Artificial Intelligence, Structural Change and Labor Income Share

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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.*

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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

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[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."

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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."

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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.

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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:

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

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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:

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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:

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

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:

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

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

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

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

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

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

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

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:

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

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

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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:

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

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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

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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

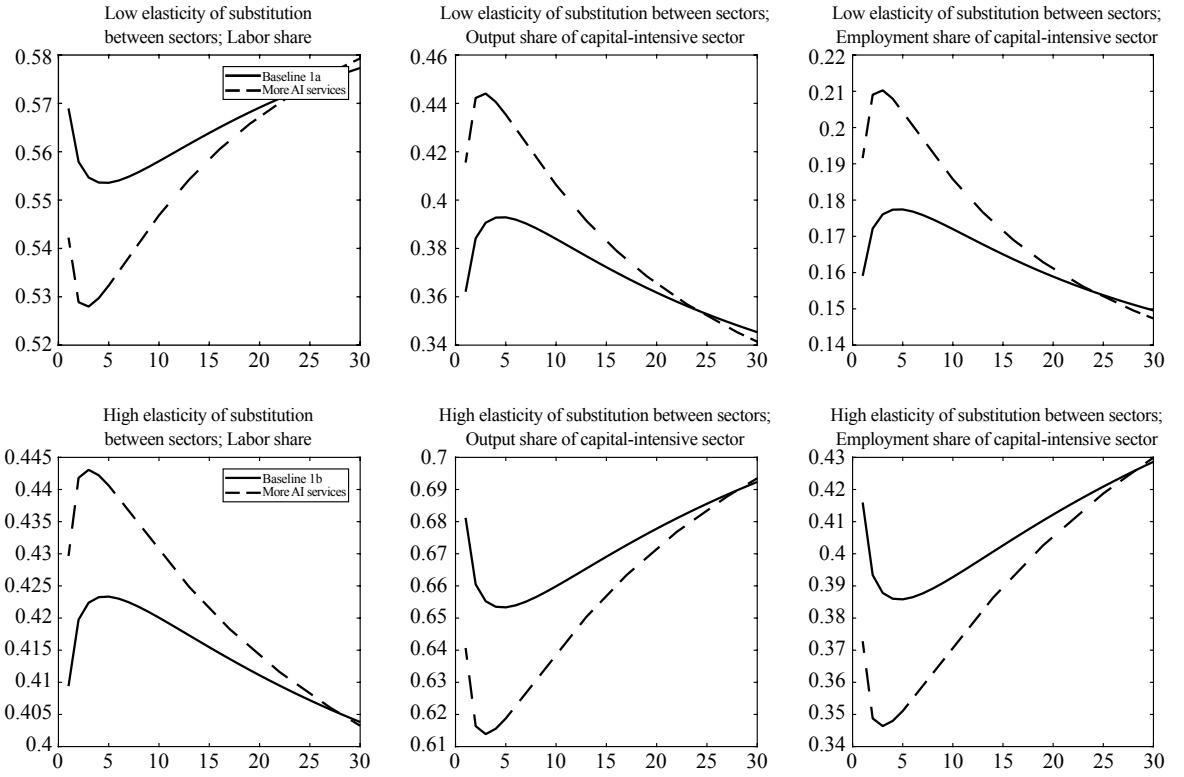

Figure 1: Effects of AI Services with a Higher Output Elasticity of AI in Labor-Intensive Sectors

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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

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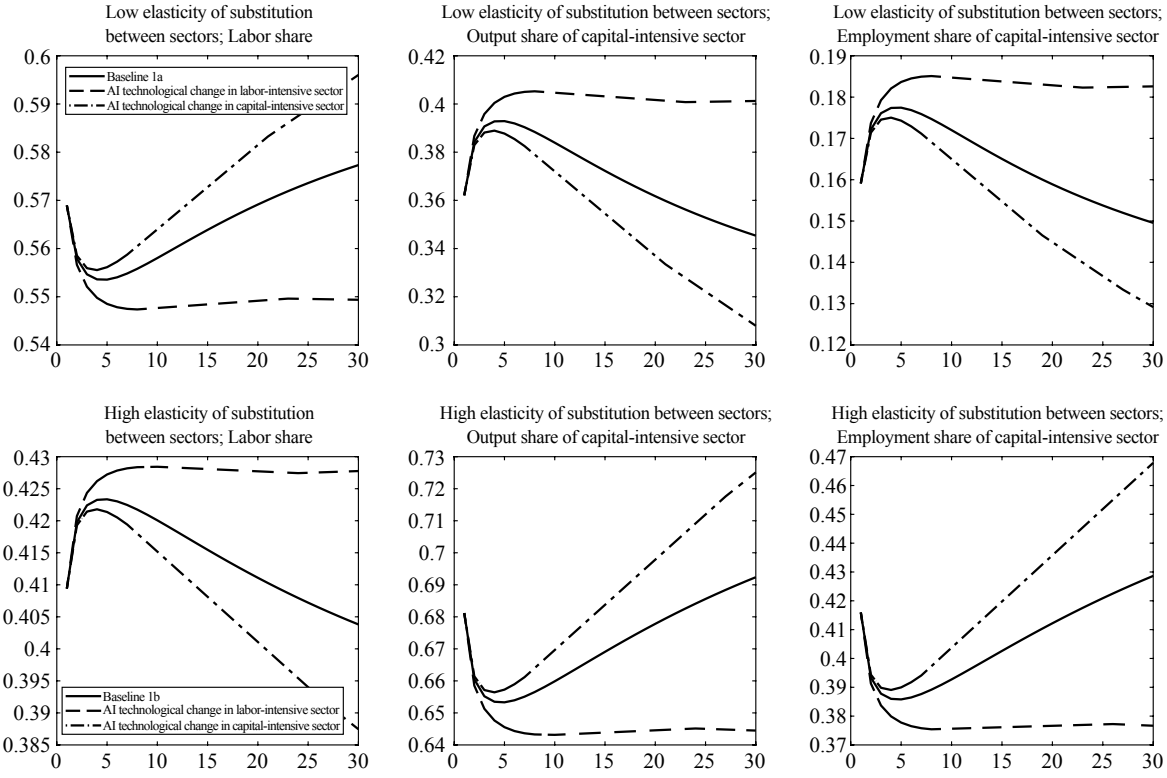

Figure 2: Effects of AI-Specific Technology with a Higher Output Elasticity of AI in Labor-Intensive Sectors

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

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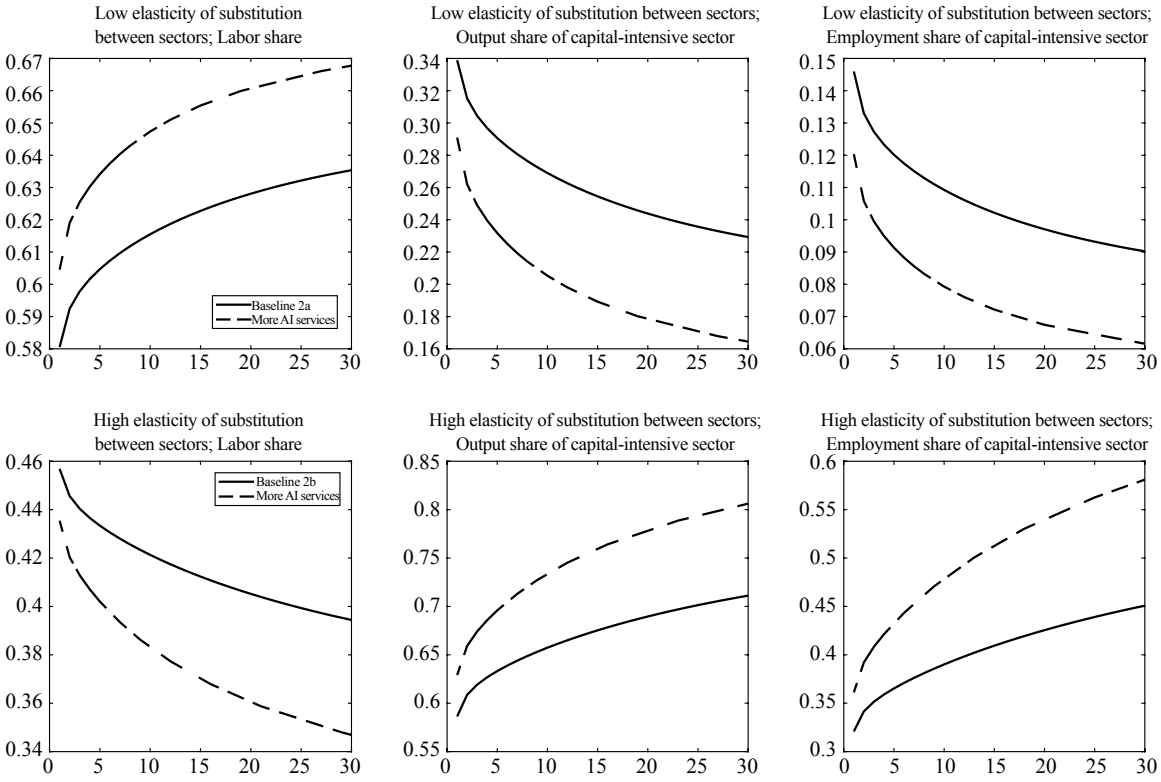

Figure 3: Effects of AI Services with a Higher Output Elasticity of AI in Capital-Intensive Sectors

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.

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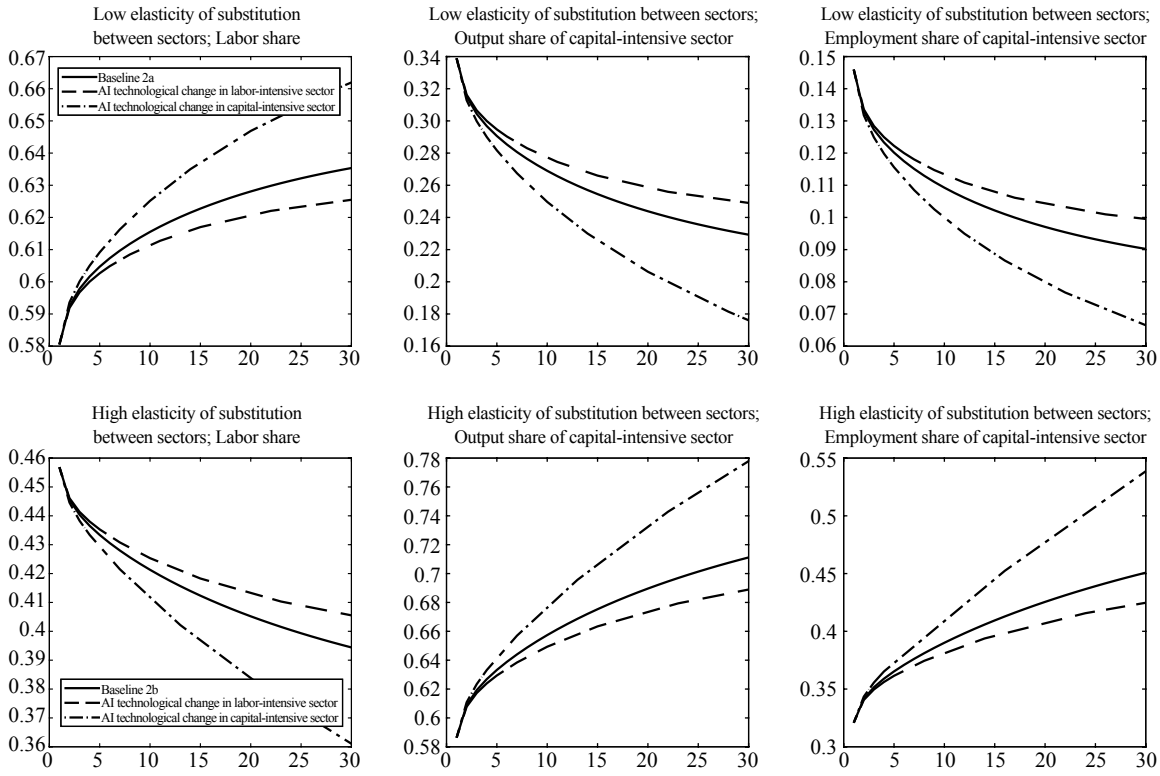

Figure 4: Effects of AI-Specific Technologies with a Higher Output Elasticity of AI in Capital-Intensive Sectors

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

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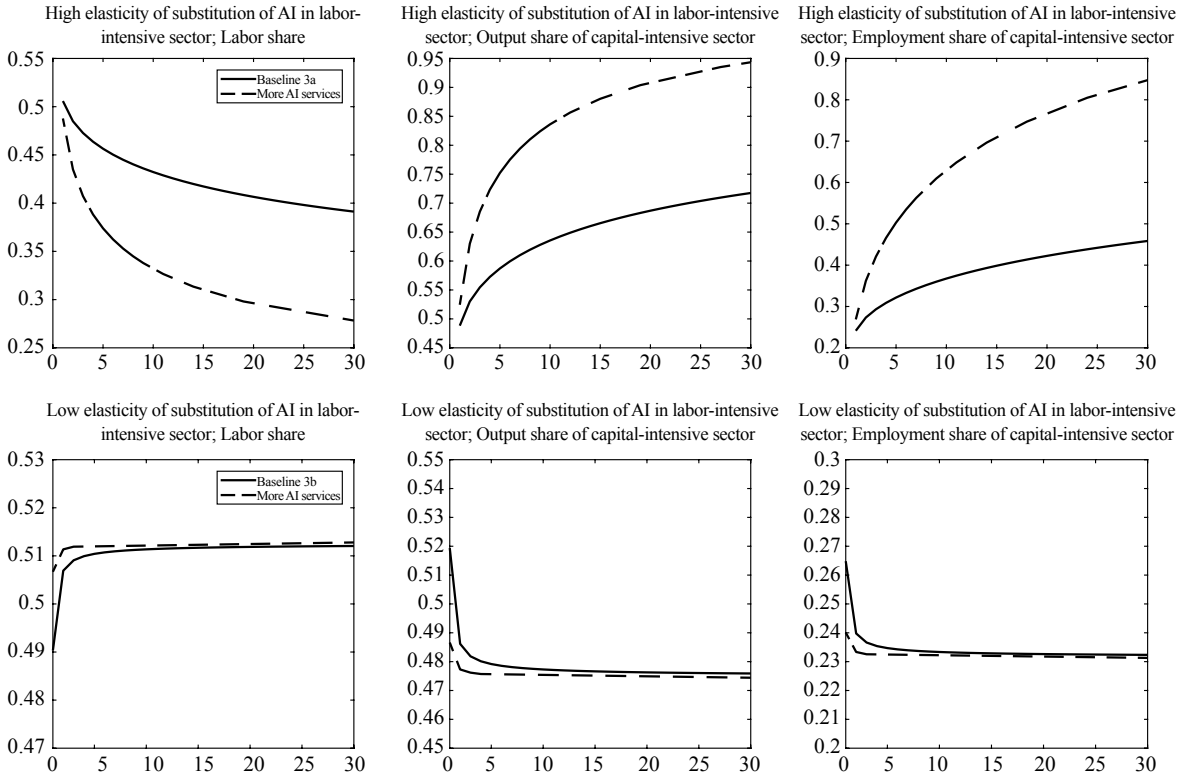

Figure 5: Effects of AI Services with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

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

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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

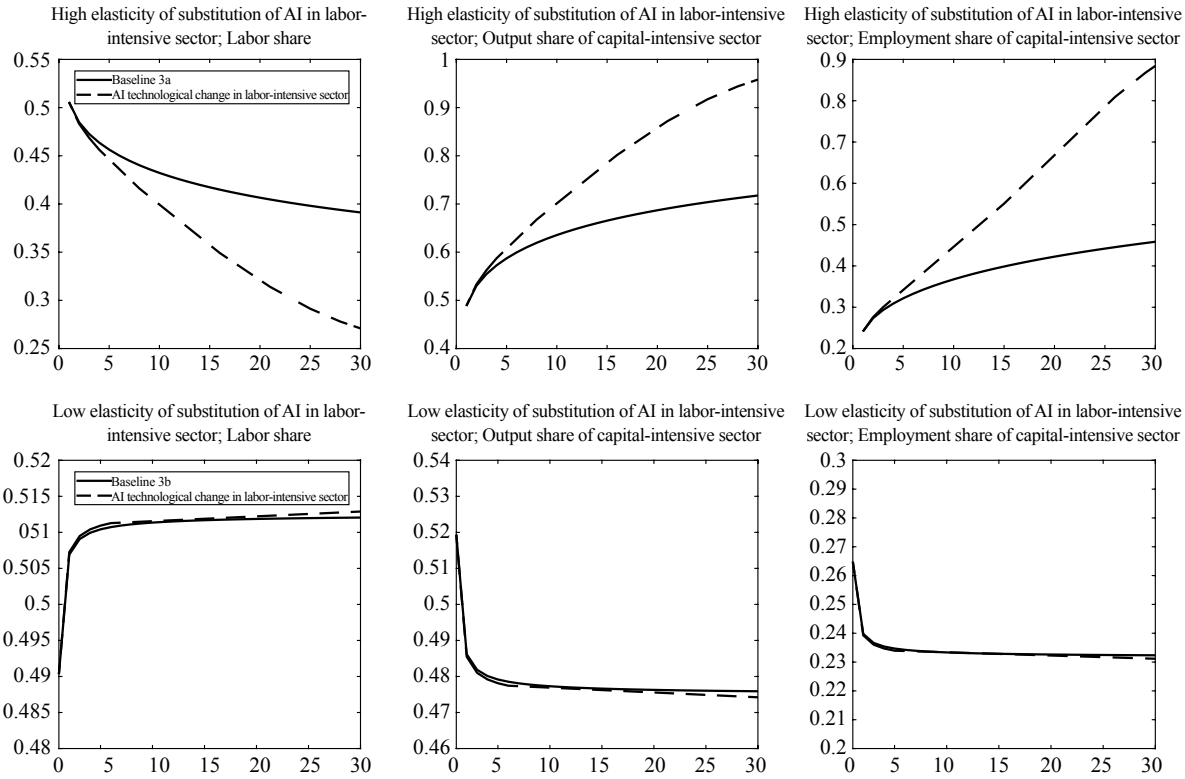

Figure 6: Effect of AI-Specific Technologies with Different Elasticities of Substitution between AI and Traditional Modes of Production across Sectors

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.

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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.

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