Automation, Wage Inequality and Optimal Income Taxation

Cui Xiaoyong (PKU) Li Wenjian (ZJU) Lu Guojun* (CUFE)

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Motivation

- AI and task displacing automation are dramatically reshaping the labor markets, with profound implications for wages, employment, and income distribution.(Acemoglu,2024,NBER; Autor,2024,QJE).
- Over the past four decades, automation technology has been widely recognized as a key contributor to the increasing wage inequality in the United States (Acemoglu and Restrepo, 2022,ECTA).
- What is the government's optimal policy response to automation technology? Should capital(income) be taxed? How to tax labor income?

Outline

This paper explores the incidence of capital and labor income taxes and empirical statistics-based optimal taxation in a general equilibrium framework with endogenous automation.

- We integrate the **task-based framework** (Acemoglu and Autor, 2011, Handbook of Labor Economics) with the **classical optimal taxation theory** (Mirrlees, 1971, RES).
- we identify and break down two important mechanisms through which capital or labor inputs affect wages: **the substitution effect** and **the automation effect**.
- We implement **tax incidence analysis**, that is, the impact of a given tax perturbation on prices, factor supplies, utilities, and social welfare. Then, we derive **the optimal labor and capital income tax formulas** in sufficient statistics.
- Finally, we conduct a numerical analysis of optimal taxation using the 2019 Distributional National Accounts.

Related Literature: Automation Technology

- With the task-based framework, some literature models automation and explores its effects on the economy. Such as growth (Acemoglu and Restrepo, 2018, AER; Jones and Liu, 2024, AER), employment (AER; 2020, JPE; Autor et al., 2024, QJE), Labor share (Hemous and Olsen, 2022) and income inequality (Acemoglu and Restrepo, 2022, ECTA; Moll et al., 2022, ECTA).
- We extend these works from positive analysis to normative analysis, and one of our contributions is introducing the discussion of optimal taxation, including both capital and labor taxation.

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Related Literature: Capital Taxation

- the classic Chamley-Judd result (Chamley, 1986, ECTA; Judd, 1985, JpubE): In the long run, the optimal capital tax should be zero.
- the design of optimal capital taxation from different perspectives, such as capital-skill complementarity (Slavik and Yazici, 2014, JME; Cui et al., 2021, JPubE), The Utility of Wealth (Saez and Stantcheva, 2018, JPubE).
- Compared to these works, we introduce endogenous automation in the dicussion of optimal capital income taxation.

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Related Literature: Mirrlees Taxation

- Since Mirrlees' (1971) seminal work, several studies have made theoretical improvements to it (Diamond,1998, AER; Saez, 2001, RES), so that their theory can be better applied to policy advice.
- Other studies introduce different elements into the standard Mirrlees taxation, such as occupational choice (Rothschild and Scheuer, 2013, QJE), technical change (Ales et al., 2015, AER). sachs et al.(2020) provide a fundamental framework for nonlinear optimal taxation under general equilibrium.
- the introduction of multi-dimensional heterogeneity and the decomposition of general equilibrium effects in our work, have both methodological and theoretical contributions.

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Setup

- Individuals.

$$\begin{aligned} \max_{a_q, l_n} \quad & U(n,q) \equiv u(y_q - a_q) + c(n,q) - v(l_n) \\ \text{s.t.} \quad & c(n,q) = w_n l_n + (1+R)a_q - T(w_n l_n, Ra_q) \end{aligned} \tag{1}$$

  Where $c(n,q)$ denotes his consumption in the second period. $T(\cdot)$ is a twice continuously differentiable income tax function implemented by the government. $-v(l_n)$ is the disutility of labor.

- Technology.
  - There is one final good, which is produced by a continuum skill output Y_n,

$$Y = \left\{ \int_{\underline{n}}^{\bar{n}} \beta_n Y_n^{\rho} dn \right\}^{1/\rho}.$$

    Where β_n is a distributional parameter.
  - The skill output is produced by a continuum task output $Y_n(i)$, where i indicates tasks.

$$\ln Y_n = \int_0^1 \ln Y_n(i) di,$$

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- The task production function is linear with respect to capital and labor,

$$Y_n(i) = \psi_n^k(i)K_n(i) + \psi_n^l(i)L_n(i)$$

Here, $\psi_n^k(i)$ and $\psi_n^l(i)$ denote, respectively, the productivity of capital and labor with skill-n in task i.

- Assume $\psi_n^l(i)/\psi_n^k(i)$ is strictly increasing with i, which means that labor has a comparative advantage in more complex tasks.

$$Y_n(i) = \begin{cases} \psi_n^k(i)K_n(i) & \text{if } i \in [0, \alpha_n] \\ \psi_n^l(i)L_n(i) & \text{if } i \in (\alpha_n, 1] \end{cases}$$

- Government.

$$B = \int_{\underline{n}}^{\bar{n}} \int_{\underline{q}}^{\bar{q}} T(z_n, x_q) f(n, q) dq dn. \tag{2}$$

- **Lemma 1** (Equilibrium Output). The skill output is given by a Cobb-Douglas production function:

$$Y_n = A_n(\alpha_n) K_n^{\alpha_n} L_n^{1-\alpha_n} \tag{3}$$

where the degree of automation coincides with the capital share. However, both of them are no longer exogenous, but adjust with the automated technological change. The final good is a function of aggregate K, labor input, and degree of automation:

$$Y \equiv F(K, \mathcal{L}; \boldsymbol{\alpha}) = \left\{ \int_{\underline{n}}^{\bar{n}} \beta_n \left[\tilde{A}_n(\alpha_n) K^{\alpha_n} L_n^{1-\alpha_n} \right]^{\rho} dn \right\}^{1/\rho} \tag{4}$$

- **Lemma 2** (Equilibrium Prices and Automation). With the price of aggregate output normalized to one, in equilibrium, wages and rental rate can be given as follows:

$$w_n \equiv w_n(K, \mathcal{L}; \boldsymbol{\alpha}) = \frac{(1-\alpha_n)\gamma_n Y}{L_n}, \quad R \equiv R(K, \mathcal{L}; \boldsymbol{\alpha}) = \frac{\alpha Y}{K}, \quad \forall n \in N. \tag{5}$$

  where $\gamma_n = p_n Y_n / Y$ denotes the the share of output value produced by skill-type n in the total output value, and with $\int_{\underline{n}}^{\bar{n}} \gamma_n dn = 1$.
  Denote $\alpha = \int_{\underline{n}}^{\bar{n}} \gamma_n \alpha_n dn$ as the average degree of automation in the economy, the equilibrium automation technology is the solution of the following equations:

$$\alpha_n \equiv \alpha_n(K, \mathcal{L}) = 1 - \frac{1}{\gamma_n} \frac{\mu_n(\alpha_n) L_n}{K + \int_{\underline{n}}^{\bar{n}} \mu_n(\alpha_n) L_n dn}, \quad \alpha \equiv \alpha(K, \mathcal{L}) = \frac{K}{K + \int_{\underline{n}}^{\bar{n}} \mu_n(\alpha_n) L_n dn} \tag{6}$$

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Elasticities

- To simplify our analysis, we restrict the tax function to be separable,i.e., $T(z_n, x_q) = T_z(z_n) + T_x(x_q)$. First-order conditions of individuals imply that labor and capital supplies are in the forms of $l_n(1 - T_z'(z_n), w_n)$ and $a_q(1 - T_x'(x_q), R)$.
- Supply-side Elasticities

$$\epsilon_{l_n,1-T_z'} = -\frac{1 - T_z'(z_n)}{l_n} \frac{dl_n}{\tau_z'(z_n)d\kappa_z}|_{\kappa_z=0}, \quad \epsilon_{l_n,w_n} = \frac{w_n}{l_n}\frac{dl_n}{dw_n} \tag{7}$$

$$\epsilon_{a_n,1-T_x'} = -\frac{1 - T_x'(x_n)}{a_n} \frac{da_n}{\tau_x'(x_n)d\kappa_x}|_{\kappa_x=0}, \quad \epsilon_{a_n,R} = \frac{R}{a_n}\frac{da_n}{dR}. \tag{8}$$

- Demand-side Elasticities
  - Equilibrium factor prices are determined by factor inputs and the equilibrium automation technology,

$$w_n \equiv w_n(K, \mathcal{L}; \boldsymbol{\alpha}) = \frac{(1-\alpha_n)\gamma_n Y}{L_n}, \quad R \equiv R(K, \mathcal{L}; \boldsymbol{\alpha}) = \frac{\alpha Y}{K}.$$

  - Holding $\boldsymbol{\alpha}$ unchanged, factor inputs can still affect equilibrium price via substitution effect, which can be captured by the following definition of elasticity,

$$\epsilon_{w_n, L_{n'}} = \frac{L_{n'}}{w_n}\frac{dw_n}{dL_{n'}}, \quad \epsilon^D_{w_n, L_n} = \frac{L_n}{w_n}\frac{dw_n}{dL_n}, \quad \epsilon_{w_n, K} = \frac{K}{w_n}\frac{dw_n}{dK}, \forall n, n' \in N. \tag{9}$$

  - Taking into account the adjustment of automation technology, we define the following elasticities to capture the automation effect,

$$\epsilon_{w_n, \alpha_n} = \frac{\alpha_n}{w_n}\frac{dw_n}{d\alpha_n}, \epsilon_{\alpha_n, L_{n'}} = \frac{L_{n'}}{\alpha_n}\frac{d\alpha_n}{dL_{n'}}, \quad \epsilon^D_{\alpha_n, L_n} = \frac{L_n}{\alpha_n}\frac{d\alpha_n}{dL_n}, \quad \epsilon_{\alpha_n, K} = \frac{K}{\alpha_n}\frac{d\alpha_n}{dK}, \quad \forall n \in N, \tag{10}$$

Note: Substitution effect vs Automation effect.

Automation Effect

- The impact of factor inputs on factor prices through automation effect can be given as follows:

$$\frac{dw_n}{w_n}|_{AE} = \epsilon_{w_n,\alpha_n}\left[\epsilon^D_{\alpha_n,L_n}\frac{dL_n}{L_n} + \int_{\underline{n}}^{\bar{n}} \epsilon_{\alpha_n,L_{n'}}\frac{dL_{n'}}{L_{n'}}dn' + \epsilon_{\alpha_n,K}\frac{dK}{K}\right], \quad \forall n \tag{11}$$

$$\frac{dR}{R}|_{AE} = \epsilon_{R,\alpha}\left[\int_{\underline{n}}^{\bar{n}} \epsilon_{\alpha,L_n}\frac{dL_n}{L_n}dn + \epsilon_{\alpha,K}\frac{dK}{K}\right] \tag{12}$$

- Assuming $0 < \rho < 1$, we have,

$$\epsilon_{R,\alpha}; \epsilon_{\alpha_n,L_{n'}}; \epsilon_{\alpha_n,K}; \epsilon_{\alpha,K} > 0, \quad \epsilon_{w_n,\alpha_n}; \epsilon^D_{\alpha_n,L_n}; \epsilon_{\alpha,L_n} < 0.$$

- For example, $\epsilon_{\alpha_n,K}$and ϵ_{w_n,α_n} mean that capital accumulation will increase the degree of automation, more tasks are assigned to capital, and the demand for labor is reduced, so capital accumulation can reduce wages through the automation effect.

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Substitution Effect

- The rate of change in wage and rental rate induced by substitution effect can be given as follows,

$$\frac{dw_n}{w_n}|_{SE} = \epsilon^D_{w_n,L_n}\frac{dL_n}{L_n} + \int_{\underline{n}}^{\bar{n}} \epsilon_{w_n,L_{n'}}\frac{dL_{n'}}{L_{n'}}dn' + \epsilon_{w_n,K}\frac{dK}{K} \quad \forall n \tag{13}$$

$$\frac{dR}{R}|_{SE} = \int_{\underline{n}}^{\bar{n}} \epsilon_{R,L_n}\frac{dL_n}{L_n}dn + \epsilon_{R,K}\frac{dK}{K}, \tag{14}$$

  Note that we do not consider the adjustment of automation technology here, but factor inputs can directly affect the prices. Among which we have $\epsilon_{w_n,K} > 0$. This implies that capital accumulation can increase wages through the substitution effect.

- In summary, capital accumulation can affect wages through two opposite channels, and the automation effect only exists if endogenous technology is considered, see Acemoglu,2024, NBER

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- Capital accumulation reduces wages through the automation effect, but this negative effect is greater for low-income individuals. Thus, capital accumulation expands the wage inequality through the automation effect.

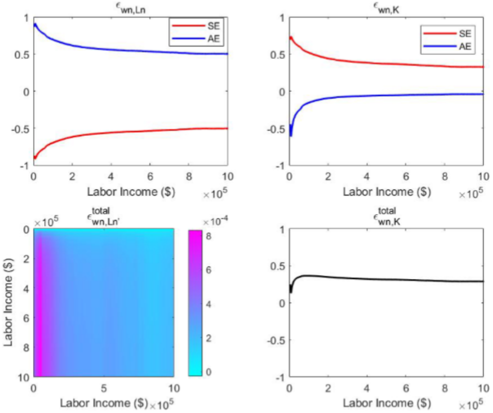

Figure 1: Elasticity of wage with respect to labor and capital inputs

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- With a separable tax function, we know that factor supplies depend on their prices and marginal tax rates, that is

$$\frac{dl_n}{l_n} = -\epsilon_{l_n,1-T'_z}\frac{\tau'_z(z_n)}{1-T'_z(z_n)} + \epsilon_{l_n,w_n}\frac{dw_n}{w_n}, \quad \frac{da_q}{a_q} = -\epsilon_{a_q,1-T'_x}\frac{\tau'_x(x_q)}{1-T'_x(x_q)} + \epsilon_{a_q,R}\frac{dR}{R}. \quad (15)$$

- Denote $\epsilon^{total}_{w_n,i} = \epsilon_{w_n,i} + \epsilon_{w_n,\alpha_n}\epsilon_{\alpha_n,i}$ and $\epsilon^{total}_{R,i} = \epsilon_{R,i} + \epsilon_{R,\alpha}\epsilon_{\alpha,i}$ for $i \in \{\mathcal{L}, K\}$, the integral equation of labor supply can be reduced to

$$\begin{aligned}\frac{dl_n}{l_n} = &\underbrace{-\epsilon_{l_n,1-T'_z}\frac{\tau'_z(z_n)}{1-T'_z(z_n)}}_{DE}\underbrace{-\epsilon_{l_n,w_n}\epsilon^{total}_{w_n,K}\chi\int\omega_q\epsilon_{a_q,1-T'_x}\frac{\tau'_x(x_q)}{1-T'_x(x_q)}dq}_{CE} \\ &\underbrace{+\epsilon_{l_n,w_n}\int\left[\epsilon^{total}_{w_n,L_{n'}} + \epsilon^{total}_{w_n,K}\chi\bar{\epsilon}_{K,R}\epsilon^{total}_{R,L_{n'}}\right]\frac{dl_{n'}}{l_{n'}}dn'}_{GE}\end{aligned} \quad (16)$$

Where $\chi = \frac{1}{1-\bar{\epsilon}_{K,R}\epsilon^{total}_{R,K}}$, $\bar{\epsilon}_{K,R} = \int\omega_q\epsilon_{a_q,R}dq$, and $\omega_q = \frac{a_q f_q(q)}{K}$.

Effects on Factor Prices and Government Revenue

- The incidence of tax reform on factor prices is given by

$$\frac{dw_n}{w_n} = -\epsilon^{total}_{w_n,K}\chi \int \omega_q \epsilon_{a_q,1-T'_x} \frac{\tau'_x(x_q)}{1-T'_x(x_q)} dq + \int \left[\epsilon^{total}_{w_n,L_{n'}} + \epsilon^{total}_{w_n,K}\chi\bar{\epsilon}_{K,R}\epsilon^{total}_{R,L_{n'}}\right] \frac{dl_{n'}}{l_{n'}} dn' \quad (17)$$

$$\frac{dR}{R} = -\epsilon^{total}_{R,K}\chi \int \omega_q \epsilon_{a_q,1-T'_x} \frac{\tau'_x(x_q)}{1-T'_x(x_q)} dq + \int \left[\epsilon^{total}_{R,L_{n'}} + \epsilon^{total}_{R,K}\chi\bar{\epsilon}_{K,R}\epsilon^{total}_{R,L_{n'}}\right] \frac{dl_{n'}}{l_{n'}} dn' \quad (18)$$

- The change in government revenue can be given as follow,

$$dB = \underbrace{\int_Q \tau_x(x_q) f_q(q) dq + \int_N \tau_z(z_n) f_n(z_n) dn}_{\text{Mechanical Effect}}$$
$$+ \underbrace{\int_Q T'_x(x_q)\left[\frac{da_q}{a_q} + \frac{dR}{R}\right] x_q f_q(q) dq + \int_N T'_z(z_n)\left[\frac{dl_n}{l_n} + \frac{dw_n}{w_n}\right] z_n f_n(n) dn}_{\text{Behavioral Effect}}. \quad (19)$$

Effects on Social Welfare.

- We define the social welfare function as $W = \frac{1}{\lambda} G\left(\{V(n,q)\}_{n\times q \in N\times Q}\right) + B$.
- The incidence of tax reforms (τ_z, τ_x) on social welfare is given by

$$\begin{aligned} dW = & \underbrace{\int (1 - g_n(n))\tau_z(z_n) f_n(n) dn + \int (1 - g_q(q))\tau_x(x_q) f_q(q) dq}_{ME} \\ & \underbrace{- \int \left[T_z'(z_n) z_n \frac{\epsilon_{l_n, 1-T_z'} \tau_z'}{1 - T_z'(z_n)} \right] f_n(n) dn - \int \left[T_x'(x_q) x_q \frac{\epsilon_{a_q, 1-T_x'} \tau_x'}{1 - T_x'(x_q)} \right] f_q(q) dq}_{BE} \\ & \underbrace{+ \int \left[g_n(n)(1 - T_z'(z_n)) + T_z'(z_n)(1 + \epsilon_{l_n, w_n}) \right] z_n \frac{dw_n}{w_n}|_{SE} f_n(n) dn + \int \left[g_q(q)(1 - T_x'(x_q)) + T_x'(x_q)(1 + \epsilon_{a_q, R}) \right] x_q \frac{dR}{R}|_{SE} f_q(q) dq}_{SE} \\ & \underbrace{+ \int \left[g_n(n)(1 - T_z'(z_n)) + T_z'(z_n)(1 + \epsilon_{l_n, w_n}) \right] z_n \frac{dw_n}{w_n}|_{AE} f_n(n) dn + \int \left[g_q(q)(1 - T_x'(x_q)) + T_x'(x_q)(1 + \epsilon_{a_q, R}) \right] x_q \frac{dR}{R}|_{AE} f_q(q) dq}_{AE} \end{aligned} \quad (20)$$

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- There is no marginal improvement in social welfare when the tax system is optimal,

$$dW = \int\int g(n,q)dV(n,q)f(n,q)dndq + dB = 0. \tag{21}$$

- With $dW = 0$ satisfied, we can derive the optimal nonlinear labor income tax formula using the variational approach,

$$\begin{aligned}\frac{T_z'(z_{n^*})}{1-T_z'(z_{n^*})} = & \frac{1}{\epsilon_{l_{n^*},1-T_z'}}(1-\bar{g}_{z_{n^*}})\frac{1-F_z(z_{n^*})}{z_{n^*}f_z(z_{n^*})} \\ & \underbrace{-\left(\frac{dz_{n^*}}{dn^*}\right)^{-1}\int\left[(1-\bar{g}_{z_n})\left(\frac{1-T_z'(z_n)}{1-T_z'(z_{n^*})}\right)\left(\frac{1-F_z(z_n)}{z_{n^*}f_z(z_{n^*})}\right)z_n\right]'\epsilon^{SE}_{w_n,L_{n^*}}dz_n}_{\text{Substitution Effect}} \\ & \underbrace{-\left(\frac{dz_{n^*}}{dn^*}\right)^{-1}\int\left[(1-\bar{g}_{z_n})\left(\frac{1-T_z'(z_n)}{1-T_z'(z_{n^*})}\right)\left(\frac{1-F_z(z_n)}{z_{n^*}f_z(z_{n^*})}\right)z_n\right]'\epsilon^{AE}_{w_n,L_{n^*}}dz_n}_{\text{Automation Effect}}\end{aligned} \tag{22}$$

Note: ABC+D formula.

Capital Income Taxation

- Nonlinear Capital Income Taxation

$$
\begin{aligned}
\frac{T_x'(x_{q^*})}{1-T_x'(x_{q^*})} = {} & \frac{1}{\epsilon_{a_{q^*},1-T_x'}}(1-\bar{g}_{x_{q^*}})\frac{1-F_x(x_{q^*})}{x_{q^*}f_x(x_{q^*})} \\
& \underbrace{-\frac{1}{RK(1-T_x'(x_{q^*}))}\int\left[(1-\bar{g}_{z_n})\left(1-T_z'(z_n)\right)(1-F_z(z_n))\,z_n\right]'\epsilon^{SE}_{w_n,K}dz_n}_{\text{Substitution Effect}} \\
& \underbrace{-\frac{1}{RK(1-T_x'(x_{q^*}))}\int\left[(1-\bar{g}_{z_n})\left(1-T_z'(z_n)\right)(1-F_z(z_n))\,z_n\right]'\epsilon^{AE}_{w_n,K}dz_n}_{\text{Automation Effect}}
\end{aligned}
\tag{23}
$$

- Linear Capital Income Taxation

$$
\begin{aligned}
\frac{t_x}{1-t_x} = {} & \frac{\int(1-g_q(q))x_qf_q(q)dq}{\int\epsilon_{a_q,1-T_x'}x_qf_q(q)dq} \\
& \underbrace{-\int\frac{1}{RK(1-t_x)}\left[(1-\bar{g}_{z_n})(1-T_z'(z_n))(1-F_z(z_n))z_n\right]'\epsilon^{SE}_{w_n,K}dz_n}_{\text{Substitution Effect}} \\
& \underbrace{-\int\frac{1}{RK(1-t_x)}\left[(1-\bar{g}_{z_n})(1-T_z'(z_n)(1-F_z(z_n))z_n\right]'\epsilon^{AE}_{w_n,K}dz_n}_{\text{Automation Effect}}
\end{aligned}
\tag{24}
$$

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Calibration

- We use the Distributional National Accounts (DINA) microfiles of Piketty et al.(2018), which provides both pretax labor income (*plinc*) and pretax capital income (*pkinc*) at the individual level, to calculate the income distribution in reality.
- Functions and parameters are given as follows:

$$u(y_q - a_q) = -B_q \frac{a_q^{1+1/\epsilon_k}}{1+1/\epsilon_k} - a_q, \quad v(l_n) = \frac{l_n^{1+1/\epsilon_l}}{1+1/\epsilon_l}, \; G(V) = \frac{V^{1-\kappa}}{1-\kappa}, \; T_0(z) = z - \frac{1-\tau}{1-\phi} z^{1-\phi},$$

$$\mu_n(i) = \frac{\psi_n^l(i)}{\psi_n^k(i)} = \delta_n \cdot i^\eta.$$

Table 3: List of calibrated parameter values

Description		Value	Target/Source
Preference			
B_q	One source of heterogeneity	vector	Target capital income distribution
ϵ_k	Elasticity of capital supply	0.65	Acemoglu et al. (2020)
ϵ_l	Elasticity of labor supply	0.33	Chetty (2012)
Technology			
δ_n	Comparative advantage across skills	vector	Target labor income distribution
η	Comparative advantage parameter	5.54	Target labor share 52.7%
$\sigma = \frac{1}{1-\rho}$	Substitution elasticity between skills	3	Sachs et al. (2020)
α_n	Automation technology across skills	vector	Target wage distribution
R	Capital rental rate	0.15	Target $K/Y = 3$
Government			
κ	Parameter for redistribution motivation	1	Sachs et al. (2020),Saez (2001)
τ	Parameter for tax function	-3	Heathcote et al. (2017)
ϕ	Parameter of progressivity	0.181	Heathcote et al. (2017)
τ_k	Initinal capital income tax rate	0.1	Acemoglu et al. (2020)

Simulation

- **NLIT-NCIT Tax System**: the general equilibrium effect leads to a more progressively optimal tax system, whereas the automation effect operates in the opposite direction to the substitution effect.

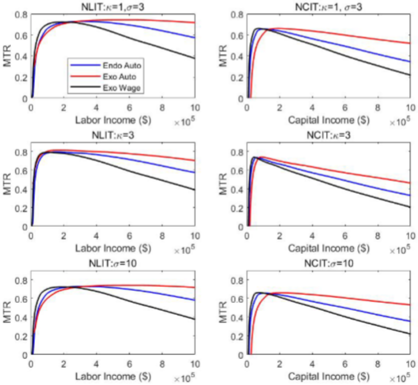

Figure 4: Optimal NLIT-NCIT Tax System

- **NLIT-LCIT Tax System**: the general equilibrium effect reduces the optimal LCIT. Moreover, the more redistributive the government (higher κ), the higher the optimal LCIT.

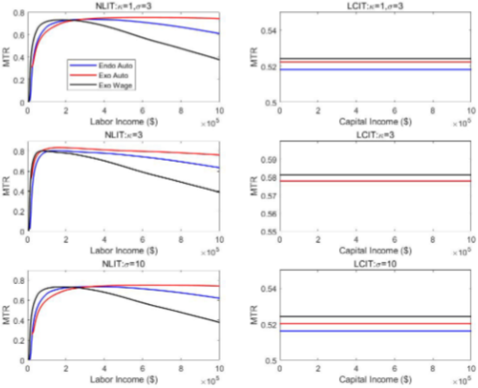

Figure 5: Optimal NLIT-LCIT Tax System

- Assuming the nonlinear labor income tax follows the functional form of Heathcote et al.(2017), that is $T_z(z) = z - \frac{1-\tau}{1-\phi} z^{1-\phi}$, We resimulate the optimal NCIT and LCIT respectively.

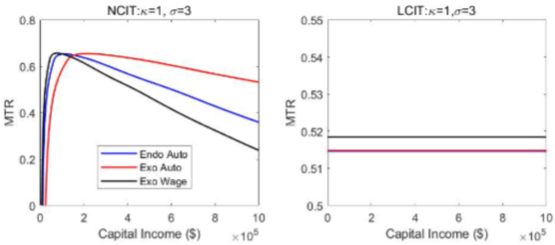

Figure 6: Optimal NLIT or LCIT Tax System

Conclusion

- Our model indicates that there are two contrary channels through which factor inputs affect factor prices, i.e., substitution effect and automation effect.
- Capital accumulation, while widening the wage inequality through the automation effect, can also reduce the wage inequality through the substitution effect.
- The general equilibrium effect leads to a more progressively optimal tax system, and it can also reduce the optimal LCIT.
- The key and counterintuitive finding of this paper shows that although automation technology exacerbates wage inequality, it also reduces the progressivity of optimal income taxation.

Thank you!