Artificial Intelligence, Structural Change and Labor Income Share

Guo Kaiming (郭凯明)*
Lingnan College, Sun Yat-sen University, Guangzhou, China

Abstract: *Artificial intelligence (AI) is a strategic technology that leads a new round of technological revolution and structural transformation. This paper studies the effects of AI on structural change and factor income shares. As a general purpose technology and new infrastructure, AI may substitute either labor or capital and its application has differential prospects across sectors. With a multi-sector general dynamic equilibrium model, we find that AI services or AI-specific technologies will reallocate factors between sectors. The direction of the reallocation depends on sectoral differences in the output elasticity of AI and in the elasticity of substitution between AI and traditional modes of production. The process of structural change will in turn change the labor income share. This paper presents the theoretical conditions for the direction of these changes and the underlying economic mechanism. We derive policy implications about how to promote high-quality development with AI.*

Keywords: *artificial intelligence (AI), structural change, labor income share, new infrastructure*
JEL Classification Code: O11, O14, O41
DOI: 10.19602/j.chinaeconomist.2021.11.06

1. Introduction

Artificial intelligence (AI) is a strategic technology for a new round of technological revolution and industrial transformation. Developing new-generation AI is of strategic importance for China to seize the opportunities from a new round of technological revolution and industrial transformation (Xi Jinping, speech at the Ninth Collective Workshop of the Political Bureau of the CPC Central Committee).[1] Globally, AI is on the rise.[2] It was estimated that the global AI market would grow from 168.4 billion yuan in 2015 to 680 billion yuan in 2020, up 26.2% on an annual average basis. China's AI industry has been growing more rapidly with an AI market expected to expand from 11.2 billion yuan in 2015 to 71 billion yuan in 2020, up 44.5% on an annual average basis.[3] By 2030, AI will contribute 15.7 trillion US dollars to the global economy, 70% of which will come from China and the United States.[4] A precise forecast of AI's impact on China's structural change and factor income distribution is of great significance to the high-quality development of China's economy and falls into the province of this paper. Specifically, this paper attempts to answer the following questions: How will AI reshape future

* CONTACT: Guo Kaiming, e-mail: guokm3@mail.sysu.edu.cn.

[1] Official website of the Central People's Government, October 31, 2018, "Xi Jinping Chairs the Ninth Collective Workshop of the Central Politburo of the CPC and Delivers a Speech" http://www.gov.cn/xinwen/2018-10/31/content_5336251.htm.

[2] According to *The Economist*, companies spent 22 billion US dollars on AI-related M&A transactions, or 26 times more than in 2015. https://www.economist.com/leaders/2018/03/28/the-workplace-of-the-future.

[3] Deloitte, 2018, *China AI Industry Whitepaper*.

[4] PwC, 2017, "Sizing the price: What's the real value of AI for your business and how can you capitalize?" According to McKinsey & Co., AI is expected to contribute 13 trillion US dollars to the global economy by 2030 and raise global annual GDP growth rate by 1.2 percentage points. See McKinsey & Co., 2018, "Notes from the AI Frontier: Modeling the Impact of AI on the World Economy."

industrial landscape? Will AI promote capital-intensive or labor-intensive industries? The previous round of technological revolution led to diminishing shares of labor income globally and widened income inequalities in emerging economies. Will the rapid development of AI as a strategic technology for a new round of technological revolution continue to worsen income distribution? Will new technology dividends be reaped by capital or labor?

Notably, AI has the following three important features related to these questions. First, AI is a general purpose technology (GPT) with spillovers on infrastructure. General purpose technologies are fundamental technologies broadly applicable to various sectors of the economy. They include, for instance, steam engine, electric power and information technologies underpinning the three industrial revolutions (Bresnahan and Trajtenberg, 1995). As a GPT behind the Fourth Industrial Revolution (Brynjolfsson *et al.*, 2018; Agrawal *et al.*, 2019a), "AI has a 'head goose effect' with very strong spillovers" (Xi Jinping, speech at the Ninth of Collective Workshop of the Political Bureau of the CPC Central Committee in 2018). Although AI technologies are applied by companies, the government still needs to invest to bring out their spillover effects. All major economies regard AI as a key driver of national technological competitiveness, vowing to plough vast sums of money into AI research.[5] At the Central Economic Work Conference at the end of 2018, the Chinese leadership called for "strengthening the development of new infrastructures such as AI, industrial internet and the internet of things (IoT)," officially defining AI as a new infrastructure.[6]

Second, AI will profoundly transform traditional modes of production with biased substitution with both labor and capital. In existing studies, AI is described primarily in two ways. Some studies considered AI as a factor-specific technology such as capital-specific technology (Sachs and Kotlikoff, 2012; Nordhaus, 2015; Graetz and Michaels, 2018) and labor-specific technology (Bessen, 2018). No matter AI is a capital-specific or labor-specific technology, its relative substitution with labor and capital is subject to the elasticity of substitution with capital and labor. That is to say, AI will not necessarily replace more labor or capital.[7] Other studies considered AI as a technology for automation and more likely to replace labor (Acemoglu and Restrepo, 2018). Yet in fact, AI-based automation will only replace a part of the workforce, and AI may also serve as a productivity tool and expand demand for specific types of labor, such as jobs that cannot be automated, require digital skills and involve AI in a supportive role. Hence, AI's effects on labor demand are more structural in nature without reducing overall labor demand (Korinek and Stiglitz, 2017; Brynjolfsson *et al.*, 2018; Acemoglu and Restrepo, 2019; Agrawal *et al*., 2019b). It is estimated that by 2030, investments in technologies such as AI and automation will create 20 million to 50 million jobs. In many cases, workers will not lose their jobs but change to new ones. Automation may cause 75 million to 375 million people to change jobs.[8] In the coming two decades, AI's net effects on China's employment could create a 12% net increase in jobs, which is equivalent to 90 million jobs.[9]

Third, AI applications vary across sectors and create business modes that drive structural change and upgrade. Driven by mobile internet, big data, supercomputing, brain science and other new theories and

---

[5] In 2017, China issued the *New-Generational AI Development Planning* and Japan issued *AI Technology Strategy*; in 2018, the UK and Germany enacted the *AI Sector Deal* and *AI Made in Germany*; in 2019, the US released the *American AI Initiative*.

[6] Xinhua.net, December 21, 2018, *Xi Jinping and Li Keqiang Deliver Important Speeches at the Central Economic Work Conference in Beijing*, website: http://www.xinhuanet.com/politics/2018-12/21/c_1123887379.htm.

[7] Related to this perspective, Huang and Xu (2009), Zhang *et al*. (2012), Chen *et al*. (2013) and Wang and Yuan (2018) all explained change in the share of labor income from the perspective of technology progress.

[8] These additional jobs include healthcare professionals; engineers, scientists, analysts and senior accountants; IT and technical specialists; senior management positions that cannot be automated; educators, especially educators for children; creative occupations; construction, infrastructure and housing; manufacturing and services in complex environments, etc. See McKinsey & Co., 2017, "Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation." According to McKinsey & Co., AI will increase the share of jobs requiring digital skills from the current 40% to around 50% by 2030. See McKinsey & Co., 2018, "Notes from the AI Frontier: Modeling the Impact of AI on the World Economy."

[9] PwC, 2018, "The net impact of AI and related technologies on jobs in China."

technologies, AI is characteristic of deep learning, cross-sector integration, man-machine coordination, crowd sensing, and autonomous operation and control. Production modes vary across sectors with different levels of integration with those AI features. This is why AI's effects are differentiated across sectors. An indirect evidence is that one AI patent will only be applied in specific sectors. In patent documents, for instance, 15% of AI patents mention communication and transportation, 12% of AI patents mention life sciences, and 11% of AI patents mention personal services, computers or man-machine interactions. Other sectors with AI applications include banking, entertainment, security, manufacturing, and cyberspace.[10] In labor and capital-intensive sectors, the role of AI is to reduce manpower and achieve low-cost customization. In technology-driven sectors and fast-changing markets, the role of AI is to raise R&D efficiency and precisely forecast and respond to market changes.[11] Sector-wise, AI has a broad prospect of applications in digital government, finance, healthcare, automobiles, retail and high-end manufacturing with varying levels of development.[12] Based on the survey data of Chinese enterprises and employees, Cheng *et al*. (2019) found significant differences in the level of robotic applications across sectors. The level of robotic applications is higher for firms that create more jobs with a higher capital-to-labor ratio.

From these perspectives, this paper builds a multi-sector dynamic general equilibrium model that captures those three properties. In this model, the government invests in new infrastructures that provide AI services and determines the amount of AI services. Each sector may use AI but needs to pay the using cost. This reflects the attribute of AI as a GPT and a new infrastructure. In each sector, capital and labor form value-added input using technologies with constant elasticity of substitution, which represents traditional modes of production. There is certain substitutability between AI services and production factors or traditional modes of production, but AI's elasticities of substitution with capital and labor are equal. This means that AI's substitution with either labor or capital could be biased. Across sectors, differences exist in the output elasticity of AI, the elasticity of substitution between AI and traditional modes of production, and AI-specific technologies, which reflect differentiated AI applications across sectors.

Based on the model, we found that an increase in AI services or AI-specific technologies would prompt a flow of production factors across industrial sectors, and the direction of such flow is subject to the difference between AI's output elasticity and AI's elasticity of substitution with traditional modes of production. This structural change has also led to change in the share of labor income. This paper provides conditions for the structural transition and the direction of change in the share of labor income, and conducts a quantitative analysis based on numerical simulation.

This study broadens the research of AI's structural effects on the economy. On this topic, extensive research carried out in recent years has arrived at different conclusions. Zeira (1998), Benzell *et al.* (2017), and Acemoglu & Restrepo (2018) regard AI as a mode of automation, and automation as a process of capital replacing labor. Companies decide whether labor or machines are to be employed to complete any specific task of production. This process, therefore, will naturally cause the share of labor income to fall.[13] Nevertheless, Sachs and Kotlikoff (2012), Nordhaus (2015), Bessen (2018), Graetz and Michaels (2018) considered AI as a factor-specific technology, whose effect on the share of labor income is uncertain and subject to capital and labor's elasticities of substitution. Aghion *et al*. (2017) noticed industrial structural changes' significance in AI's effect on the share of labor income, which is the closest literature to this study. While emphasizing the role of the elasticity of product substitution between industrial sectors, they did not consider that AI could replace traditional modes of production, and that

[10] World Intellectual Property Organization (WIPO), 2018, "Technology Trends 2019: Artificial Intelligence".
[11] Tencent Research Institute, 2018, *Research Report on AI + Manufacturing Industry Development*.
[12] Deloitte, 2018, "China AI Industry Whitepaper".
[13] Korinek & Stiglitz (2017) argued that AI would raise innovators' return and reduce the share of labor income.

AI's effect on the share of labor income was also subject to the characteristics of AI applications across industrial sectors. As a theoretical innovation, this paper employs a more generic model framework to examine AI's effects on industrial structural change and the changing share of labor income from more diverse perspectives and puts forth a new economic mechanism.

2. Model

In this section, we build a multi-sector dynamic general equilibrium model with one sector of final products and two sectors of intermediate inputs. The two sectors of intermediate inputs are differentiated by subscript $j=\{1, 2\}$. In each sector, a representative company makes production decisions in a fully competitive market. The production of final products only employs output from the sectors of intermediate inputs as inputs.

In the sector of final products, a representative firm employs technologies with constant elasticity of substitution (CES) for manufacturing:

$$Q_t=\left[\omega_1^{1/\varepsilon}Q_{1t}^{(\varepsilon-1)/\varepsilon}+\omega_2^{1/\varepsilon}Q_{2t}^{(\varepsilon-1)/\varepsilon}\right]^{\varepsilon/(\varepsilon-1)} \tag{1}$$

Where subscript t is time. Q_t is the quantity of final products, and Q_{jt} is the quantity of intermediate inputs. Parameter $\varepsilon\in[0,\infty)$ is a constant and denotes the elasticity of substitution between the outputs of the two sectors. Parameters $\omega_1,\omega_2\in(0, 1)$ are constants and satisfies $\omega_1+\omega_2=1$.

In the sectors of intermediate inputs, a representative firm employs technologies with a nested constant elasticity of substitution (CES) for manufacturing:

$$Q_{1t}=\left[\alpha_1\left(A_{1t}^m M_{1t}\right)^{(\sigma_1-1)/\sigma_1}+(1-\alpha_1)\left(Y_{1t}\right)^{(\sigma_1-1)/\sigma_1}\right]^{\sigma_1/(\sigma_1-1)} \tag{2}$$

$$Q_{2t}=\left[\alpha_2\left(A_{2t}^m M_{2t}\right)^{(\sigma_2-1)/\sigma_2}+(1-\alpha_2)\left(Y_{2t}\right)^{(\sigma_2-1)/\sigma_2}\right]^{\sigma_2/(\sigma_2-1)} \tag{3}$$

Where M_{jt} is AI services, Y_{jt} is the value-added input of capital, labor and other production factors, and A_{jt}^m is AI-specific technology. Value-added input depicts the traditional mode of production, and the elasticity of substitution between AI and production factors or traditional modes of production is a constant $\sigma_j\in[0,\infty)$. Parameter $\alpha_j\in(0, 1)$ is a constant.

Value-added is created by capital and labor and satisfies production technologies with a constant elasticity of substitution between production factors:

$$Y_{1t}=\left[\gamma_1^k\left(A_{1t}^k K_{1t}\right)^{(\eta_1-1)/\eta_1}+\gamma_1^l\left(A_{1t}^l L_{1t}\right)^{(\eta_1-1)/\eta_1}\right]^{\eta_1/(\eta_1-1)} \tag{4}$$

$$Y_{2t}=\left[\gamma_2^k\left(A_{2t}^k K_{2t}\right)^{(\eta_2-1)/\eta_2}+\gamma_2^l\left(A_{2t}^l L_{2t}\right)^{(\eta_2-1)/\eta_2}\right]^{\eta_2/(\eta_2-1)} \tag{5}$$

Where K_{jt}, L_{jt} respectively denote capital and labor, and their elasticity of substitution is η_j. A_{jt}^k, A_{jt}^l are capital- and labor-specific technologies, respectively. Parameters $\gamma_j^k\in(0, 1)$ and $\gamma_j^l\in(0, 1)$ are both constants satisfying $\gamma_j^h+\gamma_j^l=1$.

The relative demand of intermediate inputs can be satisfied by solving the problem of profit maximization for representative companies in the sector of final products:

$$\frac{Q_{1t}}{Q_{2t}}=\frac{\omega_1}{\omega_2}\left(\frac{P_{1t}}{P_{2t}}\right)^{-\varepsilon} \tag{6}$$

Where P_{jt} is the price of the two sectors of intermediate inputs. With final products as numeraire, price is standardized as 1.

By solving the problem of profit maximization for representative companies in the sector of intermediates, it can be learned that demand for AI services, capital and labor respectively satisfies the following conditions:

$$p_t^m = \alpha_j P_{jt} \left(A_{jt}^m\right)^{(\sigma_j - 1)/\sigma_j} Q_{jt}^{1/\sigma_j} M_{jt}^{-1/\sigma_j} \tag{7}$$

$$r_t = \left(1 - \alpha_j\right) \gamma_j^k P_{jt} \left(A_{jt}^k\right)^{(\eta_j - 1)/\eta_j} Q_{jt}^{1/\sigma_j} Y_{jt}^{1/\eta_j - 1/\sigma_j} K_{jt}^{-1/\eta_j} \tag{8}$$

$$w_t = \left(1 - \alpha_j\right) \gamma_j^l P_{jt} \left(A_{jt}^l\right)^{(\eta_j - 1)/\eta_j} Q_{jt}^{1/\sigma_j} Y_{jt}^{1/\eta_j - 1/\sigma_j} L_{jt}^{-1/\eta_j} \tag{9}$$

Where p_t^m, r_t, w_t are the price of AI services, capital rent, and labor compensation, respectively.

In each period, the supplies of AI services, capital and labor are M_t, K_t, L_t, respectively, whose market clearing conditions are as follows:

$$M_t = M_{1t} + M_{2t} \tag{10}$$

$$K_t = K_{1t} + K_{2t} \tag{11}$$

$$L_t = L_{1t} + L_{2t} \tag{12}$$

On the demand side, the lifetime utility of a representative household can be expressed as:

$$\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\rho} - 1}{1 - \rho}$$

Where $\beta \in (0, 1)$, $\rho \in (0, \infty)$ are both constants. In each phase, the total return on AI services $p_t^m M_t$ is used to compensate for the cost of AI services, and the household's total income is the sum between capital income and labor income $r_t K_t + w_t L_t$. After the government collects aggregate tax G_t, the household uses after-tax income for consumption C_t and investment I_t, and investment goes into capital accumulation. The household budget constraints are:

$$C_t + I_t = r_t K_t + w_t L_t - G_t \tag{13}$$

$$K_{t+1} = (1 - \delta^k) K_t + I_t \tag{14}$$

Where parameter $\delta^k \in (0, 1)$ is a constant and denotes capital depreciation rate.

In each period, the government invests aggregate tax revenue G_t into AI development to form new infrastructure:

$$H_{t+1} = (1 - \delta^h) H_t + G_t \tag{15}$$

Where H_t is new infrastructure. Parameter $\delta^h \in (0, 1)$ is a constant, and denotes the depreciation rate of new infrastructure. The amount of AI services reflects the level of AI development, which is determined by new infrastructure. It is assumed that the two satisfy the following linear relationship:

$$M_t = B H_t \tag{16}$$

Where $B \in (0, \infty)$ is the efficiency of new infrastructure in offering AI services.

3. Theoretical Analysis

This section solves static equilibrium and analyzes the structural effect of AI development. In the interest of more straightforward expression, subscript *t* is removed from all variables.

3.1 Equilibrium

The proportions of AI services, capital and labor employed in Sector 1 are defined as follows:

Change in variables x^k, x^l reflects the process of industrial structural change. Notably, x^m, x^k, x^l respectively measure the intensities in the use of AI, capital and labor in production sectors. Without losing generality, it is assumed that $x^k > x^l$, i.e. Sector 1 is capital-intensive and Sector 2 is labor-intensive.

$$x^m = M_1/M, x^k = K_1/K, x^l = L_1/L$$

Combining equations (11) and (12) may lead to three equations that determine equilibrium:

$$\frac{\alpha_1}{\alpha_2}\left(\frac{\omega_1}{\omega_2}\right)^{1/\varepsilon}\frac{Q_1^{1/\sigma_1-1/\varepsilon}}{Q_2^{1/\sigma_2-1/\varepsilon}}\frac{\left(1-x^m\right)^{1/\sigma_2}}{\left(x^m\right)^{1/\sigma_1}}=\frac{\left(A_2^m\right)^{(\sigma_2-1)/\sigma_2}}{\left(A_1^m\right)^{(\sigma_1-1)/\sigma_1}}M^{1/\sigma_1-1/\sigma_2} \tag{17}$$

$$\frac{\gamma_2^k}{\gamma_1^k}\left(\frac{A_2^k}{A_2^l}\right)^{(\eta_2-1)/\eta_2}\frac{\left(x^k\right)^{1/\eta_1}}{\left(1-x^k\right)^{1/\eta_2}}\left(\frac{K}{L}\right)^{1/\eta_1-1/\eta_2}=\frac{\gamma_2^l}{\gamma_1^l}\left(\frac{A_1^k}{A_1^l}\right)^{(\eta_1-1)/\eta_1}\frac{\left(x^l\right)^{1/\eta_1}}{\left(1-x^l\right)^{1/\eta_2}} \tag{18}$$

$$\frac{\alpha_1}{\alpha_2}\frac{\left(A_1^m\right)^{(\sigma_1-1)/\sigma_1}}{\left(A_2^m\right)^{(\sigma_2-1)/\sigma_2}}\frac{\left(x^m\right)^{-1/\sigma_1}}{\left(1-x^m\right)^{-1/\sigma_2}}M^{1/\sigma_2-1/\sigma_1}=\frac{1-\alpha_1}{1-\alpha_2}\frac{\gamma_1^k}{\gamma_2^k}\frac{\left(A_1^k\right)^{(\eta_1-1)/\eta_1}}{\left(A_2^k\right)^{(\eta_2-1)/\eta_2}}\frac{\left(x^k\right)^{-1/\eta_1}}{\left(1-x^k\right)^{-1/\eta_2}}\frac{Y_1^{1/\eta_1-1/\sigma_1}}{Y_2^{1/\eta_2-1/\sigma_2}}K^{1/\eta_2-1/\eta_1} \tag{19}$$

From equations (8) and (9), changes in the factor income shares satisfy:

$$\begin{aligned}d\log\left(\frac{rK}{wL}\right)=&\frac{\eta_1-1}{\eta_1}\frac{\eta_1x^l}{\eta_1x^l+\eta_2\left(1-x^l\right)}d\log\left(\frac{A_1^k}{A_1^l}\right)+\frac{\eta_2-1}{\eta_2}\frac{\eta_2\left(1-x^l\right)}{\eta_1x^l+\eta_2\left(1-x^l\right)}d\log\left(\frac{A_2^k}{A_2^l}\right)\\&+\frac{\left(\eta_1-1\right)x^l+\left(\eta_2-1\right)\left(1-x^l\right)}{\eta_1x^l+\eta_2\left(1-x^l\right)}d\log\left(\frac{K}{L}\right)+\frac{x^k-x^l}{\eta_1x^l+\eta_2\left(1-x^l\right)}\frac{d\log x^k}{1-x^k}\end{aligned} \tag{20}$$

From equations (17) - (19), both changes in AI services M and AI-specific technologies A_j^m will lead to upgrading of industrial structural change, i.e. changes in x^k, x^l. Based on equation (20), this has further changed the ratio of capital income and labor income, thus altering the labor income share.

3.2 Impact of AI Services

Let θ_j^k be the output elasticity of AI:

$$\theta_j^m=\frac{\alpha_j\left(A_j^mM_j\right)^{(\sigma_j-1)/\sigma_j}}{\alpha_j\left(A_j^mM_j\right)^{(\sigma_j-1)/\sigma_j}+(1-\alpha_1)\left(Y_j\right)^{(\sigma_j-1)/\sigma_j}}$$

and let θ_j^k, θ_j^l be the value-added elasticities of capital and labor, respectively:

$$\theta_j^k=\frac{\gamma_j^k\left(A_j^kK_j\right)^{(\eta_j-1)/\eta_j}}{\gamma_j^k\left(A_j^kK_j\right)^{(\eta_j-1)/\eta_j}+\gamma_j^l\left(A_j^lL_j\right)^{(\eta_j-1)/\eta_j}},$$

$$\theta_j^l=\frac{\gamma_j^l\left(A_j^lL_j\right)^{(\eta_j-1)/\eta_j}}{\gamma_j^h\left(A_j^hK_j\right)^{(\eta_j-1)/\eta_j}+\gamma_j^l\left(A_j^lL_j\right)^{(\eta_j-1)/\eta_j}}.$$

The following proposition can be obtained through a static analysis of equations (17) - (20) with respect to AI services M.

Proposition 1: If $\varepsilon \le \sigma_1$ and $\varepsilon \le \sigma_2$, then

$$\frac{d\log x^k}{d\log M}>0\Leftrightarrow\frac{d\log x^l}{d\log M}>0\Leftrightarrow\theta_1^m\left(\sigma_1-\varepsilon\right)<\theta_2^m\left(\sigma_2-\varepsilon\right)$$

$$\frac{d\log\left(rK/wL\right)}{d\log M}>0\Leftrightarrow\left(x^{k}-x^{l}\right)\frac{d\log x^{l}}{d\log M}>0$$

With rising AI services, capital and labor will be reallocated between industrial sectors, and the direction of flow is subject to the difference between the output elasticity θ_j^m of AI, the elasticity of substitution σ_j between AI and traditional modes of production, and the elasticity of substitution ε between products from different sectors. The direction of change in the labor income share is subject to the process of industrial structural change. If AI prompts a flow of production factors to capital-intensive sectors, the labor income share will decrease, and vice versa. The following two cases may bring more clarity to the economic mechanism of Proposition 1.

Case 1: $\sigma_1=\sigma_2=1$. In the case, $\theta_j^m=\alpha_j$. The elasticity of substitution between AI and traditional modes of production is 1, and parameter α_j simultaneously measures the density and output elasticity of AI. Proposition 1 becomes:

$$\frac{d\log x^{k}}{d\log M}>0\Leftrightarrow\frac{d\log x^{l}}{d\log M}>0\Leftrightarrow\alpha_1\left(1-\varepsilon\right)<\alpha_2\left(1-\varepsilon\right)$$

With rising AI services, if the elasticity of substitution between sectoral outputs is greater than 1, production factors will move to sectors with greater output elasticities of AI, and vice versa. The reason is that with more AI services, there will be a greater increase in the output of sectors with greater output elasticities of AI and hence the decreasing relative prices of output, and firms will use output from this sector to replace output from another sector.

When the elasticity of substitution between sectoral outputs is greater than 1, the effect of substitution is sufficient, and the output of a sector with relative price decreases will increase more sharply, causing this sector to expand. In this manner, production factors will flow into sectors with greater output elasticities of AI. If the output elasticity of AI is higher in capital-intensive sectors, this structural upgrade will increase demand for capital more sharply, causing the share of labor income to shrink. If the output elasticity of AI is greater in labor-intensive sectors, the share of labor income will increase. On the contrary, when the elasticity of substitution between sectoral outputs is smaller than 1, although the output of a sector with falling output elasticity of AI will increase, falling prices will play a dominant role since the effect of substitution is very small, causing this sector to shrink. Hence, production factors will flow from sectors with greater output elasticities of AI. If the output elasticity of AI is greater in capital-intensive sectors, this structural change will increase labor demand more sharply, resulting in an increase in the share of labor income. However, if the output elasticity of AI is greater in labor-intensive sectors, the labor income share will decrease.

Case 2: $\sigma_1=\varepsilon=1$. In this case, the elasticity of substitution between products from two sectors of intermediate inputs and the elasticity of substitution between AI and traditional modes of production in Sector 1 is 1. Proposition 1 becomes:

$$\frac{d\log x^{k}}{d\log M}>0\Leftrightarrow\frac{d\log x^{l}}{d\log M}>0\Leftrightarrow\sigma_2>1$$

With rising AI services, production factors will move to sectors with lower elasticities of substitution between AI and traditional modes of production. The reason is that amid rising AI services, the relative cost of using AI services will decrease, and enterprises will replace production factors with AI. In sectors with greater elasticities of substitution between AI and traditional modes of production, production factors will be replaced more broadly, causing a greater proportion of production factors to flow to sectors with smaller elasticities of substitution between AI and traditional modes of production. If the elasticity of substitution between AI and traditional modes of production is smaller than in labor-intensive sectors, this structural change will more significantly raise demand for capital, resulting in a decrease in the share of labor income. However, if the elasticity of substitution between AI and traditional modes of production is smaller in labor-intensive sectors than in capital-intensive sectors, the share of labor income will increase.

3.3 Impact of AI-Expansion Technologies

The following Proposition can be obtained after conducting a comparative static analysis of AI services A_j^m with equations (17) - (19).

Proposition 2: If $\varepsilon \leq \sigma_1$ and $\varepsilon \leq \sigma_2$, then

$$\frac{d\log x^k}{d\log A_1^m} > 0 \Leftrightarrow \frac{d\log x^l}{d\log A_1^m} > 0 \Leftrightarrow \left(\frac{1}{\varepsilon}-\frac{1}{\sigma_1}\right)\frac{1}{\sigma_2}\theta_1^m < \Omega$$

$$\frac{d\log x^k}{d\log A_2^m} > 0 \Leftrightarrow \frac{d\log x^l}{d\log A_2^m} > 0 \Leftrightarrow \left(\frac{1}{\varepsilon}-\frac{1}{\sigma_2}\right)\frac{1}{\sigma_1}\theta_2^m > \Omega$$

Where,

$$\Omega = \left(\frac{1}{\varepsilon}-\frac{1}{\sigma_1}\right)\left(\frac{1-\sigma_2}{\sigma_2}\right)\theta_1^m\left(1-x^m\right) + \left(\frac{1}{\varepsilon}-\frac{1}{\sigma_2}\right)\left(\frac{1-\sigma_1}{\sigma_1}\right)\theta_2^m x^m$$

Changes in AI-specific technologies cause factors moving across sectors, and the direction of flow is subject to the difference in the output elasticity θ_j^m of AI across industrial sectors and the elasticity of substitution σ_j between AI and traditional modes of production, as well as the elasticity of substitution between sectoral outputs ε. Similarly, the direction of change in the share of labor income is subject to the process of the industrial structural change. If AI causes production factors to flow to capital-intensive industries, the share of labor income will decrease, and vice versa. Here, we continue our discussions under the two special circumstances to give more clarity to the economic mechanism of Proposition 2.

Case 1: $\sigma_1=\sigma_2=1$. In this case, Proposition 2 becomes:

$$\frac{d\log x^k}{d\log A_1^m} > 0 \Leftrightarrow \frac{d\log x^l}{d\log A_1^m} > 0 \Leftrightarrow \varepsilon > 1,\ \frac{d\log x^k}{d\log A_2^m} > 0 \Leftrightarrow \frac{d\log x^l}{d\log A_2^m} > 0 \Leftrightarrow \varepsilon < 1$$

When the elasticity of substitution between sectoral outputs is greater than 1, production factors will flow to sectors with increasing AI-specific technologies, and vice versa. The reason is that AI-specific technology progress makes those sectors more productive in relative terms, thus reducing their relative prices.

When the elasticity of substitution between sectors is greater than 1, such effect of substitution is significant enough, and the sector with a relative price decline will experience a greater increase in output, causing this sector to expand. Hence, production factors will flow into sectors with increasing AI-specific technologies. Furthermore, if AI-specific technologies increase in capital-intensive sectors, this structural change will beef up demand for capital more sharply, causing the share of labor income to shrink. Yet if AI-specific technology improves in labor-intensive sectors, the share of labor income will rise. On the contrary, if the elasticity of substitution between sectoral outputs is smaller than 1, the price effect will cause production factors to flow out from the sector with increasing AI-specific technologies. If AI-specific technologies increase in capital-intensive sectors, this structural change will increase labor demand more sharply, causing the share of labor income to rise. If AI-specific technology increases in labor-intensive sectors, the share of labor income will decrease.

Case 2: $\sigma_1=\varepsilon=1$. In this case, Proposition 2 becomes:

$$\frac{d\log x^k}{d\log A_2^m} > 0 \Leftrightarrow \frac{d\log x^l}{d\log A_2^m} > 0 \Leftrightarrow \sigma_2 > 1,\ \frac{d\log x^k}{d\log A_1^m} = \frac{d\log x^l}{d\log A_1^m} = 0$$

After AI-specific technologies increase in a production sector, if the elasticity of substitution between AI and traditional mode of production is higher in this sector, production factors will flow to another sector with a smaller elasticity of substitution. If the elasticity of substitution between AI and traditional modes of production is lower in this production sector, more production factors will flow to this sector. The reason is that after AI-specific technologies increase, this sector will replace production factors with more productive AI. If the elasticity of substitution between AI and traditional mode of production in the sector is higher, this effect of substitution will become very strong, and production factors will be replaced more broadly, causing a greater proportion of production factors to flow to another sector.

Furthermore, if AI-specific technologies increase in labor-intensive sectors and the elasticity of substitution between AI and traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, the process of structural change will increase demand for capital more sharply, causing the share of labor income to decrease. If the elasticity of substitution between AI and traditional modes of production is lower in labor-intensive sectors than in capital-intensive sectors, the share of labor income will rise. On the contrary, if AI-specific technologies increase in capital-intensive sectors and the elasticity of substitution between AI and traditional modes of production is lower in capital-intensive sectors than in labor-intensive sectors, such structural change will increase labor demand more sharply, causing the labor income share to rise. Yet if the elasticity of substitution between AI and traditional modes of production is higher in capital-intensive sectors than in labor-intensive sectors, the labor income share will decrease.

4. Numerical Simulation

4.1 Parametric Selection

Let sectors 1 and 2 respectively represent capital-intensive sector and labor-intensive sector. γ_1^k, γ_2^k are assigned the values of 0.75 and 0.25, respectively. Accordingly, γ_1^l, γ_2^l are given the values of 0.25 and 0.75. We set both ω_1, ω_2 to be 0.5, so that the shares of output from both sectors are within the range between 40% and 60% in the initial stage. We set the elasticities of substitution with capital and labor η_1, η_2 to be both 1.

The depreciation rates of capital and new infrastructure δ^k, δ^h are both specified to be 0.05. Investment rate is specified as 40%, which is consistent with China's economy. It is assumed that the government invests 2% of the aggregate value-added in each phase in new infrastructures. These values only decide the speed of new infrastructure growth with a minimal impact on the conclusions demonstrated in the simulation. The efficiency of AI services provided by new infrastructures B is specified as a constant of 100. Labor supply remains to be 1. In the initial phase, AI services are specified as 1 to obtain the infrastructure stock of the initial phase. All technical parameters are specified as 1 and remain constant. The initial stock of capital is adjusted to make ratio of initial capital to output to be 5, which equals China's capital output ratio of 2017 in the Penn World Table 9.1 database.

Household preference parameters are configured as values commonly adopted in the literature. The value of time preference factor β is 0.96, and the reciprocal of elasticity of cross-temporal substitution ρ is 1. Parameter α_j influences the elasticity of AI output; parameter σ_j is the elasticity of substitution between AI and traditional modes of production; parameter ε_j is the elasticity of substitution between products from the two industrial sectors. In the following section, the values of those parameters will be modified within a reasonable range. Simulation will be conducted for 30 periods, i.e. economic performance in the coming three decades.

4.2 Environment with Different Output Elasticities of AI across Sectors

The values of parameters σ_1, σ_2 are both specified to be 1 to examine the effects of AI under different

AI output elasticities. Hence, parameters α_1, α_2 determine the output elasticity of AI in capital- and labor-intensive sectors. α_1, α_2 are assigned the values of 0.1 and 0.2 to simulate an environment with a higher output elasticity of AI in labor-intensive sectors, and the values of 0.2 and 0.1 to simulate an environment with higher output elasticity of AI in capital-intensive sectors. Despite smaller product substitution elasticities between agriculture, industry and services (Herrendorf *et al*., 2013), the elasticity of product substitution within each sector is high (Broda and Weinstein, 2006; Hendel and Nevo, 2006). Given that manufacturing is divided into capital-intensive and labor-intensive industries overlapping with agriculture, industry and services, we specify the value of product substitution elasticity ε to be 0.5 and 1.5, respectively, to simulate an environment with low or high substitution elasticity.

4.2.1 Environment with a higher output elasticity of AI in labor-intensive sectors

The logarithmic value of AI service level for the initial period is specified as 0 to estimate the effects of AI services. Based on benchmark model 1, the low elasticity of substitution between sectoral outputs and the high elasticity correspond to the benchmark models 1a and 1b. Then, the logarithmic value of AI service level for the initial period is raised to 4. Since differences exist in the two circumstances after the initial period and the effects of AI services cannot be separated, we are only concerned with differences in industrial structure and share of labor income in the initial period. Figure 1 shows the effects of AI services during this period. Consistent with theoretical analysis, at a higher level of AI services in the initial period, when the substitution between sectoral outputs elasticity is low, capital-intensive industries will account for higher shares of output and employment, and the share of labor income is smaller; when substitution between sectoral outputs elasticity is high, the direction of change becomes the opposite.

Table 1 reports quantitative results. After the logarithmic value of AI services is raised to 4, when

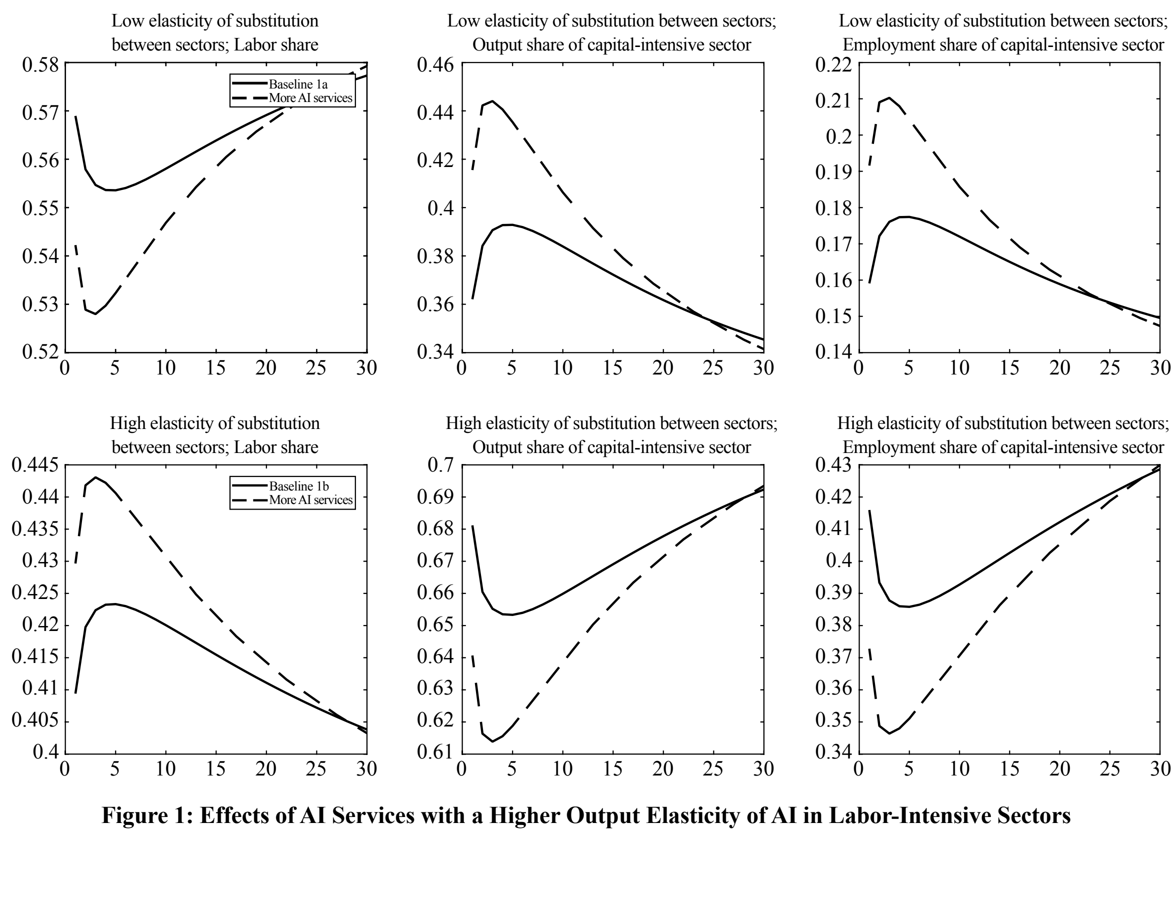

Figure 1: Effects of AI Services with a Higher Output Elasticity of AI in Labor-Intensive Sectors

Table 1: Effects of AI with a Higher Output Elasticity of AI in Labor-Intensive Sectors

Difference between key variables and the benchmark model	Logarithmic value of AI services is raised by 4 in the initial period		AI-specific technology increases by 10% on an annual average basis in labor-intensive sectors		AI-specific technology increases by 10% on an annual average basis in capital-intensive sectors	
	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high
Share of labor income	-0.027	0.020	-0.028	0.024	0.019	-0.016
Share of output from capital-intensive sectors	0.053	-0.040	0.056	-0.048	-0.037	0.033
Share of employment in capital-intensive sectors	0.032	-0.043	0.033	-0.052	-0.020	0.039

the elasticity of substitution between sectoral outputs is low, the shares of output and employment in capital-intensive sectors will increase by 5.3 and 3.2 percentage points in the initial period, respectively, causing the share of labor income to decrease by 2.7 percentage points. When the elasticity of substitution between sectoral outputs is relatively high, the shares of output and employment in capital-intensive sectors will decrease by 4.0 and 4.3 percentage points in the initial period, respectively, causing the share of labor income to rise by 2.0 percentage points.

To evaluate the effects of AI-specific technologies, we fix AI services at the level of the initial period and let AI-specific technologies in labor-intensive or capital-intensive sectors increase by an annual average of 10% for a re-simulation. Figure 2 shows the effects of AI-specific technologies with higher AI output elasticity in labor-intensive sectors, with relevant quantitative results shown in Table 1. Consistent with theoretical analysis, as AI-specific technologies increase in labor-intensive sectors, when the elasticity of substitution between sectoral outputs is low, the shares of output and employment in capital-intensive sectors will increase, causing the share of labor income to decrease. When the elasticity of substitution between sectoral outputs is higher, the direction of change is the opposite. Increases in AI-specific technologies in capital-intensive sectors and those in labor-intensive sectors create opposite effects.

As shown in Table 1, as AI-specific technology improves in labor-intensive sectors, when the elasticity of substitution is low, the shares of output and employment in labor-intensive sectors will increase at the end of the period by 5.6 and 3.3 percentage points, respectively, causing the share of labor income to decrease by 2.8 percentage points. When the elasticity of substitution between sectoral outputs is high, the shares of output and employment in labor-intensive sectors will decrease by 4.8 and 5.2 percentage points, respectively, causing the share of labor income to rise by 2.4 percentage points.

With rising AI-specific technologies in capital-intensive sectors, when the elasticity of substitution between sectoral outputs is low, the shares of output and employment in capital-intensive sectors account will decrease by 3.7 and 2.0 percentage points at the end of the period, respectively, causing the share of labor income to rise by 1.9 percentage points. When the elasticity of substitution between sectoral outputs is high, the shares of output and employment in capital-intensive sectors will increase by 3.3 and 3.9 percentage points, respectively, causing the share of labor income to decrease by 1.6 percentage points.

4.2.2 Environment with a higher output elasticity of AI in capital-intensive sectors

When the output elasticity of AI is even higher in capital-intensive sectors, we make the benchmark

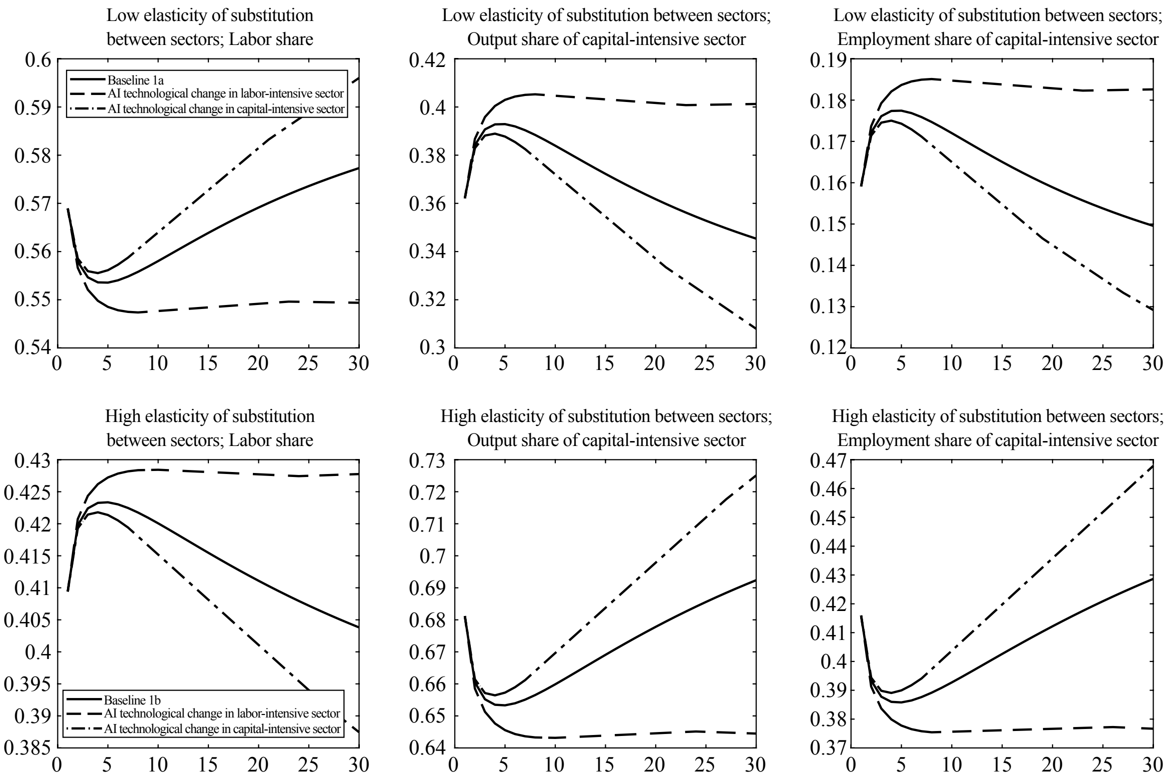

Figure 2: Effects of AI-Specific Technology with a Higher Output Elasticity of AI in Labor-Intensive Sectors

models with relatively low and high elasticities of substitution between sectoral outputs as benchmark models 2a and 2b. Figure 3 shows the effects of AI services at this moment. Consistent with theoretical analysis, the effects of AI services are in the opposite direction compared with the scenario the output elasticity of AI is higher in labor-intensive sectors. At a higher AI service level in the initial period, when the elasticity of substitution between sectoral outputs is relatively low, capital-intensive sectors will account for lower shares of output and employment in the initial period, and labor income will account for a higher share; when the elasticity of substitution between sectoral outputs is relatively high, the direction of change is the opposite.

Table 2 reports quantitative results. After the logarithmic value of AI services is raised to 4 in the initial period, when the elasticity of substitution between sectoral outputs is low, the shares of output and employment in capital-intensive sectors will decrease by 4.8 and 2.6 percentage points in the initial period, respectively, causing the share of labor income to rise by 2.4 percentage points. When the elasticity of substitution between sectoral outputs is high, the shares of output and employment in capital-intensive sectors will increase by 4.3 and 4.0 percentage points, respectively, causing the share of labor income to fall by 2.1 percentage points.

Figure 4 provides the effects of AI-specific technologies when the output elasticity of AI is higher in capital-intensive sectors with quantitative results in Table 2. Consistent with the theoretical analysis, the direction of the impact of AI-specific technologies does not change compared with the case when the output elasticity of AI is higher in labor-intensive industries, but the magnitude of impact is different.

As shown in Table 2, with increasing AI-specific technologies in labor-intensive sectors, when the substitution between sectoral outputs elasticity is low, the shares of output and employment in capital-intensive sectors will increase by 2.0 and 0.9 percentage points at the end of period, respectively, causing

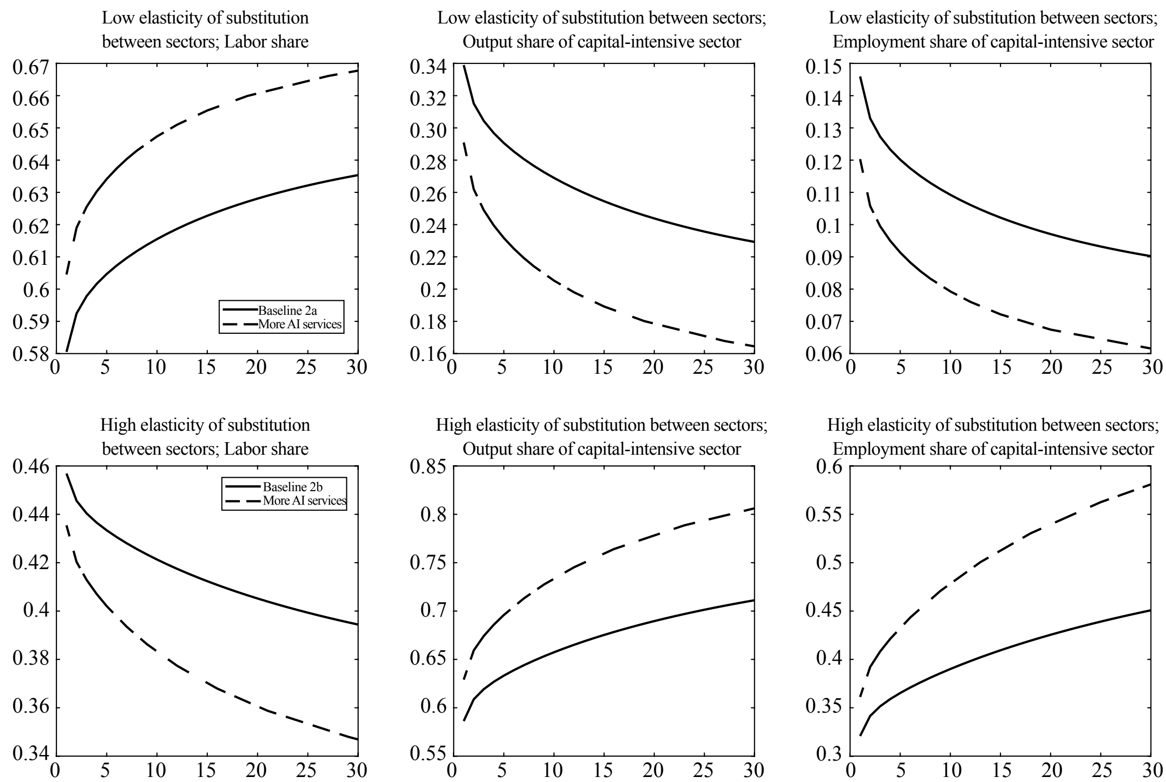

Figure 3: Effects of AI Services with a Higher Output Elasticity of AI in Capital-Intensive Sectors

Table 2: Effects of AI with a Higher Output Elasticity of AI in Capital-Intensive Sectors

Difference between key variables and the benchmark model	Logarithmic value of AI services is raised by 4 in the initial period		AI-specific technology increases by 10% on an annual average basis in labor-intensive sectors		AI-specific technology increases by 10% on an annual average basis in capital-intensive sectors	
	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high	Elasticity of substitution between sectoral outputs is low	Elasticity of substitution between sectoral outputs is high
Share of labor income	0.024	-0.021	-0.010	0.011	0.027	-0.033
Share of output from capital-intensive sectors	-0.048	0.043	0.020	-0.022	-0.053	0.067
Share of employment in capital-intensive sectors	-0.026	0.040	0.009	-0.026	-0.024	0.088

the share of labor income to fall by 1.0 percentage point. When the substitution between sectoral outputs elasticity is high, the shares of output and employment in capital-intensive sectors will decrease by 2.2 and 2.6 percentage points, respectively, causing the share of labor income to rise by 1.1 percentage points.

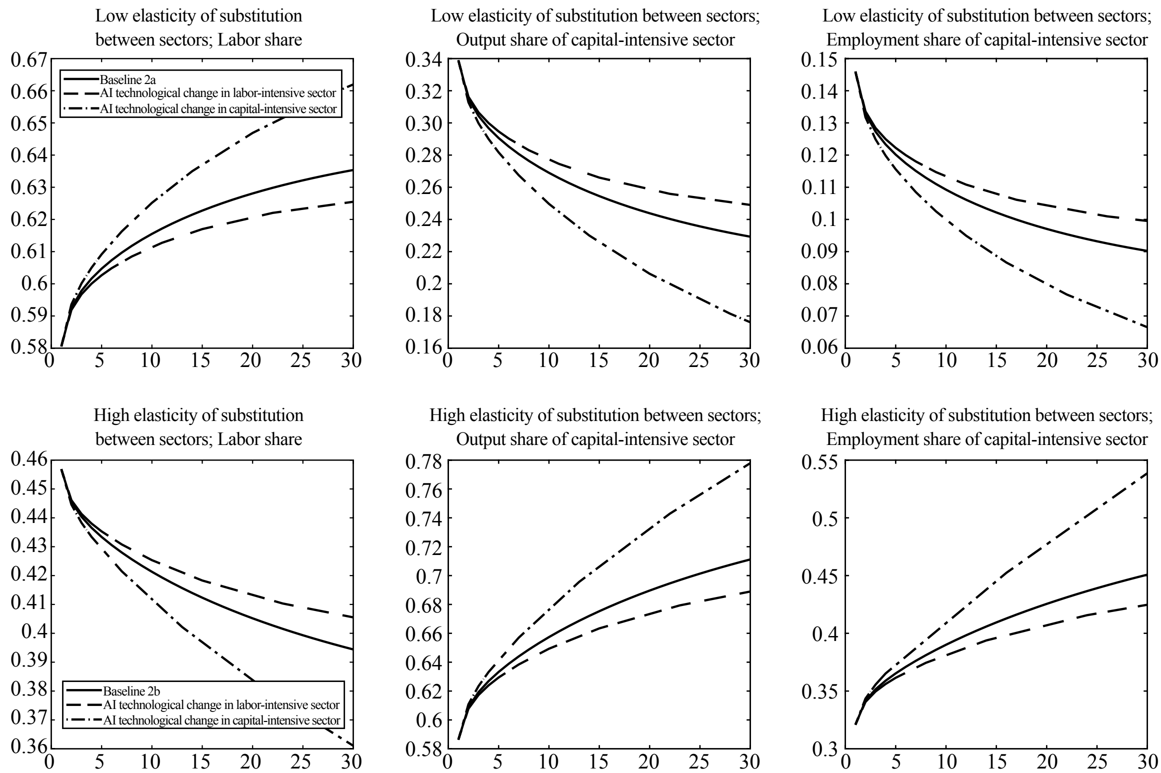

Figure 4: Effects of AI-Specific Technologies with a Higher Output Elasticity of AI in Capital-Intensive Sectors

With increasing AI-specific technologies in capital-intensive sectors, when the substitution between sectoral outputs elasticity is low, the shares of output and employment in capital-intensive sectors will decrease by 5.3 and 2.4 percentage points at the end of period, respectively, causing the share of labor income to rise by 2.7 percentage points. When the substitution between sectoral outputs elasticity is high, the shares of output and employment in capital-intensive sectors will increase by 6.7 and 8.8 percentage points, respectively, causing the share of labor income to fall by 3.3 percentage points.

4.3 Environment with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

To examine AI's effects in environments with different elasticities of substitution between AI and traditional modes of production, parameters σ_1, ε are both set to be 1, and parameters α_1, α_2 are both set to be 0.1. Parameter σ_2 is set to be 2 to simulate an environment where the elasticity of substitution between AI and traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, and the benchmark model is specified to be 3a; parameter σ_2 is assigned the value of 0.5 to simulate an environment where the elasticity of substitution between AI and traditional modes of production is lower in labor-intensive sectors than in capital-intensive sectors, and the benchmark model is specified to be 3b.

Figure 5 shows the effects of AI services. Consistent with the theoretical analysis, when AI services are at a higher level in the initial period and the elasticity of substitution between AI and traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, capital-intensive sectors account for higher shares of output and employment with a smaller share of labor income. When the elasticity of substitution between AI and traditional modes of production is smaller in

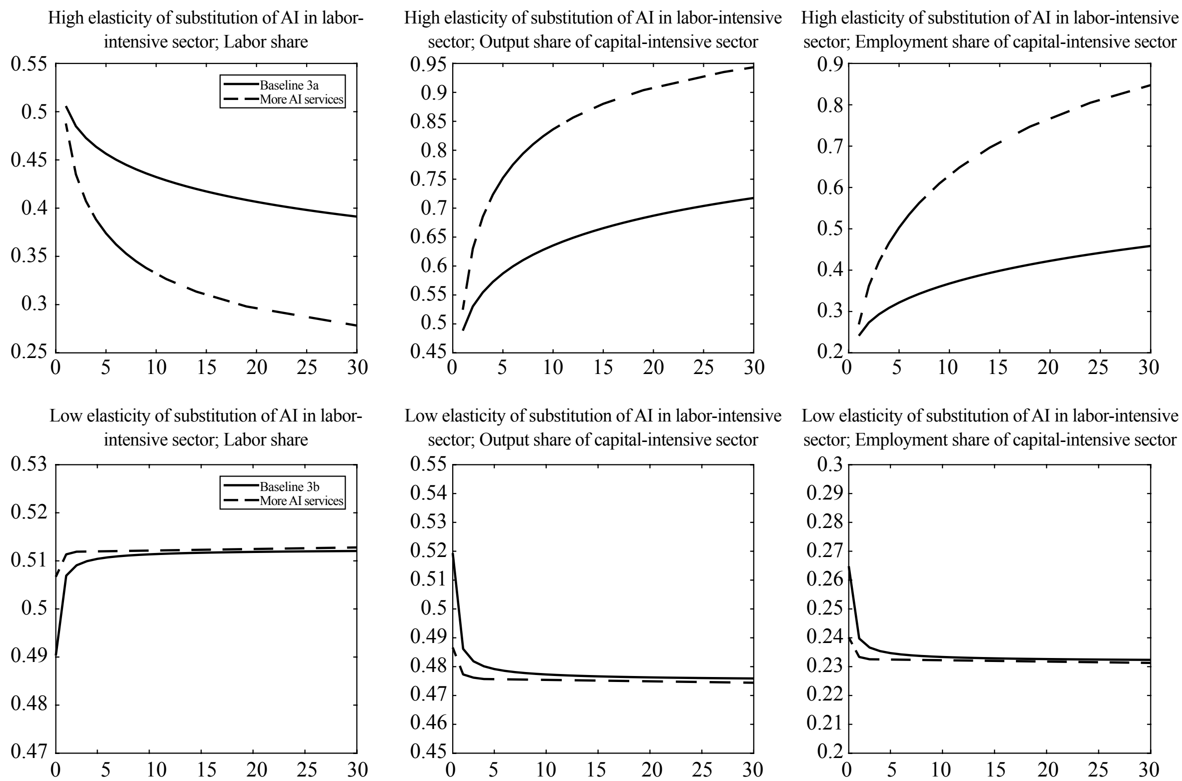

Figure 5: Effects of AI Services with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

labor-intensive sectors than in capital-intensive sectors, the direction of change is the opposite. At this moment, change in the use of AI services in the two sectors is in the opposite direction to change in the shares of output and capital.

Table 3 reports the quantitative results. After the logarithmic value of AI services is raised to 4, when the elasticity of substitution between AI and traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, the shares of output and employment in capital-intensive sectors will increase by 3.6 and 2.7 percentage points in the initial period, respectively, causing the share of labor income to decline by 1.8 percentage points. When the elasticity of substitution between AI and traditional modes of production is smaller in labor-intensive sectors than in capital-intensive sectors, the shares of output and employment in capital-intensive sectors will decrease by 3.3 and 2.5 percentage points in the initial period, respectively, causing the share of labor income to rise by 1.6 percentage points.

We make AI-specific technologies increased by an annual average of 10% for a re-simulation to evaluate the effects of AI-specific technologies and fix AI services at the level of the initial period. In evaluating the effects of AI-specific technologies in capital-intensive sectors, we may set the value of σ_2 to be 1 while changing the value of σ_1. At this moment, however, the direction of impact is opposite to the direction of impact of AI-specific technologies in labor-intensive sectors, and the degree of impact is the same. The details will not be elaborated here.

Figure 6 provides the effects of AI-specific technologies in labor-intensive sectors, and the quantitative results can be seen in Table 3. Consistent with theoretical analysis, with increasing AI-specific technologies in labor-intensive sectors, when the elasticity of substitution between AI and

Table 3: Effects of AI with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

Difference between key variables and the benchmark model	Logarithmic value of AI services is raised by 4 in the initial period		AI-specific technology increases by 10% on an annual average basis in labor-intensive sectors	
	Elasticity of substitution between AI and traditional modes of production is high in labor-intensive sectors	Elasticity of substitution between AI and traditional modes of production is low in labor-intensive sectors	Elasticity of substitution between AI and traditional modes of production is high in labor-intensive sectors	Elasticity of substitution between AI and traditional modes of production is low in labor-intensive sectors
Share of labor income	-0.018	0.016	-0.120	0.001
Share of output from capital-intensive sectors	0.036	-0.033	0.241	-0.002
Share of employment in capital-intensive sectors	0.027	-0.025	0.426	-0.001

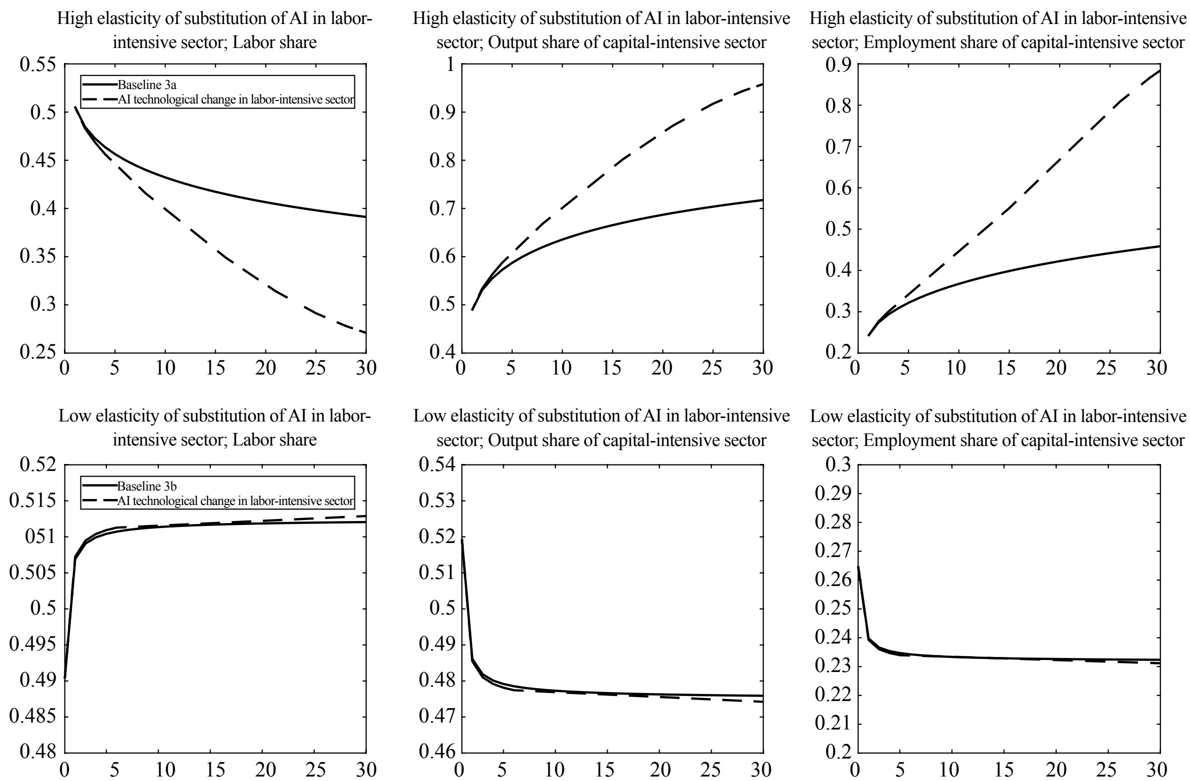

Figure 6: Effect of AI-Specific Technologies with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, the shares of output and employment in capital-intensive sectors will increase, and the share of labor income will decrease. When the elasticity of substitution between AI and traditional modes of production is smaller in labor-intensive sectors than in capital-intensive sectors, the direction of change is the opposite.

Since sectors with higher elasticities of substitution between AI and traditional modes of production have stronger inclinations to substitute the factors of production with AI, the direction of change in the share of AI services in the two sectors is the opposite to that of change in the shares of output and labor.

As can be learned from Table 3, when the elasticity of substitution between AI and traditional modes of production is higher in labor-intensive sectors than in capital-intensive sectors, increasing AI-specific technologies in labor-intensive sectors will cause the shares of output and employment in capital-intensive sectors to increase by 24.1 and 42.6 percentage points at the end of the period, respectively, resulting in a reduction in the share of labor income by 12.0 percentage points. When the elasticity of substitution between AI and traditional modes of production is lower in labor-intensive sectors than in capital-intensive sectors, the shares of output and employment in capital-intensive sectors will drop by 0.2 and 0.1 percentage points, respectively, resulting in an increase in the share of labor income by 0.1 percentage point.

6. Concluding Remarks and Policy Discussions

This paper analyzes the effects of AI on industrial structural change and labor income share. Policymakers should consider the differences in the output elasticities of AI and the elasticities of substitution between AI and traditional modes of production across sectors. This paper specifies the conditions for the direction of the effects of AI, and discusse the underlying economic mechanisms.

The theoretical perspectives in this paper contribute to analyses of AI's structural effects on the economy. Within manufacturing sectors, the elasticity of substitution between different goods is generally considered to be high, which implies that industries with more extensive AI applications will account for a much greater share of the manufacturing industry. Hence, whether capital-intensive or labor-intensive sectors will expand in the manufacturing industry depends on differences in the output elasticity of AI and the elasticity of substitution between AI and traditional modes of production. If capital-intensive sectors expand, the share of labor income will decline, and vice versa. On the other hand, the elasticity of substitution between manufactured goods and services is generally considered to be small. Change in the share of services is also subject to the prospect of AI applications in the two sectors. If AI accounts for a greater share of applications in manufacturing than in services, AI will promote service development. If AI accounts for a greater share of applications in services than in manufacturing, AI's development is likely to increase the share of manufacturing. Whether manufacturing and services are labor-intensive or capital-intensive will also further decide the directions of change in the share of labor income.

We derive two policy recommendations to facilitate industrial restructuring and promote equal access of labor and capital to technology dividends for high-quality development. First, AI's applications in specific sectors will create indirect effects on the development of other sectors. We suggest that the government improve business bankruptcy protection and market clearing systems, facilitate interregional industrial relocation, and avoid excess capacity in some sectors during the rapid transition of industrial structure. Second, since the government allocates public resources to support AI, the technology dividends of AI should be equally shared between labor and capital. If AI causes labor-intensive sectors to shrink, the share of labor income will decrease sharply, worsening income distribution. We suggest that the government adopt a more proactive redistribution policy. On one hand, the government should increase educational spending and skills training for workers, foster versatile talents and AI specialists, and adapt the workforce to new industries and technologies. On the other hand, the government may take steps to lower labor income tax and raise capital income tax. It may even levy a tax on robots. State-owned enterprises (SOEs) adopting AI technologies should take steps to increase the percentage of employee shareholding. The basic share of labor income should be stipulated for private enterprises receiving government subsidies for their R&D and application of AI technologies.

References:

[1] Acemoglu, Daron, and Pascual Restrepo. 2018. "The Race between Man and Machine: Implications of Technology for Growth, Factor Shares, and Employment." *American Economic Review*, 108(6): 1488-1542.

[2] Acemoglu, Daron, and Pascual Restrepo. 2019. "Automation and New Tasks: How Technology Displaces and Reinstates Labor." *Journal of Economic Perspectives*, 33(2): 3-30.

[3] Aghion, Philippe, Benjamin F. Jones, and Charles I. Jones. 2017. "Artificial Intelligence and Economic Growth." Working Paper, No.17-027.

[4] Agrawal, Ajay K., Joshua S. Gans, and Avi Goldfarb. 2019a. "Economic Policy for Artificial Intelligence." *Innovation Policy and the Economy*, 19: 139-159.

[5] Agrawal, Ajay, Joshua S. Gans, and Avi Goldfarb. 2019b. "Artificial Intelligence: The Ambiguous Labor Market Impact of Automating Prediction." *Journal of Economic Perspectives*, 33(2): 31-50.

[6] Benzell, Seth G., Laurence J. Kotlikoff, Guillermo LaGarda, Jeffrey D. Sachs. 2017. "Robots Are Us: Some Economics of Human Replacement." Working Paper.

[7] Bessen, James. 2018. "Automation and Jobs: When Technology Boosts Employment." Working Paper, No.17-09.

[8] Bresnahan, Tim, and Manuel Trajtenberg, 1995. "General Purpose Technologies: Engines of Growth." *Journal of Econometrics*, 65(1): 83-108.

[9] Broda, Christian, and David E. Weinstein. 2006. "Globalization and the Gains from Variety." *Quarterly Journal of Economics*, 121(2): 541-585.

[10] Brynjolfsson, Erik, Tom Mitchell, and Daniel Rock. 2018. "What Can Machines Learn and What Does It Mean for Occupations and the Economy." *AEA Papers and Proceedings*, 108(5): 43-47.

[11] Chen, Yufeng, Binwei Gui, Qiqing Chen. 2013. "Revisiting Technology Bias and the Share of Labor Income in China." *Economic Research Journal*, 48(6):113-126.

[12] Cheng, Hong, Ruixue Jia, Dandan Li, and Hongbin Li. 2019. "The Rise of Robots in China." *Journal of Economic Perspectives*, 33(2): 71-88.

[13] Graetz, Georg, and Guy Michaels. 2018. "Robots at Work." *Review of Economics and Statistics*, 100(5): 753-768.

[14] Hendel, Igal, and Aviv Nevo. 2006. "Measuring the Implications of Consumer Inventory Behavior." *Econometrica*, 74(6): 1637-1673.

[15] Herrendorf, Berthold, Richard Rogerson, and Akos Valentinyi. 2013. "Two Perspectives on Preferences and Structural Transformation." *American Economic Review*, 103(7): 2752-2789.

[16] Huang, Xianhai, and Sheng Xu. 2009. "Analysis of China's Falling Labor Income." *Economic Research Journal*, 44(7):34-44.

[17] Korinek, Anton, and Joseph E. Stiglitz. 2017. "Artificial Intelligence and Its Implications for Income Distribution and Unemployment." NBER Working Paper, No.W24174.

[18] Nordhaus, William. 2015. "Are We Approaching an Economic Singularity? Information Technology and the Future of Economic Growth." NBER Working Paper, No.W21574.

[19] Sachs, Jeffrey D., and Larry Kotlikoff. 2012. "Smart Machines and Long-Term Misery." NBER Working Paper, No.W18629.

[20] Wang, Linhui, and Li Yuan. 2018. "Biased Technology Progress, Industrial Restructuring and China's Factor Income Distribution." *Economic Research Journal*, 53(11): 115-131.

[21] Zeira, Joseph, 1998. "Workers, Machines, and Economic Growth." *Quarterly Journal of Economics*, 113(4): 1091-1117.

[22] Zhang Li, Jieyu Li, and Xianxiang Xu. 2012. "International Trade, Biased Technology Progress and Factor Income Distribution." *China Economic Quarterly*, 11(2):409-428.

Evaluation of Sustainable Infrastructure in the Context of the Belt and Road Initiative: A Case Study of Kenya C12 Road Reconstruction Project

Ran Aobo (冉奥博)[1*] and Wang Pusheng (王蒲生)[2]
[1] *Department of Sociology, Tsinghua University, Beijing, China*
[2] *Shenzhen International Graduate School, Tsinghua University, Shenzhen, China*

Abstract: *Sustainable development presents a challenge to most countries involved in the Belt and Road Initiative (BRI). Given the importance of infrastructure as a key aspect of the BRI, it is of great importance to investigate sustainable infrastructure in BRI countries. This paper explores how infrastructure meets the criteria of sustainable development and promotes sustainability. However, existing evaluation frameworks are not target-oriented, systematic, and practical. To fill this gap, we provide the framework based on the United Nations Sustainable Development Goals and apply it to the evaluation of the C12 Road Reconstruction Project. We find that the project promotes local sustainable development as a whole but has negative effects in some respects. In addition to excellent project management, the project still can improve public communication and local integration. In terms of policy implementation, we suggest summarizing the successful business model and promoting top-down and multi-dimensions designs.*

Keywords: *sustainable infrastructure, Sustainable Development Goals (SDGs), Belt and Road Initiative (BRI), Kenya, China, evaluation*
JEL Classification Code: Q01, Q56
DOI: 10.19602/j.chinaeconomist.2021.11.07

1. Introduction

The Belt and Road Initiative (BRI) is an international economic initiative put forth by China and an important platform for China's opening up. A priority of the BRI is to create a network of interconnection among BRI countries, and infrastructure is the material foundation of this network. Most BRI countries are developing countries, including some of the least developed countries (LCDs), which have a strong desire for sustainable development. What types of infrastructure should be built is a real question facing the BRI and determines the long-term benefits of sustainable development. The concept of sustainable infrastructure[1] has received great attention from academia and the industry and is recognized as a future direction of infrastructure development; in recent years, it has also been recognized by the international

* CONTACT: Ran Aobo, email: ranaobo@mail.tsinghua.edu.cn.

Acknowledgement: This paper is supported by National Social Science Fund of China (NSSFC) (Grant No.18VDL015) and Shenzhen Major Research Base of Humanities and Social Sciences. All thanks to China Wu Yi Co. Ltd (Nairobi, Kenya) and the China-Africa Leadership Development Institute, Tsinghua University. They support Ran to conduct the fieldwork in 2018 and 2020.

[1] Sustainable infrastructure development represents a general trend. In May 2017, the then Ministry of Environmental Protection, the Ministry of Foreign Affairs, the National Development and Reform Commission and the Ministry of Commerce jointly issued the *Guiding Opinions on Promoting the Green BRI*.

academia as a key challenge to the BRI. This paper offers a response to the heated discussions on this topic.

In the context of the BRI, the development of sustainable infrastructure offers great theoretical and practical benefits. Compared to the green infrastructure theory, sustainable infrastructure extends the original objective of specific ecological engineering to general infrastructure projects and the original ecological dimension to integration of economics, society, and ecology. Given the diverse cultural and natural conditions of BRI countries, case studies on different BRI countries will enrich the conceptions of sustainable infrastructure. As Thomé *et al.* (2016) noted, the future research on infrastructure should incorporate particular economic, social, and other factors. Meanwhile, such research contributes to the sustainable development of the BRI and BRI countries. Traditional infrastructure constructions may intensify income inequality and social injustice in sub-Saharan Africa (Calderón and Servén, 2010), so the relevant research would improve the current situation. This paper uses the framework based on the United Nations Sustainable Development Goals (SDGs) to evaluate a particular case.

Qualitative research is essential to evaluating sustainable infrastructure against the backdrop of the BRI. Despite an abundance of quantitative research on sustainable infrastructure, Conway *et al.* (2019) pointed out that with its people-centered and bottom-up attributes, sociological research remains an important supplement to quantitative research with a particularly important role in investigating economic and social fragility. Given the postcolonial background of many BRI countries, Anderson (2002) and Khandekar *et al.* (2017) both raised doubts over the applicability of the Western-dominated scientific research methods in the post-colonial setting, and scientific innovation requires local knowledge and wisdom. In this sense, qualitative research based on sociological and anthropological methods offers great inspiration, particularly for sustainable infrastructure research under the framework of SDGs. Since qualitative research offers interpretations based on more diverse and person-centered data at the local level, frontier research still requires qualitative analysis (Chester *et al*., 2019; Scott *et al*., 2019). Meanwhile, quantitative research is subject to data collection, which is intractable in many BRI countries, especially African countries, with missing local evaporation and air pollution data, as well as local socio-economic data and other data. Hence, this paper offers a qualitative analysis of the sustainable development effects of Kenya's C12 road reconstruction project based on a field survey.

Kenya is China's comprehensive strategic partner and a fulcrum of the BRI in East Africa and on the west coast of the Indian Ocean. Kenya is faced with many challenges to sustainable development. Kenya's economic and social structures are highly unequal, as manifested in its volatile GDP and nationwide riots triggered by the general elections of 2007 and 2017. Situated at the intersection between the equator and the Great Rift Valley, Kenya is home to numerous nature reserves and national parks under great pressures for environmental and biodiversity protection. Therefore, sustainable development is the only way Kenyan can pick. Unless adequate importance is attached to sustainable development concepts and standards, not only the Kenyan's benefits but also the long-term goals of the BRI will be compromised.

2. Sustainable Infrastructure Concept and Evaluation Framework

2.1 The Current Evaluation Framework

After the United Nations Conference on Environment and Development (UNCED) put forwards the concept of sustainable development, the infrastructure-related academia and industry proposed sustainable infrastructure as a response. From a sociological perspective, Choguill (1996) offered an interpretation of sustainable infrastructure. He identified material infrastructure systems as prerequisites for ensuring the sustainability of human settlements and serving the basic needs of human society. Since traditional infrastructure provided by the public sector could only serve certain groups of people rather than the entire people, a new paradigm is thus required to achieve sustainable development for all. Besides, most studies have proceeded from an environmental perspective.[2] Parkin (2000) regarded infrastructure as a boundary between the natural environment and the human society, the stability of which is predicated upon sustainable infrastructure. Martland (2011) and Raworth (2012) believed that infrastructure is subject to environmental sustainability and has to rely on nature to meet the basic needs of human society. In general, sustainable infrastructure refers to the whole process of infrastructure design, construction, and operation in line with the concept of sustainable development and to meet sustainable development goals.[3]

With the popularization of the sustainable infrastructure concept, the research on its evaluation models and frameworks is making progress. Focusing on inequality and sustainability in the social dimension and with the town system infrastructure and on-site infrastructure as the two aspects, Choguill (1996) bridged the social rift by integrating the two aspects and developed ten principles for sustainable infrastructure.[4] Ainger and Fenner (2014) identified the following criteria of sustainable infrastructure: Environmental sustainability, including setting goals and making measurements in response to environmental restrictions, and organizing and operating sustainable business modes and projects; socio-economic sustainability, including setting goals and making measurements to achieve socio-economic objectives, and respecting the people and human rights; cross-generational management mode, including long-term planning and full life-cycle considerations; complex systems, including opening problem areas, tackling uncertainties, considering integrated requests, and integrating various objectives and disciplines; learning new skills for sustainable activities, and challenging orthodox and encouraging change. Sarté (2010) provided various sustainable infrastructure models: The pillar model consisting of water, energy, material, ecological and community sustainability, the scale-density model and the cross-section model based on spatial hierarchies; and the built-ecological environment model based on human activity and ecosystem services. The American Institute of Architects and its Committee on the Environment (2015) also identified ten guidelines for promoting sustainable development, including conceptual innovation, regional/community design, land use and site ecology, biological climatology design, lighting and ventilation, water cycle, energy flow and future energies, material and construction, longevity and high-quality development, and collective wisdom and effective feedback. The American Society of Civil Engineers (2018) believed that the principle of sustainable infrastructure is to "do the right projects" and "do projects right," including performing life cycle assessment from planning to reuse, using resources wisely, planning for resiliency, and validating application of principles.

Most existing evaluation frameworks have the following problems. From the perspective of proactive behavior, they clearly regulate and encourage the sustainable behaviors of building and design, but their goal and vision are rather unclear. Therefore, the disconnection between behaviors and goals is unfavorable for evaluation to be carried out effectively. Although Ainger and Fenner (2014), the American Institute of Architects and its Committee on the Environment (2015) and the built-ecological environment model (Sarté, 2010) considered the realization of sustainable goals, their studies are not

[2] This part of research primarily stemmed from research on green infrastructure. Thomé et al. (2016) and other scholars saw green infrastructure as part of sustainable infrastructure, but this view is possibly incomplete. The concept of sustainable infrastructure came into existence in the 1980s when sustainable development was put forth while the research and practice of green infrastructure started as early as the 1960s. So, it is more likely that the environmental aspects of sustainable infrastructure have drawn upon the existing research results of green infrastructure.

[3] Ainger and Fenner (2014) described sustainable infrastructure as "infrastructure for sustainable development."

[4] The ten principles include: The co-existence of formal and informal dwellings in a city; the town system of infrastructure should be operated either by a city authority or a private firm nominated by that city, on a full cost-plus recovery basis; irregular land tenure issues should be resolved within the informal residential sectors of the city; informal infrastructure should be designed and built using external technical assistance as required, to be upgradable from a basic standard to that which can be incorporated, with time, into the town system; informal infrastructure built by the local community should be under its control; the technology adopted for informal-sector infrastructure must be maintainable by the community; the informal structure must be affordable by its low-income users; informal-sector infrastructure must be socially acceptable to the community involved; the government should adopt the role of facilitator and enable rather than merely as provider; non-governmental organizations can play a key role in assisting communities to develop infrastructure systems.

systematic enough and cannot depict the full picture of sustainability. They are far from the UN's SDGs, which means their frameworks are different to connect with SDGs-related policies, limiting their applicability. Furthermore, the models put forth by Choguill (1996) and the American Society of Civil Engineers (2018) are only guiding principles, which are hard to be applied at the practical level. Due to the problems, we suggest designing the new evaluation framework based on SDGs.

2.2 The Evaluation Framework Based on SDGs

Sustainable infrastructure refers to infrastructure at the service of sustainable development, which points out its goal for service. In establishing a new evaluation framework, therefore, we should reference relevant research on sustainable development. Although scholars (Shepherd, 2015; Chester, 2019) used or called for using the SDGs as the evaluation framework for sustainable infrastructure, in-depth case studies are absent. This paper fills this gap with a detailed case study on Kenya's C12 road renovation project.

In 2015, the United Nations adopted 17 Sustainable Development Goals (as shown in Table 1) to guide and evaluate sustainable development in various countries. This system of indicators is an

Table 1: Sustainable Development Goals (SDGs)

Goals	Descriptions
No poverty	End poverty in all its forms everywhere.
Zero Hunger	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
Good health and well-being	Ensure healthy lives and promote well-being for all at all ages
Quality education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Gender equality	Achieve gender equality and empower all women and girls.
Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all.
Affordable and clean energy	Ensure access to affordable, reliable, sustainable and modern energy for all.
Decent work and economic growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
Industry, innovation and infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
Reduced inequality	Reduce income inequality within and among countries.
Sustainable cities and communities	Make cities and human settlements inclusive, safe, resilient, and sustainable.
Responsible consumption and production	Ensure sustainable consumption and production patterns.
Climate action	Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.
Life below water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
Life on land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
Peace, justice and strong institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
Partnership for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Source: The United Nations (2015); The General Assembly, the United Nations (2015).

important supplement of the above-mentioned frameworks for the following reasons. The SDGs comprise a systematic network covering various aspects of sustainable development (Le Blanc, 2015), fully reflecting the economic, social, ecological, and institutional dimensions of sustainable development. The SDGs are goals-oriented, result-oriented, and evaluable, which can be more easily to be applied in specific cases. The SDGs have been agreed upon after long-term and extensive research and discussions among the academia and policymakers and ratified by all UN member states, so they are more acceptable.

It is feasible and original to introduce this framework for evaluating sustainable infrastructure. In terms of feasibility, the SDGs framework has already some applications at the national level (Bureau of the United Nations and Statistical Commission, 2015) and is also applicable to infrastructure to some extent. Griggs *et al*. (2013) and Shepherd *et al*. (2015) suggested incorporating the SDGs into the decision-making process, and infrastructure contain a series of decision-making about not only engineering but economics, society, and environment as well. In terms of originality, our evaluation under this framework integrates firms and local people into sustainable development, since we interviewed employees and local people about SDGs and the C12 road. The traditional pathway of realizing the SDGs is the top-down approach led by governments and intergovernmental organizations, and that in the future, firms, cities, and the public all need to participate (Hajer *et al*., 2015). Similarly, Stafford-Smith *et al*. (2017) believed that the achievement of the SDGs required the participation of diverse actors including local governments, the government sector, and the private sector in such areas as public finance, financial industry, energy, and transportation under an integrated platform involving high-income, middle-income, and low-income countries. Infrastructure is an integrated platform involving various sectors and actors, and the case study in this paper is also a cross-national one.

The evaluation of sustainable infrastructure also requires overall considerations to add or remove some evaluation criteria due to the complex correlation between various SDGs (Nilsson *et al*., 2016). Firstly, when various measures can be directly or indirectly linked to poverty eradication, it is hard to evaluate their respective poverty-reducing effects. The General Assembly of the United Nations (2015) identified poverty in all its forms as the biggest challenge to the world. The Open Working Group on Sustainable Development Goals (2014), Pradhan *et al.* (2017) and El-Maghrabi *et al.* (2018) also identified poverty as a manifestation of other sustainable development dilemmas. Secondly, the features of certain programs may also make some SDGs hard to evaluate. For instance, projects located in the hinterland of a continent (such as the case study in this paper) do little to protect life below water, and projects located in uninhabited regions do little to promote sustainable urbanization. Thirdly, infrastructure projects also need to consider the sustainability of the measurements to achieve sustainable development themselves. Projects without sustainable sources of income may promote sustainable development for a certain period but cannot last long. As Ainger and Fenner (2014) emphasized, sustainable business models are indispensable when approaching sustainability. In this case, we adjust the overall evaluation framework by removing the two goals of no poverty and on life below water of the SDGs while adding the goal of sustainable business model for achieving the SDGs.

3. Case Study: Kenya's C12 Road Reconstruction Project

We select Kenya's C12 Road Reconstruction Project as the case considering its importance, complexity, and effective management. Located in Narok County, the C12 Project is 82 kilometers long and serves as a golden channel from Narok County to the Sekenani Gate of Maasai Mara National Reserve. As Kenya's national project, C12 is undertaken by China WuYi (Kenya) Company. The main contents are road surface renovation from 0 to 23rd kilometers, construction of new sub-base, road base, and asphalt road surface from 23rd to 45th kilometers, and construction of road base and asphalt road surface from 45th to 82nd kilometers. The project faces complex social, economic, and ecological contradictions. Maasai Mara is the home to multiple ethnic groups with the Maasai being the dominant ethnic group.[5] The region is economically less developed with household income primarily from livestock and tourism industries. This area is located in arid and semiarid regions and adjacent to the Maasai Mara National Reserve, presenting challenges to protecting the fragile ecology. In response, the C12 Project has taken a swathe of mitigation measures to secure sustainable development.

3.1 Clean Water and Sanitation

C12 construction has greatly improved local water conditions and environment and led to progress in environmental sanitation. Although the road construction is normally irrelevant to the water and sanitation, this case is different. The WuYi Company built over 120 ponds for free for local people, each of which is about 8,000 cubic meters and values 1.5 million Kenyan shillings. These ponds store rainwater in rainy seasons preparing for activities during dry seasons. The WuYi Company constructed a small water supply pipeline network for free in the neighborhood near the Sekenani Gate to provide local residents with safe and paid access to drinking water. The Maasai Mara region has distinctive dry and rainy seasons, and water stored in ponds could provide much-needed water in the dry season. In the past, local residents relied on groundwater, sewer water, and crudely filtered domestic wastewater as sources of drinking water. In this region, groundwater has a high saline content and cannot be used as drinking water. Sewer water and domestic wastewater are of poor quality, vulnerable to contamination, unstable across seasons, and susceptible to the transmission of waterborne diseases. Meanwhile, the WuYi Company also planned to provide some households with simple water purification devices made of alums and bamboo charcoal to improve drinking water quality.

The ponds have generated huge social benefits by providing local households with sanitary and stable water sources. During the drought of 2017, in particular, the ponds served as a valuable water source for local households and livestock. In March 2020, the ponds storing unusually a mass of rainwater decreased the losses caused by continuous floods. During C12 construction, some ponds were under the joint management of the project headquarters and local communities and were transferred to local communities after project completion with a safety warning signboard. Most ponds are already under the management of local communities and have enhanced the management of water environment in local communities. Additionally, the WuYi Company made some wasted asphalt barrels into makeshift toilets to prevent open defecation.

3.2 Decent Work and Economic Growth

The WuYi Company offered a large number of jobs of all types, contributing to local economic growth and C12 will make such contribution as well. Without experiences of non-farm occupation, most Maasai people performed poorly in terms of punctuality, arithmetics and working efficiency in this case. The WuYi Company cultivated the culture of modern and industrial occupation, since it is the largest infrastructure project in Maasai Mara. The company directly employed 283 local workers and local subcontractors employed about 80 workers, offering local people decent jobs ranging from unskilled workers, mechanical drivers, gaugers, foremen, domestic helpers, gardeners, and cooks. The company also provided local employees with accommodations and non-local workers with job security[6] and basic vocational training to reduce the proportion of untrained youngsters. The company has also

---

[5] The Maasai is the most famous (semi)nomadic tribe in East Africa who was the biggest tribe in this area before colonization. Even now, the Maasai tribe still mainly keep the original and distinctive lifestyles, folk customs and social structure. The details can be referred to Homewood *et al*.(2009) for the Maasai ethnic group's history and evolution in modern society.

[6] Under Kenya's local parliament institution, local protectionism is prevalent among various counties. Members of local assemblies and executive officers would create barriers for residents from other countries to seek jobs in local jurisdictions to protect local employment. To some extent, legal aid may help nonlocal employees overcome those barriers.

brought banking and insurance services to local employees. In the past, most Maasai employees had no social insurance, medical insurance, and bank accounts. The WuYi Company purchased social insurance and medical insurance for all its employees and invited the Equity Bank to assist employees in applying for bank accounts. After its completion, C12 will facilitate transportation to the Maasai Mara National Reserve and promote tourism and Maasai folk culture such as folk art and handicrafts.[7] Many interviewed local women aim to sell Maasai souvenirs as self-employment.

3.3 Industry, Innovation and Infrastructure

C12 has greatly improved local infrastructure and expedited industrial development and innovation. C12 is intended to provide an affordable and high-quality road in Maasai Mara, designed to withstand rainstorms and other natural disasters, to shorten the journey from the original 2-2.5 hours to one hour. However, given the sporadic settlements of local residents, they were difficult to access the main road, which means the transportation in the area alongside C12 cannot be greatly improved. Therefore, the WuYi Company also constructed village roads when building stockyards and reservoirs in the local villages for local residents to access the main road with more convenience. The construction is conducive to logistical transportation and the development of industrial enterprises. Along the road, some private investors have established clothes factories and slaughterhouses. Improving access to transportation, as a whole, is conducive to an open socio-economic environment and helps promote small businesses in catering, hospitality, and manufacturing businesses. The WuYi Company also spent 1.5 million Kenyan shillings on the construction of base stations to eliminate mobile signal blindspots and deliver full signal coverage from Narok to Sekenani Gate.

3.4 Reducing Inequality

C12 will generally reduce national-wide regional and tribes' inequalities in Kenya and inequalities in local communities. The Narok County is a less developed region in Kenya with GDP per capita ranking the 33rd out of 47 Kenyan counties (Bundervoet *et al.*, 2015) primarily due to its failure to make effective use of local tourism, farming, and livestock resources. C12 road accelerates external flows of people, materials, capital, and information to Narok County and facilitates tourism development based on the Maasai Mara National Reserve, as well as agriculture and livestock. With Narok County as one of its primary settlements, the Maasai ethnic group has been at the fringe of Kenya's economy. By promoting local development, C12 helps balance the economic status of ethnic groups. The problem of wealth gaps also exists within the Maasai ethnic group, sharpened by drought in the dry season. While prosperous residents paid for the construction of ponds, the poor became worse off in drought. By constructing ponds free of charge for the poor, the WuYi Company helped to improve the abilities of local communities to cope with drought and water shortages, and thus narrowing wealth gaps within the Maasai tribe.

3.5 Sustainable Cities and Communities

C12 has facilitated the development of towns along the route, especially Narok. C12 passes through Narok, Ewaso Ng'iro, Nkoilale, Ngoswani, and Sekenani, bringing a greater flow of tourists to those villages and towns and prospering new settlements along the road. Narok is a vital city connecting Nairobi with the Maasai Mara National Reserve. In the past, Narok's development has been hindered by more than 2.5 hours' travel time to the Maasai Mara National Reserve. With improving the road condition and halving the amount of time, Narok has the promise to become an important distribution

[7] In our interview with Prof. Moses Muraya, dean of the Tourism and Hotel Department of the Maasai Mara University, he believed that road construction and the external shocks would change the Maasai people's ways of life but would not fundamentally weaken the Maasai culture. On the contrary, it would promote Maasai culture through tourism development and make it better known to outsiders.

hub of tourism and logistics[8] and develop a thriving serving industry, including hotels, restaurants, and retail business. By linking urban areas with suburban areas and the nature reserve, C12 helps forge economic, social, and environmental linkages in the locality. C12 used to be a rural dirt road rife with floating dust polluting local communities alongside the road caused by motor vehicle travel. After its completion, the new asphalt road is expected to sharply reduce floating dust.

3.6 Responsible Consumption and Production

This project contributes to local sustainable production and consumption, also in terms of C12 and the WuYi Company. Improving road conditions will facilitate transporting livestocks to other regions with fewer losses during the transportation. Increasing visitors and the local population will increase the consumption of milk, which often became wasted due to the lack of preservation techniques. The WuYi Company procured materials locally, such as stones, earth, and other industrial materials, and recycled surplus building materials and lubricants in an eco-friendly manner. It regularly drafted environmental performance reports, HIV/AIDS reports and incorporated relevant sustainability information into those reports. Its effective initiatives of sustainable development have been summarized and communicated to the headquarters for broader implementation.

3.7 Climate Actions

The WuYi Company has built large and medium-sized ponds to cope with regional climate change and extreme weather. The seasonal distribution of precipitation is extremely uneven in the Maasai Mara, which has been intensified in recent years amid climate change. Increasing volatility in precipitation - as reflected in the drought in 2017 followed by excessive rainfall in 2018 (Kahongeh *et al*., 2018), has posed severe challenges to local residents. Ponds constructed by the WuYi Company can store the excess rainwater and alleviate water shortage in the dry season. Instead of searching for water in the daily grazing during the dry season as they did in the past, the Maasai people now have convenient access to drinking water from ponds at or near their homes. In addition, the regional microclimate can also be improved by using ponds at scale. The WuYi Company is expected to reach the density of one pond every 500 meters, which will increase the humidity of the area by expanding the evaporation area, thereby improving the extremely arid climate and biodiversity.

3.8 Life on Land

By building ponds and green channels, the WuYi Company promotes sustainable ecosystems on land. Increasing water areas and improving grassland ecosystems and biodiversity will prevent desertification. Ecological improvement, in turn, broadens the space of survival for wildlife. The ponds have attracted wildebeests, zebras, kangaroos, and occasionally even elephants, as their drinking water resources. On both sides of the road, “no poaching” and “no wildlife trading” signboards have been put up at short intervals. C12 has also erected speed humps in the road sections frequented by wildlife to slow traffic and avoid road accidents that may kill wild animals or built culverts allowing wild animals to pass through. Wild animals unexpectedly killed in car crashes are required to be buried.

3.9 Partnerships for the Goals

C12 project has strengthened partnerships between China and the local community in Maasai Mara, as well as cooperation among industry, universities and research institutions. In particular, the WuYi Company has maintained good relationships with the chief of Maasai tribe Sayialel and local

---

[8] The best visiting time for the Maasai Mara National Reserve is dawn and dusk. Without C12, travel time is too long and forces many tourists to either stay at the reserve overnight or miss the best visiting time. Therefore, it makes no difference whether tourists stay in Nairobi or Narok since they will miss the best visiting time anyway. As soon as C12 road is put into operation, tourists will be able to stay in Narok and still reach the reserve in the best visiting time.

sheriffs,County Assembly members and executive officers. In the project design stage, the Chinese contractor worked closely with and offered numerous suggestions to the Kenyan designer, which represents a kind of technology transfer. Since 2017, C12 started to develop a doctoral internship program with Tsinghua University, China, which accepted postgraduate students from various disciplines such as water conservancy, environmental engineering, social sciences and business management.

3.10 Sustainability Measures

Instead of traditional one-way spending, the WuYi Company's sustainability measures are mutually beneficial in the long run. The company reduced material costs for road construction by making use of standard stone and earth materials left over from pond excavation or materials mined from the area belonging to the household whose pond is constructed by the company. While each pond with ancillary facilities costs 1-2 million Kenyan shillings to build, a borrow pit for stone and earth costs 1-1.5 million Kenyan shillings. Therefore, the pond construction is partly reciprocal. In addition, C12 supplies water stored in some of the ponds to the construction site, thus conserving water costs. These measures have reduced financial pressures for sustainable infrastructure and are easier to implement sustainably.

3.11 Other SDGs

Regarding zero hunger, the ponds would facilitate irrigated agriculture and create conditions for the development of privately invested farms alongside the road. At vegetable farms built in the WuYi Company's main camp, local residents are trained to use goat manure as organic fertilizer, build wind sheds and apply regular irrigation and other farming techniques. Regarding good health and well-being, the WuYi Company proactively carried out public communication on HIV/AIDS and distributes free condoms, and attaches great importance to their psychological health. Kenyan employees are free to go to church on Sunday, and the company allows religious practice in their living area provided by the company. Regarding quality education, C12 and village roads provide local children, especially Maasai children, with convenient transportation to schools, thus increasing local gross enrolment rates. The WuYi Company also provide unskilled local workers with vocational education. Regarding gender equality, the WuYi Company has implemented the policy of prioritizing female workers and paying female workers equally with their male counterparts. In addition, the project construction teams have also hired local women as cooks, providing them with job opportunities. Regarding cost-effective clean energy, the WuYi Company's camps use solar energy to heat water.

In a nutshell, the project has significantly positive effects on the achievement of ten SDGs, including clean water and sanitation, decent work and economic growth, industry, innovation and infrastructure, inequality reduction, sustainable cities and communities, responsible consumption and production, climate actions, life on land, and partnerships for the goals. It has relatively small or indirect effects on five SDGs, including no hunger, good health and well-being, quality education, gender equality and affordable and clean energy.

4. Policy Implications

This case demonstrates how the SDGs framework can be applied into a specific case and how a infrastructure project promotes sustainable development. Based on the previous analysis, we put forth the following policy implications:

4.1 Focus on the Key Goals and Key Initiatives

Sustainable infrastructure should find the main conflicts and key goals of the sustainable development which should be resolved and achieved respectively by the key initiatives, thus contributing to local sustainable levels increasing. In our case study, opening up and water resources are the key goals to infrastructure projects in the Maasai Mara. The construction of C12 increases the openness of this region, allowing it to be integrated into a broader and nationally unified market and even the global value chain. The ponds will improve local water environment and the capacity of climate response. Ecological environment is a fundamental factor of Maasai Mara's local economy dominated by tourism and livestock industries.

4.2 Sustainable Business Model for Win-Win

Sustainable infrastructure projects should match local conditions and adopt long-lasting business modes. In our case study, unlike the traditional model of one-way aid, the WuYi Company has designed a sustainable business model for the construction of ponds at scale. The company considers what the local community desires and what it can provide, and also what the local community can provide and what it wants. Based on both sides, the company launched the initiative of local ponds. Only when the business model considers what the local community really needs are the initiatives put into practice.

4.3 Attaching Importance to Localization and Cultural Exchanges

Sustainable infrastructure should participate in local governance and conduct cultural exchanges with local communities. In our case study, the WuYi Company has demonstration programs for modern agriculture, sanitation, and solar heaters, but their influences are limited due to the insufficiency of public communication with local communities, not to mention contributing to the SDGs. Although the company established friendly relationships with some local leaders, the company has little cooperation with diverse local institutions, especially universities and other institutions without direct business ties. We suggest infrastructure projects should cooperate with universities, cultural institutions, and restaurants for cultural activities such as the Chinese culture festival and the Chinese food party. Through cooperation with local communities, tribes, and churches, we can create a governance platform of cross-border consultation, joint contribution, and shared benefits and deepen local public awareness of the BRI and sustainable infrastructure.

4.4 Top-Level Policy Design for Global Governance

Through high-level dialogues and top-level policy framework, we should create a global governance system encompassing business environment, risk management, and green finance. The BRI is faced with great challenges of business climate and risk mitigation. Without a conducive business climate, it would be difficult to form sustainable business interactions. Without appropriate risk management, it would be challenging for the BRI to yield fruitful results in the long run. Negative effects of the infrastructure project as in this case study on local peace, justice and corruption are also common challenges for other infrastructure projects alongside the Belt and the Road. Transparency, supervision, and the rule of law are essential but beyond the remit of companies and require top-level policy design. The green finance system should be integrated into the BRI initiative to offer preferential loans and subsidies based on the evaluation criteria for sustainable infrastructure. Successful models of sustainable infrastructure operation should be identified and promoted according to local conditions.

4.5 Materializing the Concept of Community with Shared Future for Humankind

Sustainable infrastructure development under the BRI is not only an improvement of material conditions but represents the concept of community with a shared future for humankind by applying Chinese experience and wisdom in light of local conditions. A community with a shared future for mankind is a concept that goes beyond the concept of a country and a nation and is based on the unity of mankind. It is a value-guide for the development of diversification, civilization, and modernization. In promoting sustainable infrastructure, China can bring its experience and lessons of modernization and ecological civilization to BRI countries, expand the achievements of the BRI, and develop an awareness of the concept of community with shared future for humankind.

References:

[1] Abdalla Bujra. 2009. “Mijadala: A Discourse on Social Policy, Governance and Development Issue in Kenya.” Nairobi: Development Policy Management Forum.

[2] AIA and its COTE. 2015. “Ten Sustainability Measures.” http://www.acsa-arch.org/programs-events/competitions/competition-archives/2014-2015-cote-top-ten-for-students/ten-sustainability-measures. (accessed August 1, 2018).

[3] Ainger, Charles, and Fenner Richard. 2014. *Sustainable Infrastructure: Principles into Practice*. London: ICE Publishing.

[4] Anderson, Warwick. 2002. “Introduction: Postcolonial Technoscience.” *Social Studies of Science*, 32(5-6): 643-58.

[5] ASCE. 2018. “Policy Statement 418 - the Role of the Civil Engineer in Sustainable Development.” https://www.asce.org/issues-and-advocacy/public-policy/policy-statement-418---the-role-of-the-civil-engineer-in-sustainable-development/ (accessed August 1, 2018).

[6] Ascensão, Fernando, Fahrig Fernando, and Clevenger Anthony P. 2018. “Environmental Challenges for the Belt and Road Initiative.” *Nature Sustainability*, 1(5): 206-9.

[7] Bundervoet, Tom, Maiyo Laban, Sanghi Apurva. 2015. “Bright Lights, Big Cities: Measuring National and Subnational Economic Growth in Africa from Outer Space, with an Application to Kenya and Rwanda.” *The World Bank Policy Research Working Paper 7461*.

[8] Bureau of the United Nations Statistical Commission. 2015. “Technical Report by the Bureau of the United Nations Statistical Commission on the Process of the Development of an Indicator Framework for the Goals and Targets of the Post-2015 Development Agenda.” https://sustainabledevelopment.un.org/index.php?page=view&type=111&nr=6754&menu=35. (accessed May 15, 2018).

[9] Calderón, César, and Servén Luis. 2010. “Infrastructure and Economic Development in Sub-Saharan Africa.” *Journal of African Economies*, 19(s1): 13-87,

[10] Chester, Mikhail, V. 2019. “Sustainability and Infrastructure Challenges.” *Nature Sustainability*, 2: 265–6.

[11] Chester, Mikhail, V., Markolf Samuel, and Allenby Braden. 2019. “Infrastructure and the Environment in the Anthropocene.” *Journal of Industrial Ecology*, 23(5): 1006-15.

[12] Choguill, Charles, L. 1996. “Ten Steps to Sustainable Infrastructure.” *Habitat International*, 20(3): 389-404.

[13] Conway, Declan, Nicholls Robert J., and Brown Sally, et al. 2019. “The Need for Bottom-up Assessments of Climate Risks and Adaptation in Climate-sensitive Regions.” *Nature Climate Change*, 9(7): 503-11.

[14] Editorials. 2019. “Build a Sustainable Belt and Road.” *Nature,* 569: 5.

[15] El-Maghrabi M H, Gable S, Rodarte I O, et al. 2018. “Sustainable Development Goals Diagnostics: An Application of Network Theory and Complexity Measures to Set Country Priorities.” *The World Bank Policy Research Working Paper 8481*.

[16] Griggs, David, Stafford-Smith Mark, and Gaffney Owen, et al. 2013. “Sustainable Development Goals for People and Plane.” *Nature*, 7441(495): 305-307.

[17] Hajer, Maarten, Nilsson Måns, and Raworth Kate, et al. 2015. “Beyond Cockpit-ism: Four Insights to Enhance the Transformative Potential of the Sustainable Development Goals.” *Sustainability*, 7(2): 1651-60.

[18] Homewood, Katherine, Kristjanson Patti, Trench Pippa C. 2009. *Staying Maasai? Livelihoods*, *Conservation and Development in East African Rangelands*. New York: Springer.

[19] Kahongeh, James, Mutua, Kitavi, Atieno Winnie. 2018. *Kenyans to Battle Severe Climate Change Effects. Daily Nation News*, February 28.

[20] Khandekar, Aalok, Beumer Koen, and Mamidipudi Annapurna, et al. 2017. “STS for Development.” In *Handbook of Science and Technology Studies* (4th edition), edited by Ulrike F, Fouché R, Miller C, and Smith-Doerr L. Cambridge, MA: MIT Press.

[21] Le Blanc David. 2015. “Towards Integration at Last? The Sustainable Development Goals as a Network of Targets.” *Sustainable Development*, 23(3): 176-87.

[22] Liu, Wei, Hughes Alice C., and Sachdeva Gulshan, et al. 2020. “The Belt and Road Initiative and the Sustainable Development Goals.” *One Earth*, 3(3): 263-67.

[23] Martland, Carl, D. 2011. *Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers*. Hoboken, NJ: Wiley.

[24] Nilsson, Måns, Griggs Dave, and Visbeck Martin. 2016. “Map the Interactions between Sustainable Development Goals.” *Nature*, 534: 320-2.

[25] Open Working Group on Sustainable Development Goals. 2014. “Open Working Group on Sustainable Development Goals Annex 1. Interlinkages.” https://sustainabledevelopment.un.org/content/documents/3387Annex_interlinkages_1903.pdf. (accessed May 21, 2018).

[26] Parkin, S. 2000. “Sustainable Development: the Concept and Practical Challenges.” *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 138(6): 3-8.

[27] Pradhan, Prajal, Costa Luís, Rybski Diego, et al. 2017. “A Systematic Study of Sustainable Development Goal (SDG) Interactions.” *Earth’s Future*, 5: 1169-79.

[28] Raworth, Kate. 2012. A Safe and Just Space for Humanity: Can we Live Within the Doughnut? *Oxfam Discussion Paper*.

[29] Sarté, Bry, S. 2010. *The Green Infrastructure Guide: Innovative Water Resource, Site Design, and Land Planning Strategies for Design Professionals*. Hoboken, NJ: Wiley.

[30] Scott, Thacker, Daniel Adshead, and Marianne Fay. 2019. "Infrastructure for Sustainable Development." *Nature Sustainability*, 2: 324-31.

[31] Shepherd, Keith, Hubbard Douglas, amd Fenton Norman, et al. 2015. "Development Goals should Enable Decision-making." *Nature*, 523(7559): 152-4.

[32] Stafford-Smith, Mark, Griggs David, and Gaffney Owen, et al. 2017. "Integration: the Key to Implementing the Sustainable Development Goals." *Sustainability Science*, 12(6): 911-9.

[33] The General Assembly, the United Nations. 2015. "Transforming Our World: the 2030 Agenda for Sustainable Development." https://www.un.org/ga/search/view_doc.asp?symbol=A/69/L.85&Lang=E. (accessed March 18, 2018).

[34] The United Nations. 2015. "Take Action for the Sustainable Development Goals." https://www.un.org/sustainabledevelopment/sustainable-development-goals/(accessed March 17, 2018).

[35] Thomé, Antonio, M. T., Ceryno Paula S, and Scavarda Annibal, et al. 2016. "Sustainable Infrastructure: A Review and a Research Agenda." *Journal of Environmental Management*, 184(2): 143-56.