effect of carbon sequestration in trees is closely related to their growth cycle. It is generally believed that the storage capacity in a young tree is low but the potential for carbon sequestration is high. When trees enter the vigorous growth period, the net carbon sequestration effect will be the greatest. When the tree reaches maturity, its carbon storage will reach the maximum, but the net carbon sequestration effect will be the lowest. When the tree reaches its over-mature stage, its carbon sequestration will remain the largest for a period of time, but the net carbon sequestration effect will become zero. As time goes on, tree health will gradually deteriorate, the carbon sequestration will disappear, and the properties of tree carbon sources will gradually show (Li, 2006).

When forest carbon sequestration was first investigated, scholars believed that the amount of CO_2 fixed by tree photosynthesis was basically the same as the amount of CO_2 released through respiration, and the net carbon sequestration effect of trees was not obvious. However, scientific research has now shown that the carbon sequestration capacity of trees was greatly underestimated in the past. Over a set period, forest land productivity and natural forces can be manipulated to the maximum by rational logging and proper management of forest resources, thus increasing carbon sequestration and the carbon sequestration effect of trees.

(2) Carbon sequestration by understory plants and humus

Understory plants include small shrubs and vines, herbaceous plants, and bryophytes living close to the ground. Generally, they are shade loving plants and have evolved to photosynthesize effectively under sporadic sunlight. They can absorb large amounts of CO_2 during active growth and convert solar energy into chemical energy which is stored in the plant body. In general, these plants grow rapidly and have relatively short life cycles. The high volume of dead branches and deciduous leaves formed during tree growth create humus, and the carbon sequestrations formed in the forest are stored on the woodland floor. Most of this material decomposes relatively rapidly and returns to the atmosphere in the form of carbon elements. The carbon cycle is continuous.

(3) Carbon sequestration in forest soil

The soil carbon pool is the largest carbon pool on the earth's surface. It is estimated that the carbon content of the soil carbon pool is as high as 1500-1800 Petagram, which is about 2.5 times that of terrestrial biomass and 3 times that of the atmospheric carbon pool. The soil carbon pool plays a very important role in the earth's carbon cycle system (Pan et al., 2007). The main sources of carbon sequestration in forest soils are the litter of vegetation, the exudates of underground roots, and the organic detritus produced by the turnover of fine roots. Modern studies have shown that, although the carbon sequestration capacity of trees on the ground is almost zero, forest soil can accumulate organic carbon continuously and has a huge carbon sequestration function. Chinese scientists monitored the dynamic changes in organic carbon in the mature forest soil in the Dinghu Mountain National Nature Reserve (Qian, 2010). Their results showed that the amount of organic carbon stored in the upper 20 cm soil layer increased at a rate of 0.61 tons per hectare. Intensive deforestation will lead to a decrease of carbon sequestration in forest soil; this means that as far as possible the nature of woodland should not be changed. Soil fertility can limit carbon sequestration by forest ecosystems in a CO_2-enriched atmosphere and the assessment of future carbon sequestration should consider the limitations imposed by soil fertility, as well as interactions with nitrogen deposition (Oren et al., 2001).

(4) Carbon sequestration in forest products

After a forest is cut, trees no longer absorb CO_2. Some harvested residues are burned or decomposed, and the carbon elements return to the atmospheric carbon cycle in the form of CO_2. However, most of the biomass accumulated by standing trees has been used by human beings for a long time in the form of timber and fuel, thus forming a continuous fixation function for CO_2. Wood is processed to form timber, furniture, synthetic and composite board, paper and other forest products, and the form of carbon converted into forest products is stored. Extending the life span of forest products and recycling resources can effectively reduce carbon emissions. Generally speaking, building materials can be stored for 30 to 50 years, furniture for more than ten years, synthetic composites can be stored for 10 to 25 years, and paper for years. In general, calculating the total length of time forest products can be stored is an important issue, but it is difficult to calculate accurately. Experts believe that the overall carbon storage time of forest products is from 10 to 30 years, with 20 years as the average period; in France it is estimated to be 18 years (Winjum et al., 1998).

The effect of carbon sequestration on forest products can also be indirectly reflected by their substitution as a building material and for energy. It is estimated that if the energy consumed by wood raw materials is 1, the energy consumed in the production of cement, plastic, steel, aluminum and other materials is 4, 45, 60, and 130, respectively. It can be seen that the use of wood instead of plastic, steel, and aluminum is a very powerful tool to protect the environment (Chen, 2005). In addition, as a renewable green energy, charcoal, timber building materials, and other wood products can be used to replace fossil energy to reduce CO_2 emissions after their useful life has ended. The data show that the amount of heat released by burning 1 ton of wood is equivalent to that of 500 kilograms of oil, but the former releases less CO_2.

3. Economic Attributes of Forest Carbon Sequestration

Forest carbon sequestration has the economic attributes of resource, scarcity, public product, externality and trade.

3.1 Resource Attributes of Forest Carbon Sequestration

Resource is the generic term for material, financial and human resources owned by a country (or region), including natural resources and social resources. The former refers to natural material wealth, such as air, water, sunshine, land, minerals, grassland, forest, and animals. The latter refers to the material wealth created by human labor, such as human resources and information resources. The definition of natural resources by UNEP is ‘the general name of the natural environmental factors and conditions for the present and future welfare of human beings, which can produce economic value under certain time and place conditions’ (Yu, 2004).

In general, people's understanding of the value of natural resources focuses solely on their economic value. With the increasingly serious environmental problems, this judgment standard has gradually changed. People recognize the importance of sustainable survival and development, and the understanding of resources is extended from the natural resources of traditional physical forms to the ecological environment resources including landscape, climate and environmental capacity. These ecological resources can more reflect the ecological value contained in the natural resources, such as the function of the forest to regulate the climate and clean the air, and the water circulation can promote the circulation and renewal of the material.

According to the definition of resources, forest carbon sequestration should belong to an invisible environmental resource. From a global perspective, the economy is bound to increase energy consumption in the process of growth, which will inevitably increase the amount of CO_2 emissions, and then the space of CO_2 emissions will be reduced. Forest carbon sequestration can be fixed to CO_2, which can slow down the greenhouse effect, prevent further deterioration of the natural environment, and give humankind more time to control climate change and adapt to it. Forest carbon sequestration can provide a critical ecological environment service for human beings.

For forest carbon sequestration to act as a tangible resource, there are three questions which require clarification. First, it is necessary to clarify the property rights of forest carbon sequestration. The property rights of forest carbon sequestration resources should be consistent with the property rights of forest resources (Chen, 2015). When carbon resource property relations are determined and agreed it will be possible to construct the internal mechanisms for efficient utilization of carbon resources and promote the process of marketization. Second, the value of forest carbon sequestration resources needs to be recognized and valued, and the attitude that they are inexhaustible and free must stop. This is determined by many factors such as its usefulness, scarcity and the conditions for its development and use. Third, we need to calculate the quantity and value of forest carbon sink resources. This is an important measure to improve forest carbon sequestration management, to fully realize resource value and promote the sustainable development of forestry; such calculations are also the basis for developing forest carbon sequestration trade.

3.2 The Scarcity of Forest Carbon Sequestration

All resources are scarce in the face of mankind’s insatiable desires. The scarcity of economics and the general sense of scarcity are not the same. The scarcity of production resources emphasized by economics does not mean that resources are either non-renewable or depleted, and the term bears no relation to the absolute quantity of resources. It refers to the relative shortage of resource supplies over a certain period of time compared to demands (Ma, 2006). Therefore, the scarcity of production resources can be considered not only as a natural state, but also closely related to people's subjective psychological state. The scarcity of resources is also a dynamic concept. With the increase in population and the rapid development of science and technology, clean air, water, and forests, once believed to be limitless, have gradually been recognized as limited.

The scarcity of forest carbon sequestration comes primarily from the following two aspects:
(1) The limited space for carbon emission in the atmosphere

Before the age of agriculture, when the population was smaller and production methods were less intensive, the earth's atmospheric resources could be used all the time and anywhere. After the industrial revolution and particularly in recent years, the amount of carbon emissions in the atmosphere has increased rapidly as a result of rapidly increasing population and the intensive use of fossil fuels. In 1971, the world's carbon emissions were less than 150 billion tons, but by 2017, it was predicted to reach 368 billion tons, with an upward trend year on year. Carbon emissions surpass the carrying capacity of the environment (Liu, 2017) and the enormous uncertainty caused by the greenhouse effect comes as a huge cost to mankind.

(2) The scarcity of forest resources

Forest carbon sequestration is produced by forest resources. As long as timely cultivation, positive protection and rational development are implemented we can achieve sustainable utilization of forest resources. But the reproductive cycle of forest resources is very long and it can take decades for forests to become established and reach maturity. The cost of afforestation also makes it challenging to supply forest resources in the short term. Nevertheless, the cost of forest production cannot be underestimated. The cost of forest production includes direct and indirect expenses mainly incurred in the development of forest resources. Direct expenditure includes three parts: direct wage, direct material expenditure, and other direct expenditures. Direct wage expenses include wages, bonuses, and allowances for forest operators. Direct material expenditure includes raw materials such as seed and nursery stock for afforestation, auxiliary materials, fuel, and power. Other direct expenditures include afforestation, management, forest fire prevention, pest and disease control, and forest management facilities. Indirect expenses incurred for the production of forest resources should be included in the cost of managing forest production (Feng, 2010). With economic development and increase in population, the demand for forest resources is increasing. The consumption of forest resources exceeds its production, which is leading to a decline in the total quantity and quality of forest resources. In addition, the phenomenon of deforestation and destruction of woodland aggravates the increasing scarcity of forest resources and the scarcity of forest carbon sequestration. The characteristics of scarcity requires people to develop and utilize forest carbon sequestration resources reasonably, effectively and sustainably.

3.3 Public Goods of Forest Carbon Sequestration

Public goods and private goods are important concepts in economics. Public goods are goods that can benefit all members of society regardless of whether they are willing to buy. Private goods refer to goods that can be partitioned, provided to different individuals for consumption, and do not generate external interests or costs for others. Compared with private goods, public goods have three characteristics; namely, inseparable utility, non-competitive consumption, and non exclusion of benefit. These make it easy to understand the phenomenon of ‘the tragedy of the commons’ (Lloyd, 1833). In the case of unclear property rights, maximizing the interests of individuals and enterprises are the inevitable results of excessive use of public resources. In the international response to global climate change, there is a demand for public goods such as climate and environment, but individual states and enterprises are often reluctant to take on the responsibility of governing climate change. They want to consume fossil energy without restraint and allow massive emissions of greenhouse gases in all countries. This will lead to a similar phenomenon of ‘the tragedy of the commons’ for the global climate and ecological environment (Roopnarine, 2013).

In fact, forest carbon sequestration has the characteristics of public goods. First, forest carbon sequestration is inseparable from utility. The function of forest carbon sequestration is to absorb and fix CO_2, and to slow down the process of climate warming. This function depends on the joint action of all forest carbon sequestrations, globally. It is clear that when an individual is benefitting from carbon sequestration, there is no need to determine exactly where it has come from. Forest carbon sequestration can benefit all members of society, including their descendants. The utility of forest carbon sequestration has global characteristics and cannot be divided. Second, forest carbon sequestration is non-competitive in consumption. Under certain conditions, all members of society can share the results of carbon sequestration without exclusion and there is no exclusive competitive relationship between people. Moreover, any increase or decrease in the number of consumers enjoying these benefits will have no impact on the cost of production of forest carbon sequestration. Finally, forest carbon sequestration is non-exclusive in terms of benefit. In theory, the property rights of forest carbon sequestration should be owned by forest owners or operators. In fact, the property holders of forest carbon sequestration cannot impose any technical restrictions on one or more individuals enjoying the results of forest carbon sequestration. At the same time, no individual can refuse to accept such results for any reason. In other words, there is no benefit selectivity between forest carbon sequestration and its consumption by individuals. However, the characteristics of public products means that forest operators lack the economic incentive to generate carbon sequestration (Guo et al., 2017).

3.4 The Externality of Forest Carbon Sequestration

Externality is another important concept in economics. Externality theory has become an important theoretical basis in environmental economics. Based on the consequences of economic activities, externalities can be divided into positive and negative. The key problem in externality is that it separates private cost (or income) and social cost (or income), which makes unequal the actual price and the optimal price and distorts the price mechanism. Price has not become an effective signal for the scarcity of resources, so that the allocation of resources can not be effectively carried out. Generally, levying or defining property rights are ways to solve externalities (Buchanan et al., 1962).

Forest carbon sequestration has positive externality. Trees will continue to naturally absorb and fix CO_2, which slows the process of global warming as long as owners or operators of forest resources carry out afforestation or forest protection and sustainable management. All mankind will benefit generally, but society does not pay any reward to forest resource owners or operators to pay for forest carbon sequestration. The value of forest carbon sequestration cannot be reflected in its profit function, which means that forest carbon sequestration has positive externalities. As shown in Figure 3, the longitudinal axis represents price. Because the amount of forest carbon sequestration is positively related to the number of trees planted, tree number is used to represent the quantity of forest carbon sequestrations. The marginal cost of planting trees is MC. The social marginal benefit produced by planting trees is MSB. The private marginal benefit of planting trees is MPB, which can be realized through the market. The marginal benefit of forest carbon sequestration resources is MEB. The products that forests can provide to society include economic products such as trees, and also ecological products such as forest carbon sequestration. To simplify the problem, it is assumed here that forests only provide the ecological product of forest carbon sequestration. Therefore, the total demand for forest products for society is the demand for economic products plus the demand for ecological products. The formula is expressed as MSB = MPB + MEB. Generally, the value of economic products provided by a forest can be realized in the market through the transaction. The demand curve is MPB, when the intersection of MC and MPB is the equilibrium point of the market; the corresponding Q_1 is the balanced tree planting number, and P_1 is the equilibrium price. However, forest carbon sequestration is not reflected in the price, but there is still a certain demand for it. MEB is the demand curve. When the number of trees is Q_1, the MSB curve is above the MC curve, indicating that the number of trees has not yet met the general needs of society. The number of trees must be increased to Q_2, when the MC curve and MSB curve intersect at a new equilibrium point (Q_2, P_2), so as to meet the general needs of society. However, the marginal cost curve of forest producers is MC. When the price is P_2, the volume of tree planting will increase to Q_2. However, under Q_2 production, the price confirmed by the market is only P_3, and there is still no compensation for the spread of P_2-P_3. This price difference is the external marginal benefit generated by forest carbon sequestrations; that is, MEB = MSB - MPB, which is the concrete embodiment of the positive externalities of forest carbon sequestration.

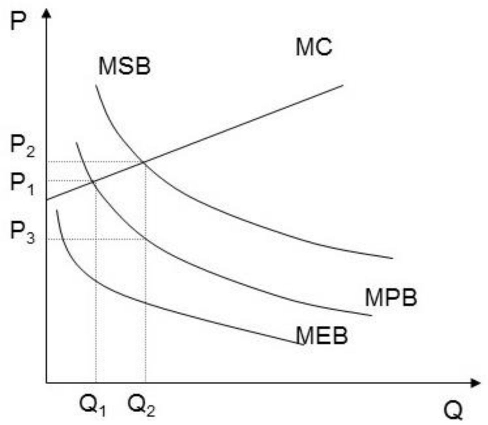

Figure 3: Forest carbon sequestration externality

3.5 The Tradability of Forest Carbon Sequestration

As mentioned before, forest carbon sequestration has the characteristics of resource and scarcity. It is useful for human beings, or it is of use value. Forest carbon sequestrations generally need to be afforestation and reforestation, which has invested in the cost of afforestation and management, condensing a large number of human labor and creating value. According to Marx's theory of labor value, the forest carbon sequestration has the dual attribute of value and value, so it needs to be commercialized to realize its value through market exchange.

It is now possible to increase carbon sequestration through afforestation and reforestation, rehabilitating degraded ecosystems, and strengthening the sustainable management of forests. In particular, using an improved method of estimating forest biomass and a 50-year national forest resource inventory in China to estimate changes in the storage of living biomass between 1949 and 1998, Fang et al. (2001) demonstrated that carbon storage increased significantly after the late 1970s from 4.38 to 4.75 petagram of carbon by 1998, with a mean accumulation rate of 0.021 petagram of carbon per year, mainly due to forest expansion and regrowth. Since the mid-1970s, planted forests (afforestation and reforestation) have sequestered 0.45 petagram of carbon, and their average carbon density has increased from 15.3 to 31.1 megagrams per hectare, while natural forests have lost an additional 0.14 petagram of carbon, suggesting that carbon sequestration through forest management practices addressed in the Kyoto Protocol could help offset industrial carbon dioxide emissions. The demand for forest carbon sequestration is increasing all over the world, resulting in both the necessity the potential for trade. The property rights of forest carbon sequestration can be defined, and its output can be measured and calculated, with the measurability and operability of trade. However, some scholars argue that forest carbon sequestration, which generates CO_2 offset credits, should not be regarded as one of the effective strategies to mitigate climate change. They demonstrated that the duration problem might preclude analysts from providing clean estimates for the cost of carbon uptake in forest sequestration (Van Kooten et al., 2007). Furthermore, research has not provided sufficient information for external analysts to determine how much carbon can be sequestered and at what cost, mainly because authors failed to address the duration problem (Stavins, 1999; Richards and Stokes, 2004).

Forest carbon sequestration commodity attributes are being recognized and accepted gradually, especially after the effectiveness of the Kyoto protocol. The property of forest carbon sequestration is more fully recognized. The appendix countries can obtain CO_2 emission rights through afforestation and reforestation projects implemented in developing countries. The sale of carbon sequestrations has been funded and a reasonable economic compensation has been achieved. Some scholars concluded that for most of the recent carbon price projections, carbon sink projects can be economically viable for Certified Emission Reductions (CER) suppliers and, at the same time, attractive to CER demanders looking for cost-efficient emission abatement opportunities (Olschewski et al., 2005). In addition, the actual use and distribution of forest carbon sequestration itself is not necessarily the characteristic of the same period. It has the advantages of homogeneity and ease of storage, and it is easy to standardize in quality grade and specification, and transaction units. Therefore, the futures trading mechanism can be introduced into the forest carbon exchange trade in the future (Yuan, 2011).

4. The Social Attributes of Forest Carbon Sequestration

It is often difficult to calculate and quantify the social attributes of forest carbon sequestration. They are described, as follows.

4.1 The Effects on the Ecological Environment

As mentioned previously, forest carbon sequestration fixes atmospheric carbon in forests, which can reduce the concentration of CO_2 in the atmosphere and thus restrain and slow down the greenhouse effect. Forests associated with production of forest carbon sequestration have many unique functions, including water conservation, wind protection, sand fixation, soil conservation, species conservation, carbon fixation, and oxygen release and air purification. In the process of forest carbon sequestration, measures must be taken to strengthen forest management in order to increase forested areas, enrich the forest ecological community, maintain the diversity of forest species, and further develop a source of biomass. The increase of forest carbon sequestration can also create areas for tourism, ecological recuperation, leisure vacation, and cultural inheritance. Of course, forest carbon sequestration will also cause some negative effects on the ecological environment in the process of production. It may cause carbon leakage due to the increase in deforestation or reclamation activities outside the project area. The large-scale construction of a single artificial pure forest may have a negative impact on biodiversity. But in general, the positive impact of forest carbon sequestration on the ecological environment will be far greater than negative effects, and it has a positive effect on the construction of the ecological environment for the sustainable development of society.

4.2 Bring Economic Benefits

Forest carbon sequestration has obvious advantages in comparison to other methods for reducing carbon emissions. For some countries, the production of forest carbon sequestration can effectively increase the amount of forest carbon sequestration. This can offset the obligations and adverse economic impact of mandatory emission reductions, and it can maintain the price competitiveness of domestic products. Through international cooperation in forestry Clean Development Mechanism (CDM) projects, developed countries can obtain low cost carbon emissions, and developing countries can obtain financial and technical assistance.

Forests attached to forest carbon sequestrations can produce large quantities of timber and other forest products for their owners or operators, so that their forestry incomes can be increased. The total value of lumber and non-timber harvesting in the world reached over $121 billion in 2005, of which the total value of logging for industrial logs and wood fuels reached over $86 billion and over $17 billion, respectively (FAO, 2010). It is particularly important to emphasize that non-timber forest products, such as forest food, medicinal materials, wild animals, woven goods and other non-wood forest products that have potentially huge economic value, yet this value is often ignored. As can be seen in Table 2, the total production income of non-woody forest products in 2011 was about $88 billion, primarily from the production of plant derived non-woody products ($77 billion). The remaining $10 billion was income obtained from animal products, and jungle meat. The income generated by medicinal plant collection was about $700 million, but this figure only includes the income from the collection of raw materials for the production of drugs, not the revenue created on the further extension of the production chain (FAO, 2014). Therefore, the increase of forest carbon sequestration and the use of non-woody forest products can effectively promote economic development, increase the income of forest, and achieve a 'win-win' situation to address climate change.

Table 2: Estimated income of non timber forest products in informal production in 2011 (Unit: million dollars)

Region	Medicinal plant	Non-woody forest products derived from animals	Non-woody forest products derived from plants	Total
Africa	52	3165	2082	5299
Asia & Oceania	171	3549	63688	67408
Europe	446	2130	5450	8026
North America	0	1016	2627	3643
Latin America and the Caribbean	29	646	2963	3638
Whole world	697	10506	76810	88013

Data source: FAO. World Forest Situation in 2014. www.fao.org/forestry/sofo/en/.

4.3 The Effects on Employment

The forestry sector is the main body for the production of forest carbon sequestrations and employment in this sector is an important indicator of its contribution to society. Employment can provide income for workers engaged in forest carbon sequestration. Generally, rural areas where forest carbon sequestrations are produced are relatively poor, and employment of this kind is very important. In the process of forest carbon sequestration, the government, as one of the main components of production, can carry out the development of ecological forestry by increasing investment and employment. In 2005, the total employment in global forestry was about 11 million. From a regional perspective, employment levels in Asian forestry reached the maximum in 2005, amounting to over 8 million. Forestry related employment in China was over 1 million, accounting for 15% of the total employment in Asian countries in the forestry sector (FAO 2010). Perhaps due to increased labor productivity, employees in the forestry sector decreased by 0.45% annually from 1990 to 2010 (FAO, 2016). In 2011, the number of practitioners in the formal forestry sector around the world was about 13 million. These data represented an underestimation, because informal employment in the forestry sector included at least 41 million people (FAO, 2014). This means that the real contribution of forestry to social employment is likely to be far greater than statistics suggest.

5. The Relationship between the Three Attributes of Forest Carbon Sequestration

Natural, economic and social are three major attributes of forest carbon sequestration, and there are relationships and constraints between them (as shown in Figure 4) (Jian, 2011).

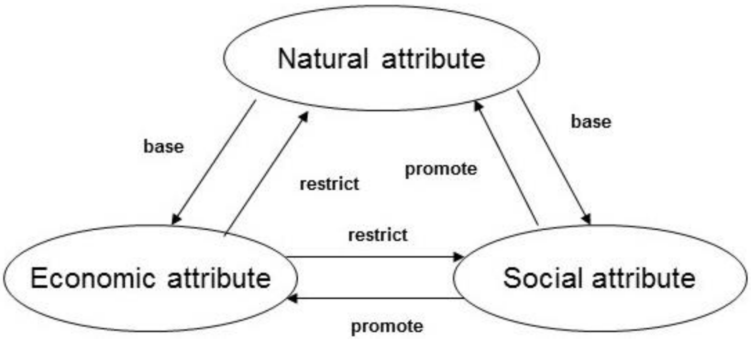

Figure 4: Forest carbon sequestration attributes relationship

5.1 The Relationship between Natural and Economic Attributes of Forest Carbon Sequestration

On the one hand, the natural attribute of forest carbon sequestration is the basis of economic attributes. Forest carbon sequestration can be carried out in various forms, reducing the concentration of CO_2 in the atmosphere and slowing the trend of global warming. This is an important natural attribute of forest carbon sequestration, which creates forest carbon sequestration characteristics such as resource, scarcity, public product, externality, and trade. On the other hand, the economic nature of forest carbon sequestration restricts natural attributes. The public product attributes of forest carbon sequestration can easily lead to 'free riding', resulting in the consequences of 'the tragedy of the commons', and externality will lead to a lack of reasonable compensation for forest carbon sequestration. Therefore, if we cannot solve these economic property problems, the production of forest carbon sequestration will lack the necessary incentives and this will affect the increase in the number of forest carbon sequestrations and the full use of their natural attributes. If we can make proper use of the tradability of forest carbon sequestration, it will make forest carbon sequestration produce moderate ecological compensation, which is beneficial to the use of natural attributes.

5.2 The Relationship between Natural Attributes and Social Attributes of Forest Carbon Sequestration

On the one hand, natural attributes of forest carbon sequestration are also the basis of social attributes. The full display of the natural attributes of forest carbon sequestration will effectively improve the ecological environment for human survival. If the natural attribute is not fully developed, it will have an adverse impact on the ecological environment. On the other hand, the social attributes of forest carbon sequestration can also play a catalytic role in the development of natural attributes. The improvement of the ecological environment; the increase of income, and the increase in employment will encourage people to pay more attention to forest carbon sequestration, thus increasing production to slow the pace of global warming and create a sustainable environment for society as a whole.

5.3 The Relationship between Forest Carbon Sequestration Economic Attributes and Social Attributes

On the one hand, the economic attributes of forest carbon sequestration will have a restrictive effect on its social attributes. The characteristics of externalities and public products in economic attributes will restrict the production of forest carbon sequestration, which will lead to a shortage of forest carbon sequestration, and this will restrict the social properties and value of forests. On the other hand, the social attributes of forest carbon sequestration will also contribute to economic attributes. The improvement of the ecological environment, the increase of income, and the improvement of employment will make people fully realize the characteristics of forest carbon sequestration resources. At the same time, people will try to find ways to limit the negative effects brought about by externalities and public products. It is one of the ways to develop trade in carbon sequestration by defining forest carbon sequestration rights. Thus, some scholars have suggested that the measurement of forest carbon sequestration should pay more attention to long-term trend changes, especially the impacts of carbon sequestration in social and economic development (Zhang, 2010).

6. Recommendations

Based on the above analysis, we can draw the following policy recommendations. First, in view of the natural properties of carbon sequestration, we should take effective measures to expand forest acreage and prevent agricultural land from being requisitioned for residential purposes. This is supported by Khatibi et al. (2018), who predicted that, in the 15 year period from 2014 to 2029, much agricultural land will be transformed into residential land, resulting in a severe reduction in the level of carbon sequestration. Therefore, the expansion of forest areas in urban counties would be an effective means to increase the levels of carbon sequestration. Second, effective measures should be taken to improve forest management and enhance accumulation volume per unit, since China has huge potential for forest carbon sequestration (Shen and Zhao, 2010). Third, in view of the social and economic attributes of forest carbon sequestration, forest carbon sequestrations should be embedded in the carbon emission trading system, so that the value compensation of forest ecological benefit can be realized through market mechanisms. Specifically, through emission trading systems, the demand enterprises for forest carbon sequestration with higher cost of emission reduction can undertake their corresponding emission reduction responsibility and reduce emission costs, and the suppliers of forest carbon sequestrations can obtain the corresponding economic benefits, which is beneficial to regulating the carbon emission behavior of demand enterprises, and encourages the carbon neutral behavior of forest carbon sequestrations (Xie and Shao, 2012). Fourth, considering the dual characteristics of producing bioenergy and carbon sequestration in standing forests, increasing the harvest from a forest in order to produce more bioenergy may conflict with the direct benefit of the forest as a sink of carbon. In principle, the social optimum may be achieved through a market mechanism with the correct use of policy instruments to correct carbon externalities. Specifically, the first-best policy is to tax all energy use (fossil and biological) at the same rate per unit gross carbon emissions and subsidize forest growth (measured in carbon) at the same rate. If this common tax/subsidy rate is set equal to the climate cost, the social optimum can be achieved (Hoel and Sletten, 2016).

Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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