Postprint: Evaluation of Ecological Well-being and Eco-economic Efficiency in Mainland China from the Perspective of Equity and Efficiency

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Abstract

Based on ecosystem service value theory, "terminal products and services that humans directly obtain or enjoy from ecosystems" is defined as ecological well-being, with corresponding characterization methods proposed from the perspective of equity and efficiency. Building upon this, an empirical analysis of the spatio-temporal evolution patterns of per capita ecological well-being and eco economic efficiency for provinces in mainland China during 2001–2013 reveals: 1) Overall, the Gini coefficient of inter-provincial per capita ecological well-being in mainland China ranged between 0.798–0.806 during the study period, indicating an extremely unequal distribution; the standard deviation of inter-provincial eco economic efficiency ranged between 2.110–7.716, demonstrating a relatively high degree of dispersion; 2) Temporally, the convergence trends (convergence) of inter-provincial per capita ecological well-being and eco economic efficiency in mainland China were relatively insignificant during the study period; per capita ecological well-being exhibited absolute convergence characteristics but at a low rate (0.16%); eco economic efficiency displayed conditional convergence under the significant driving influence of technological progress and R&D investment factors. 3) Spatially, the regional differentiation of per capita ecological well-being and eco economic efficiency across the "Hu Huanyong Line" in mainland China was pronounced during the study period, with their centroids located in Qinghai and Anhui provinces, respectively, shifting overall toward the northeast and northwest at velocities of 5.76 km / a and 3.95 km / a. Against the backdrop of high-consumption, high-pollution industries gradually shifting to central and western regions, it is imperative to balance ecological protection and economic development from an equity and efficiency perspective, thereby promoting concurrent improvements in eco economic efficiency in western regions and per capita ecological well-being in eastern regions.

Full Text

Preamble

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Evaluation of Ecological Well-being and Eco-economic Efficiency in the Chinese Mainland: From the Perspective of Justice and Efficiency

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Abstract

Terminal products and services that human beings directly acquire or enjoy from ecosystems are defined as ecological well-being, based on the theory of ecosystem services. Relevant characterization methods were established from the perspective of justice and efficiency. This study analyzed the spatial and temporal patterns of per capita ecological well-being and eco-economic efficiency across Chinese mainland provinces from 2001 to 2013. The results indicate that during the study period, the inter-provincial Gini coefficient for per capita ecological well-being in mainland China ranged between 0.798 and 0.806, representing a state of extreme inequality. The standard deviation of inter-provincial eco-economic efficiency ranged from 2.110 to 7.716, indicating relatively high dispersion. Overall, both per capita ecological well-being and eco-economic efficiency showed inconspicuous -convergence trends during the 13-year study period. Per capita ecological well-being exhibited absolute -convergence, albeit at a low rate of 0.16%, while eco-economic efficiency demonstrated conditional -convergence driven significantly by advancements in science, technology, and research investment. Spatially, mainland China' s per capita ecological well-being and eco-economic efficiency displayed pronounced heterogeneity across the northwest-southeast axis relative to the "Hu Line." Their centroids were located in Qinghai and Anhui provinces, respectively, moving northeastward and

northwestward at speeds of 5.76 km/yr and 3.95 km/yr. Against the backdrop of high-consumption, high-pollution industries gradually relocating to central and western regions, China should balance ecological protection and economic development from a justice and efficiency perspective, promoting simultaneous improvements in eco-economic efficiency in the west and per capita ecological well-being in the east.

Keywords: ecosystem ecology; human well-being; empirical analysis; temporal and spatial heterogeneity; justice and efficiency

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1. Introduction

Ecosystems are unified wholes composed of organisms and their surrounding environment, serving as the foundation for human survival and well-being. They provide ecosystem services that create essential natural conditions and economic benefits for humanity, constituting natural capital alongside manufacturing and human capital. The link between ecosystem services and human well-being has garnered increasing attention as fundamental to sustainable development. As land use intensity increases in certain regions, the relationship between local ecosystem services and human well-being grows increasingly complex. Research paradigms have gradually shifted from natural science approaches to integrated socio-ecological systems perspectives, with methods evolving from initial monetary valuation studies toward comprehensive assessments within coupled human-environment frameworks.

International scholars have conducted extensive theoretical and empirical research, revealing trade-offs and synergies among various ecosystem services and the complex relationships between ecosystem services and human well-being at multiple scales. In China, ecological civilization construction emphasizes good ecological environments as the most equitable public welfare. Domestic scholars are increasingly focusing on the interaction between ecosystem services and human well-being, yet quantitative evaluations and regional comparisons from justice and efficiency perspectives remain scarce. This study builds upon existing research to define ecological well-being concepts and develop evaluation models for regional ecological well-being equity and efficiency, using mainland China as a case study to inform strategies for enhancing human welfare and ecological efficiency.

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2. Concepts and Evaluation Methods

2.1 Conceptualizing Ecological Well-being Based on Ecosystem Service Theory

Well-being, synonymous with welfare, encompasses all desirable living conditions and environmental states. Drawing from the Millennium Ecosystem Assessment (MA) framework, we define ecological well-being as the terminal products and services that humans directly obtain or enjoy from ecosystems through primary and secondary production. While ecosystem services represent the ecological products and services provided through ecological processes, ecological well-being specifically focuses on terminal products and services directly relevant to human production and life.

Ecosystem service valuation often involves double-counting issues. To address this, scholars have proposed four principles for identifying terminal ecosystem services: (1) directly obtainable by beneficiaries, (2) naturally produced by ecosystems, (3) what beneficiaries are willing to pay for, and (4) for which beneficiaries would pay extra when other inputs remain constant. Based on these principles, we propose a classification scheme for ecological well-being that establishes relationships between ecosystem functions and service types.

compares ecosystem service value classifications with ecological well-being categories. The key distinction lies in perspective: ecological well-being focuses on human consumption and demand (resource needs, environmental needs, and cultural-spiritual needs), while ecosystem service valuation adopts a production-supply perspective that includes direct use, indirect use, option, and existence values. This differentiation temporarily separates ecosystem products and services from conventional human well-being concepts to clarify interactions with economic and social indicators, thereby enhancing scientific understanding of how human demand changes affect ecosystem services.

2.2 Evaluation Models for Per Capita Ecological Well-being and Eco-economic Efficiency

Given spatiotemporal heterogeneity in ecosystems, scientific calculation of ecosystem service values remains challenging. Drawing on the concept of per capita GDP and valuation methods for China' s terrestrial ecosystem services, we construct the following per capita ecological well-being (PGEW) model:

$$PGEW = \frac{GEW}{P} = \frac{g \cdot p \cdot \sum_{i=1}^{n} \sum_{j=1}^{9} a_i \cdot e_{ij}}{P}$$

where p represents the average grain price in primary grain markets, g denotes average yield per unit cropland area, both reflecting local price levels and productivity. The term e_{ij} represents the equivalent factor for the jth ecosystem service value in the ith ecosystem type, with i indexing six ecosystem types

(cropland, forest, grassland, water bodies, unused land, etc.) and j indexing nine service categories (E1-E9). The variable a_i represents the area occupied by ecosystem type i. The resulting PGEW value indicates per capita ecological well-being, where smaller differences between regions signify greater equity.

During economic production and daily life, most consumed ecosystem service values become embedded in socioeconomic development achievements. Through ecosystem service consumption combined with labor and capital inputs, regional ecological well-being transforms into economic well-being. To quantify the relationship between ecosystem services as natural capital inputs and corresponding economic outputs, we construct the eco-economic output efficiency (EEOC) model:

$$EEOC = \frac{GDP}{GEW}$$

where GDP represents regional economic achievement. EEOC measures the conversion capacity of ecosystem services to economic benefits during national economic production, with higher values indicating greater economic well-being per unit of ecosystem service consumed.

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3. Temporal Convergence Characteristics

3.1 -Convergence Testing

In economics, -convergence refers to declining disparities in per capita income across economies over time. Originating from neoclassical growth theory, this concept suggests that long-term growth depends on technological progress. Given the public goods nature of ecosystem services in meeting human ecological well-being needs, we apply this theoretical framework to test whether per capita ecological well-being and eco-economic efficiency converge toward a common steady state.

We employ standard deviation and Gini coefficient to test -convergence from relative and absolute perspectives. If the standard deviation of an indicator series shows a declining trend, it suggests -convergence, meaning inter-provincial differences in per capita ecological well-being or eco-economic efficiency are narrowing. The formulas are:

$$S_t = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(y_{i,t} - y_{j,t})^2}{2n^2\bar{Y}_t}}$$

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|y_{i,t} - y_{j,t}|}{2n^2\bar{Y}_t}$$

where $y_{i,t}$ and $y_{j,t}$ represent values for units i and j in period t, $\bar{Y}_t$ is the national mean, and n is the number of provinces. A declining Gini coefficient indicates absolute convergence.

3.2 -Convergence Testing

Absolute -convergence tests whether all provinces share identical land use conditions and socioeconomic development status. If the growth rate of per capita ecological well-being or eco-economic efficiency correlates negatively with its initial level, absolute -convergence exists. The regression model is:

$$\frac{1}{T}\ln\left(\frac{y_{i,t+T}}{y_{i,t}}\right) = \alpha + b\ln(y_{i,t}) + h_i + k_t + \varepsilon_{i,t}$$

where h_i represents provincial fixed effects, k_t represents time fixed effects, and $\varepsilon_{i,t}$ is the error term. If coefficient b is negative and significant, absolute -convergence holds, with convergence speed calculated as $\beta = -\ln(1+b)/T$ and half-life as $T_{1/2} = \ln(1/2)/\ln(1-\beta)$.

3.3 Conditional -Convergence Testing

Given that different provinces have varying steady states due to differences in urban-rural population ratios, industrial structure, resource endowments, and natural conditions, we identify key influencing factors. Drawing on previous research, we select four categories of conditional variables: (1) economic and market factors (foreign direct investment, road density, total import-export volume, tertiary industry share), (2) social and cultural factors (proportion of college students), (3) natural and technological factors (technology market transaction share, R&D investment share), and (4) environmental technology efficiency. The conditional -convergence model is:

$$\frac{1}{T}\ln\left(\frac{y_{i,t+T}}{y_{i,t}}\right) = \alpha + b\ln(y_{i,t}) + \gamma X_{i,t} + h_i + k_t + \varepsilon_{i,t}$$

where γ represents coefficients for conditional variables. Positive γ values indicate factors that positively drive improvements in per capita ecological well-being or eco-economic efficiency, while negative values indicate constraints.

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4. Spatial Pattern Analysis Methods

To identify spatial patterns and evolution characteristics, we apply a gravity center model to measure the centroid location, movement distance, and direction of per capita ecological well-being and eco-economic efficiency across Chinese provinces:

$$\text{long}_t = C \cdot \frac{\sum_{k=1}^{n} I_k \cdot \text{long}_k}{\sum_{k=1}^{n} I_k}, \quad \text{lat}_t = C \cdot \frac{\sum_{k=1}^{n} I_k \cdot \text{lat}_k}{\sum_{k=1}^{n} I_k}$$

$$D = C \cdot \sqrt{(\text{long}_{t+1} - \text{long}_t)^2 + (\text{lat}_{t+1} - \text{lat}_t)^2}$$

where $(\text{long}_k, \text{lat}_k)$ are the longitude and latitude coordinates of unit k, I_k is the indicator value, C is a distance coefficient representing planar distance between longitudes/latitudes on Earth' s surface, and D is the movement distance of the gravity center between years. Direction is determined by the angle relative to the baseline position.

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5. Data Sources and Processing

Due to data availability constraints, this study examines 31 Chinese mainland provinces (excluding Hong Kong, Macau, Taiwan, and South China Sea islands). Data sources and processing methods are summarized in . Provincial population, GDP, and grain yield data were obtained from the National Bureau of Statistics. Grain prices were based on minimum purchase prices and market average prices published by the National Development and Reform Commission, adjusted using price indices. Land use area data were compiled from the China Statistical Yearbook and China Land and Resources Statistical Yearbook, combined with remote sensing survey data.

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6. Results

6.1 Overall Trends

Applying standard deviation and Gini coefficient tests reveals the evolution of inter-provincial disparities. [Figure 1: see original paper] presents -convergence test results for per capita ecological well-being (PGEW) and eco-economic efficiency (EEOC) from 2001-2013.

The standard deviation of PGEW showed a fluctuating upward trend (increasing from 2.110 to 7.716), indicating growing dispersion relative to the national average. The Gini coefficient for PGEW declined linearly but remained extremely high, ranging from 0.798-0.806—substantially exceeding China' s household income Gini coefficient (0.491 in 2003). This persistent extreme inequality suggests that despite narrowing absolute differences, per capita ecological well-being distribution remains highly uneven.

Conversely, EEOC' s standard deviation exhibited a linear increase, indicating widening gaps relative to the national average. However, its Gini coefficient showed a hump-shaped trend (declining after 2007) and remained lower

than PGEW' s, suggesting that disparities in economic returns from ecosystem services are gradually diminishing. Overall, -convergence trends for both indicators were inconspicuous, implying that China will continue facing interprovincial ecological well-being inequity.

6.2 Convergence Speed

Despite slowly declining absolute differences, we tested absolute -convergence characteristics. After logarithmic transformation and panel unit root testing, fixed-effects and random-effects models were estimated via OLS regression. summarizes the results.

The PGEW regression model showed high significance, with a negative coefficient b (-0.001625) significant at the 1% level, confirming absolute -convergence at a slow rate of 0.16% annually. In contrast, EEOC' s coefficient was positive (0.001626) and insignificant, rejecting absolute -convergence. These findings align with -convergence results: PGEW exhibits weak absolute convergence, while EEOC does not.

6.3 Influencing Factors

Regional natural conditions, biomass differences, and socioeconomic factors create spatial heterogeneity in ecosystem service supply and demand. Conditional -convergence tests were conducted using the specified variables. presents regression results after unit root and cointegration testing.

Both PGEW and EEOC showed negative coefficients b in conditional models, but only EEOC achieved significance at the 1% level, indicating conditional -convergence driven primarily by technological factors. Technology market transaction share and R&D investment share exhibited positive coefficients, confirming that scientific and technological progress significantly drives eco-economic efficiency convergence across provinces. According to ecological modernization theory, technological advancement can reconcile economic growth with environmental protection through resource conservation and pollution control. These findings underscore the importance of promoting technological innovation to improve eco-economic efficiency while optimizing land use patterns and guiding rational inter-regional population flows to reduce natural resource consumption and environmental costs.

6.4 Spatial Patterns

Applying the gravity center model to 2001-2013 data reveals distinct spatial patterns. PGEW exhibited a "high in west, low in east" distribution, with western provinces (Tibet, Qinghai, Inner Mongolia) showing values exceeding 18,600 yuan per capita, while most eastern provinces fell below the national average. This pattern reflects the scarcity of ecosystem service values in economically and demographically dense regions.

Conversely, EEOC displayed an opposite "high in east, low in west" gradient, with eastern provinces achieving values 1.0, indicating higher economic returns per unit of ecosystem service consumed. The PGEW gravity center remained in Qinghai (95.67°-96.17°E, 33.83°-33.97°N), moving northeastward 69.08 km total (5.76 km/yr). The EEOC gravity center stayed in Anhui (116.42°-116.71°E, 34.35°-34.54°N), moving northwestward 47.36 km total (3.95 km/yr). [Figure 2: see original paper] and [Figure 3: see original paper] illustrate these spatial dynamics.

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7. Discussion and Conclusions

This study advances previous research by explicitly defining ecological well-being, emphasizing the human welfare orientation of ecosystem service values, and evaluating regional performance from justice and efficiency perspectives. Unlike qualitative ecosystem service studies or conventional well-being indices (e.g., HDI), we applied convergence theory and gravity center models for comprehensive spatiotemporal analysis, enhancing result reliability through multiple validation approaches.

The findings reveal significant spatial differentiation across the Hu Line: northwestern regions show high ecological well-being but low eco-economic efficiency, while southeastern regions exhibit the opposite pattern. This aligns with recent industrial transfer trends—high-consumption, high-pollution industries moving westward have improved eastern environments but reduced western ecological well-being, while technological progress and R&D investment have driven eco-economic efficiency convergence.

Population migration patterns further influence these dynamics. Sixth census data show net immigration concentrated in eastern provinces and net emigration in central-western regions. While western regions experience environmental costs from industrial transfer, out-migration mitigates per capita impacts on ecological well-being. Eastern environmental improvements are partially offset by population influx, which may constrain per capita ecological well-being gains. This interplay between industrial transfer and population migration shapes national convergence patterns.

Several limitations warrant attention. Human well-being is multidimensional, and this study focuses specifically on ecological dimensions from justice and efficiency perspectives. Future research should expand indicator systems and analyze driving mechanisms more comprehensively. Additionally, while our empirical parameters show consistency with improved valuation methods, static quantification approaches require further refinement with more precise land use data and longer time series.

Key Conclusions

1. During 2001-2013, China' s inter-provincial Gini coefficient for per capita ecological well-being ranged 0.798-0.806 (extreme inequality), while eco-economic efficiency standard deviation ranged 2.110-7.716 (high dispersion). Overall -convergence was inconspicuous, indicating persistent ecological well-being inequity.

2. Per capita ecological well-being exhibited absolute -convergence at a slow 0.16% annual rate. Eco-economic efficiency showed no absolute convergence but demonstrated conditional -convergence driven significantly by technological progress and R&D investment.

3. Spatially, per capita ecological well-being and eco-economic efficiency showed pronounced heterogeneity across northwest-southeast axes relative to the Hu Line, with centroids in Qinghai and Anhui provinces moving northeastward (5.76 km/yr) and northwestward (3.95 km/yr), respectively.

4. Against the backdrop of industrial relocation to central-western regions, China should balance ecological protection and economic development from justice and efficiency perspectives, promoting simultaneous improvements in western eco-economic efficiency and eastern per capita ecological well-being through technological innovation, optimized land use patterns, and rational population distribution strategies.

References

[1] Costanza R, d' Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O' Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M. The value of the world' s ecosystem services and natural capital. *Nature*, 1997, 387(6630): 253-260.

[2] Daily GC. *Nature' s Services: Societal Dependence on Natural Ecosystems*. Washington: Island Press, 1997.

[3] de Groot RS, Wilson MA, Boumans RMJ. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 2002, 41(3): 393-408.

[4] Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, DC: Island Press, 2003.

[5] Li S-C, Wang Y. Progress and prospects of ecosystem service geography from spatial and regional perspectives. *Geographical Research*, 2014, 69(11): 1628-1639.

[6] Li S-C. A geographical framework for ecosystem services based on spatial and regional perspectives. *Acta Geographica Sinica*, 2013, 68(8): 1038-1047.

[7] Zhang YM, Zhao SD, Guo RC. Recent advances and challenges in ecosystem service research. *Journal of Resources and Ecology*, 2014, 5(1): 82-90.

[8] Bennett DE, Gosnell H. Integrating multiple perspectives on payments for ecosystem services through a social-ecological systems framework. *Ecological Economics*, 2015, 116: 172-181.

[9] Pascual M, Miñana EP, Giacomello E. Integrating knowledge on biodiversity and ecosystem services: Mind-mapping and Bayesian Network modelling. *Ecosystem Services*, 2016, 17: 112-122.

[10] Gissi E, Gaglio M, Reho M. Sustainable energy potential from biomass through ecosystem services trade-off analysis: the case of the Province of Rovigo (Northern Italy). *Ecosystem Services*, 2016, 18: 1-19.

[11] Jopke C, Kreyling J, Maes J, Koellner T. Interactions among ecosystem services across Europe: bagplots and cumulative correlation coefficients reveal synergies, trade-offs, and regional patterns. *Ecological Indicators*, 2015, 49: 46-52.

[12] Villasante S, Lopes PFM, Coll M. The role of marine ecosystem services for human well-being: disentangling synergies and trade-offs at multiple scales. *Ecosystem Services*, 2016, 17: 1-4.

[13] Kovacs E, Kelemen E, Kalóczkai Á, Margóczi K, Pataki G, Gébert J, Málovics G, Balázs B, Robozc Á, Kovacse EK, Mihók B. Understanding the links between ecosystem service trade-offs and conflicts in protected areas. *Ecosystem Services*, 2015, 12: 117-127.

[14] Fischer A, Eastwood A. Coproduction of ecosystem services as human–nature interactions—an analytical framework. *Land Use Policy*, 2016, 52: 41-50.

[15] Lautenbach S, Kugel C, Lausch A, Seppelt R. Analysis of historic changes in regional ecosystem service provisioning using land use data. *Ecological Indicators*, 2011, 11(2): 676-687.

[16] Yoskowitz DW, Werner SR, Carollo C, Santos C, Washburn T, Isaksen GH. Gulf of Mexico offshore ecosystem services: relative valuation by stakeholders. *Marine Policy*, 2016, 66: 132-136.

[17] Lee H, Lautenbach S. A quantitative review of relationships between ecosystem services. *Ecological Indicators*, 2016, 66: 340-351.

[18] Egoh B, Rouget M, Reyers B, Knight AT, Cowling RM, van Jaarsveld AS, Welz A. Integrating ecosystem services into conservation assessments: a review. *Ecological Economics*, 2007, 63(4): 714-721.

[19] Wainenger LA, King DM, Mack RN, Price EW, Maslin T. Can the concept of ecosystem services be practically applied to improve natural resource management decisions? *Ecological Economics*, 2010, 69(5): 978-987.

[20] Lautenbach S, Kugel C, Lausch A, Seppelt R. Analysis of historic changes in regional ecosystem service provisioning using land use data. *Ecological Indicators*, 2011, 11(2): 676-687.

[21] Yoskowitz DW, Werner SR, Carollo C, Santos C, Washburn T, Isaksen GH. Gulf of Mexico offshore ecosystem services: relative valuation by stakeholders. *Marine Policy*, 2016, 66: 132-136.

[22] Li S-C, Wang Y. Trade-offs and synergies of ecosystem services: progress and geographical research issues. *Geographical Research*, 2013, 32(8): 1379-1390.

[23] Li S-C. A multi-level ecosystem service classification framework connecting human well-being. *Acta Geographica Sinica*, 2013, 68(8): 1038-1047.

[24] Zhen L, Li F, Xie G-D, Zhang C-X. Ecosystem service consumption and ecological compensation in vulnerable ecological regions: progress and challenges. *Resources Science*, 2010, 32(5): 797-803.

[25] Koenig H, Batkhishig O, Li F. Ecosystem service consumption measurement: a case study of Congjiang County, Guizhou Province. *Acta Ecologica Sinica*, 2010, 30(11): 2846-2855.

[26] Liu X-L, Zhen L, Wei Y-J, Xie G-D. Community consumption of and willingness to pay for ecosystem services: a case study of the Jinghe River Basin. *Acta Ecologica Sinica*, 2012, 32(6): 672-680.

[27] Yang L, Li S-C, Jin L. Empirical study on spatial differences in ecosystem service consumption in the Mongolian Plateau. *Journal of Natural Resources*, 2014, 29(2): 129-137.

[28] Johnston RJ, Russell M. An operational structure for clarity in ecosystem service values. *Ecological Economics*, 2011, 70(12): 2243-2249.

[29] Mäler KG, Aniyar S, Jansson Å. Accounting for ecosystem services as a way to understand the requirements for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America*, 2008, 105(28): 9501-9506.

[30] Xie G-D, Zhen L, Lu C-X, Xiao Y, Chen C. Valuation of ecosystem services in China. *Journal of Natural Resources*, 2015, 30(8): 1243-1254.

[31] Barro RJ, Sala-i-Martin X. Convergence. *Journal of Political Economy*, 1992, 100(2): 223-251.

[32] Sala-i-Martin X. The classical approach to convergence analysis. *The Economic Journal*, 1996, 106(437): 1019-1036.

[33] National Bureau of Statistics of China. *China Statistical Yearbook 2002-2014*. http://www.stats.gov.cn/tjsj/ndsj [2016-01-01].

[34] National Development and Reform Commission. Notice on 2012 temporary grain purchase and storage. http://www.gov.cn/gzdt/2012-11/21/content_2271750.htm [2016-01-01].

[35] National Development and Reform Commission. Notice on 2012 minimum wheat purchase price implementation. http://www.sdpc.gov.cn/zcfb/zcfbtz/201205/t20120523_481328.html [2016-01-01].

[36] National Development and Reform Commission. Notice on 2012 late rice minimum purchase price implementation. http://www.sdpc.gov.cn/zcfb/zcfbtz/201209/t20120903_503554.htm [2016-01-01].

[37] Ministry of Land and Resources of China. *China Land and Resources Statistical Yearbook 2002-2014*. Geological Publishing House.

[38] Simonis U. Ecological modernization of industrial society: three strategic elements. *International Social Science Journal*, 1989, 41(121): 347-361.

[39] Zhang Y, Zheng H, Yang M. Improved ecosystem service valuation method based on unit area value equivalent factors. *Resources Science*, 2015, 37(9): 1740-1746.

[40] Wang G-X, Cheng G-D. Analysis of inter-provincial water footprint intensity convergence in China. *Resources and Environment*, 2014, 24(9): 59-67.

[41] Li S-C, Wang Y. Ecosystem service trade-offs and synergies: progress and geographical research issues. *Geographical Research*, 2013, 32(8): 1379-1390.

[42] Li S-C. A geographical framework for ecosystem services based on spatial and regional perspectives. *Acta Geographica Sinica*, 2014, 69(11): 1628-1639.

[43] Zhen L, Li F, Xie G-D, Zhang C-X. Ecosystem service consumption and ecological compensation in vulnerable ecological regions: progress and challenges. *Resources Science*, 2010, 32(5): 797-803.

[44] Koenig H, Batkhishig O, Li F. Ecosystem service consumption measurement: a case study of Congjiang County, Guizhou Province. *Acta Ecologica Sinica*, 2010, 30(11): 2846-2855.

[45] Liu X-L, Zhen L, Wei Y-J, Xie G-D. Community consumption of and willingness to pay for ecosystem services: a case study of the Jinghe River Basin. *Acta Ecologica Sinica*, 2012, 32(6): 672-680.

[46] Yang L, Li S-C, Jin L. Empirical study on spatial differences in ecosystem service consumption in the Mongolian Plateau. *Journal of Natural Resources*, 2014, 29(2): 129-137.

[47] Johnston RJ, Russell M. An operational structure for clarity in ecosystem service values. *Ecological Economics*, 2011, 70(12): 2243-2249.

[48] Mäler KG, Aniyar S, Jansson Å. Accounting for ecosystem services as a way to understand the requirements for sustainable development. *Proceedings of the*

National Academy of Sciences of the United States of America, 2008, 105(28): 9501-9506.

[49] National Bureau of Statistics of China. Analysis of population migration characteristics based on sixth census data. *Population Research*, 2014, 29(2): 129-137.

[50] Xie G-D, Zhen L, Lu C-X, Xiao Y, Chen C. Valuation of ecosystem services in China. *Journal of Natural Resources*, 2015, 30(8): 1243-1254.

Note: Figure translations are in progress. See original paper for figures.