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Natural capital utilization based on a three-dimensional ecological footprint model: A case study in northern Shaanxi, China

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ABSTRACT

Utilization of the capital stock and capital flow is the basis for evaluation of regional ecological construction, it is helpful to promote the coordinated development of economic and natural capital utilization, and improve the utilization efficiency of natural capital. Northern Shaanxi is characterised as being rich in energy resources and having a fragile ecological environment. Taking northern Shaanxi as an example, based on the analysis of ecological footprint per capita and ecological carrying capacity per capita in northern Shaanxi from 2001 to 2015, the driving factors behind changes in the ecological footprint of the region are revealed by using a partial least squares method. And this study describes the utilization of capital stocks and flows with the ecological footprint depth (*EF depth*) and ecological footprint size (*EF size*). Additionally, the *TEF size* and R_{FLOW}^{STOCK} are firstly used in practice. The research conclusions of this paper are as follows: Firstly, the ecological deficit increased significantly from 2001 to 2015 by a factor of 9.35, and the pull effect of the fossil energy account was the most clear. Secondly, the main driving factors behind the change in the ecological footprint are population, and above-scale industrial output value. Thirdly, northern Shaanxi needs 4.08 times its present area in order to meet its resource consumption level. Fourthly, both the consumption of natural capital stocks and flows were found to be increasing, and the consumption of capital stocks is found to be 3.05 times as fast as the utilization of capital flows. These findings not only is of realistic significance in promoting the coordinated development between economy and natural capital utilization in northern Shaanxi under the constraint of fragile environment, but also has policy implications in improving the utilization efficiency of natural capital in ecologically fragile areas. And this study will help in understanding the fragile ecosystems of these regions, provide a reference for similar energy-rich and ecologically fragile areas and promote practical construction at the same time.

1. Introduction

Eco-economics has developed a consensus on sustainable development stating that the minimum level of sustainable development is that which prevents the stock of natural capital from diminishing (Costanza and Daly, 1992; Pearce et al., 1989; Pezzey, 1990). Therefore, the use and evaluation of natural capital has always been a focus area for sustainable development (Farley and Daly, 2006). Pearce and Turner (1989) defined natural capital as "any natural asset capable of producing an economically valuable ecosystem service stream". Daly divides natural capital into natural capital stocks and natural capital flows. The former refers to the total natural capital in material form in geographical space on the Earth, given certain conditions in time and space, and the latter refers to the output of natural capital within a certain geographical space and certain time (Daly, 1996). The ecological footprint theory is based on the use of natural capital (Rees, 1992), and the productive land in the footprint theory can represent natural capital as well as the flow of resources and the services supporting livelihoods (Wackernagel et al., 1999). Since the development of this theory, the ecological footprint approach has been widely used to assess the use of natural capital. Using a historical time series analysis, Rugani et al. (2014) identifies the state of Luxemburg's natural capital use, indicating that Luxemburg's natural capital has been directly or indirectly overused. Li et al. (2016) analysed the dynamic changes in the ecological footprint of arid areas in northern China from 1990 to 2010, indicating that the region has become unsustainable. Liu and Xu (2010) quantifies the capital occupied by the debt among countries and finds that the United States has the largest ecological debt. Li et al. (2013) takes the ecological footprint as a measure of natural capital, using the product with coefficient matrix method based

Abbreviations: 3D EF model, three-dimensional ecological footprint model; 2D EF, two-dimensional ecological footprint model; *ef*, ecological footprint per capita; *ec*, ecological carrying capacity per capita; *ed*, ecological deficit per capita; *TEF size*, theoretical ecological footprint size; R_{FLOW}^{STOCK}, the utilization ratio of stock and flow capital

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on the analysis of ecological benefits from the Sino-US bilateral trade in goods from 1992 to 2010. The article estimates the ecological footprint of the import and export of all goods between China and the U.S. and discusses the balance between the ecological resource cost of product export and of ecological resources protection, demonstrating the policy relevance of the ecological footprint method. Lazarus et al. (2015) analyses the cross-regional flows of natural capital and ecosystem services worldwide from the perspective of trade and proposes that China is the main importer of natural capital. Borucke et al. (2013) improves the natural capital accounting method and compares the natural capital footprint of more than 200 countries, finding that most countries have an ecological deficit. The academic community has recognised the measurement of capital utilization using the ecological footprint method, but the value of *ef* does not fully represent the degree of sustainable development in a region, which is often characterised by the degree of openness in local economic development (Chen and Lin, 2008). Moreover, a two-dimensional ecological footprint (2D EF model) cannot accurately represent the utilization of natural capital or the flow of natural capital. Regarding the use of capital, it is difficult to reflect the importance of keeping natural capital stocks constant to maintain the stability of important ecosystems (Fang and Li, 2012). Moreover, there are some limitations in the analysis of excessive land use and the depletion of renewable resources (Zhang et al., 2017). There is a need to develop a methodology to differentiate between the use of natural capital stocks and flows in ecological footprint accounting (Mancini et al., 2017). The analysis of natural capital stock consumption can include a more detailed characterization of the ecological status of the region. Niccolucci et al. (2011) introduced the ecological footprint depth (*EF depth*) and ecological footprint size (*EF size*) measurements and established a three-dimensional ecological footprint model (3D EF model) to characterise the level of natural capital stocks and flows, further developing on previous ecological footprint research methods. Fang and Heijungs, 2012; Fang (2013, 2014, 2015) improved and applied the 3D EF model, analysed the utilization of natural capital and put forward new indexes, including the ratio of natural capital stocks to capital flows (R_{FLOW}^{STOCK}) and theoretical ecological footprint size (*TEF size*). At present, there is no relevant research which applied these indicators to practice. Du et al. (2016) used a 3D EF model to identify the pattern of natural capital utilization and ecological sustainability in the Beijing-Tianjin-Hebei Metropolitan region. The sustainability of natural capital use was quantified by comparing *EF depth* and *EF size*, and the consumption of natural capital stocks and flows is complementary (Peng et al., 2015). Due to the limitation of the 2D EF model, it is more reliable to analyse the ecological imbalance of ecologically fragile areas in the Loess Plateau using the 3D EF model.

The northern Shaanxi region is the largest area of loess in both China and the world, and is located on the edge of the Mu Us Desert. The environment in this area is sensitive, complex and fragile. To improve the living conditions, in the late 1990s, the Chinese government implemented ecological projects such as the “Returning Farmland to Forest” and “Returning Grazing Land to Pasture” projects in northern Shaanxi, which effectively improved the environment around human settlements and developed valuable ecological stocks. However, it may exceed the spending capacity of local governments. Studying the usage of capital can be the decision-making basis for improving the utilization efficiency of financial capital. Since 2000, with the implementation of the “Western China Development” plan, the “Belt and Road Initiative” and other national strategies, northern Shaanxi has witnessed great development opportunities, the large-scale “mountaintop removal” and “gas oil” projects have resulted in northern Shaanxi suffering unprecedented ecological threats. At present, the research shows that northern Shaanxi, Yan’an and Yulin are in a state of unsustainable development (Li et al., 2006; Xing et al., 2009; Niu et al., 2009), but the research does not show how natural capital is used in northern Shaanxi, which has rich natural resources, a fragile ecological environment and exhibits remarkable effects of ecological policy implementation. Ulucak and Lin (2017) shows that policy has a long-term impact on ecological footprint changes and that the ecological footprint is also an important consideration in the implementation of global and local policies. Therefore, taking northern Shaanxi in China as an example, from a three-dimensional ecological footprint perspective, the relationship between natural capital stock appropriation and natural capital flow consumption were reveal by the *TEF size* and R_{FLOW}^{STOCK} index firstly, allowing for the exploration of driving factors behind resource consumption, the evaluation of the population, and an assessment of resources subject to complex ecological and environmental changes on the Loess Plateau.

2. Study area, methods and relative indicators

2.1. Study area

Northern Shaanxi is the core of the Loess Plateau, which is the most ecologically fragile area in China and even in the world (Shi and Shao, 2000). Under the impacts of human activities, the ecological and economic systems in northern Shaanxi were in a vicious cycle (Tong and Long, 2003). The area of northern Shaanxi is 83,000 km^2, the average altitude is 1224 m, the average slope is 17°, the drainage density is 0.08 km/km^2, and the population density is 66 persons/km^2 (Guo et al., 2012).Northern Shaanxi is to the west of the Yellow River and adjacent to Shanxi Province, to the east of Gansu and Ningxia provinces, to the south of Inner Mongolia, and to the north of Tongchuan City. The northern Shaanxi region includes Yan’an City and Yulin City. Yan’an has an inland arid and semi-arid climate. With an annual temperature of 7.7 °C-10.6 °C, the average annual hours of sunshine are 2300–2700 h, and annual precipitation is approximately 500 mm (Yan’an, China). Environmental degradation increased in Yan’an at the end of 20th century, and the soil loss area reached 2,880,000 hm^2, and land erosion reached a scale of 90,000 kg/hm^2 (Yan’an Conversion of Cropland to Forest Project Management Office, 2016). Since the start of the twenty-first century, in order to improve the environment and promote local sustainable development, Yan’an has carried out two large-scale ecological construction projects, namely, the Returning Farmland to Forests and the Cut Mountains and Build Cities projects. The evolution of the present ecological patterns was mainly due to economic development before 1999, but after 1999, these patterns were mainly because of the implementation of the Conversion of Cropland to Forest Policy (Zhong et al., 2014). By the end of 2016, the forest coverage rate reached 46.35%, the vegetation coverage reached 67.7%, the city built-up green area coverage reached 4,882.38 hm^2, and the green coverage rate reached 42.65%. Yulin has a warm temperate and temperate semi-arid continental monsoon climate, annual average temperature of 10 °C, the average annual sunshine 2600 – 2900 h, and average annual precipitation of approximately 400 mm (Weather China). This area is home to the largest desert freshwater lake in China, Hongjiannao, with a water area of approximately 31.51 km^2 in 2015. Compared with that in 1986, the water area of this lake decreased by 27.09 km^2, a decrease of 46.2% (Shaanxi Daily, 2015). One of four major sand regions in China, the Mu Us Desert, is also located in Yulin. Yulin has implemented state-level ecological projects such as the “Returning Farmland to Forests and Grassland”, “Three-North Shelter Forest Program”, and the “Thousands of Miles of Green Corridor” project and other provincial and municipal ecological projects. In April 2015, Yulin was recognised by the national Development and Reform Commission and 11 other ministries as a demonstration zone for ecological construction. In July of the same year, Yulin plans to establish a model for a liveable desert oasis city and a liveable mining city model. By the end of 2016, the forest area of Yulin reached 1,438,000 hm^2, and the forest coverage rate reached 33%. In 2017, Yulin will promote the Wuding River Ecological Corridor and along the Great Wall town zone, construct “one corridor belt” in Yellow Town, create a national forest city, and become a“desert forest city” and a “desertification city”. In