Annex for Online Publication
For the Benefit of All:
Fiscal Policies and Equity-Efficiency
Trade-offs in the Age of Automation

by Andrew Berg, Lahcen Bounader, Nikolay Gueorguiev, Hiroaki Miyamoto, Kenji Moriyama, Ryota Nakatani, and Luis-Felipe Zanna

July 2021

CONTENTS

I. MODEL DESCRIPTIONS

A. Environment

An economy consisits of the representative firm, workers (skilled and unskilled), owners of capital (or capitalists), and the government. The measures of skilled workers, unskilled workers, and capitalists are denoted by N_S, N_L, and N_C, respectively. Without loss of generality, we can normalize the total population to be one. Thus,

$$N_S + N_L + N_C = 1.$$

We assume that N_C is exogenous and constant over time. The ratio of skilled workers to total workers is denoted by ϕ, which depends on public spending on education G. Thus,

$$\phi = \phi(G_t).$$

B. Firms' Problems

Let us introduce heterogeneity across firms. This heterogeneity is the basis for adding monopolistic competition that creates mark-ups in the model. Only the elasticity of substitution between different goods (but they are assumed symmetric) matters the model after firms are aggregated. Also, to create mark-ups, we divide the production sector into three parts: final goods producers, wholesalers, and intermediate goods producers. Both assumptions are very common in the literature to introduce market power into macro models.

Final Goods Firms

The final goods are produced by combining a continuum of differentiated goods indexed by j. The production function of the final good producer is given by

$$Y = \left[\int_0^1 y_{j,t}^{\frac{\epsilon-1}{\epsilon}} \, dj \right]^{\frac{\epsilon}{\epsilon-1}},$$

where y_j is the quantity of output sold by wholesale firm j and ϵ is the elasticity of substitution across the differentiated goods. In other words, *ϵ is a parameter that represents the degree of imperfect (monopolistic) competition*. With the current set-up of the model, market power belongs to the wholesale firms. If this parameter becomes smaller, goods are less substitutable (note that we assume $1 < \epsilon < \infty$).

The final goods producer maximizes profits subject to the above production technology, taking input price $p_{j,t}$ and the final goods price P_t as given. The profit maximization problem yields

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\epsilon} Y_t$$

and the aggregate price index:

$$P_t = \left[\int_0^1 p_{j,t}^{1-\epsilon} \, dj \right]^{\frac{1}{1-\epsilon}}.$$

Without loss of generality, we can normalize the output price to be one $P_t = 1$.

Wholesalers

There is a unit measure of wholesale firms. Wholesalers buy homogeneous goods from the intermediate goods firms and transform them to heterogeneous goods, which are sold to final goods firms. We assume that wholesalers are owned by capitalists. The production technology is linear: $y_{j,t} = Q_{j,t}$. The representative wholesaler chooses $Q_{j,t}$ and $p_{j,t}$ to solve the following maximization problem:

$$\max \Pi_{j,t} = \int_0^1 \left(p_{j,t} y_{j,t} - \theta_t Q_{j,t} \right) dj$$

subject to the demand function. θ_t is price of intermediate goods. Assuming symmetric pricing, we have

$p_{j,t} = \left(\frac{\epsilon}{\epsilon-1} \right) \theta_t$

By normalizing the price of final goods to be one, the above equation gives

$$\theta_t = \frac{\epsilon - 1}{\epsilon}.$$

In the endogenous mark-up model, we assume that there is a link between the mark-up and the use of robots in the production process. For a moment, let's assume that the size of mark-up depends on the density of robots (i.e., robot stock over either population or labor supply).

$$\frac{1}{markup_t} = \theta_t = m_0 (rd_t)^{-x}, rd_t = \frac{Z_{d,t}}{S_{d,t} + L_{d,t}}$$

where θ_t is the inverse of mark-up (the sales price of the intermediate good that the firm faces, in our setup) and its derivative with respect to rd_t is negative. Let's assume it has constant elasticity -x (where $x > 0$). However, *these marginal conditions are fairly flexible to have different specifications of endogenous mark-up*. For example, mark-up can depend only on stock of robots in percent of GDP instead of the density of robots. Also, mark-up may depend only on the production share of robots.

Intermediate Goods Firm

The firm produces output by using capital K_d, robots Z_d, skilled labor S_d, and unskilled labor L_d. We continue to use the following triple-nested CES production function:

$$Q_t = A(\Gamma_t) \left[a^{\frac{1}{\sigma_1}} H_t^{\frac{\sigma_1-1}{\sigma_1}} + (1-a)^{\frac{1}{\sigma_1}} V_t^{\frac{\sigma_1-1}{\sigma_1}} \right]^{\frac{\sigma_1}{\sigma_1-1}},$$

where A is an aggregate productivity, which depends on public spending on infrastructure Γ, and

$$V_t = \left[e^{\frac{1}{\sigma_2}} L_{d,t}^{\frac{\sigma_2-1}{\sigma_2}} + (1-e)^{\frac{1}{\sigma_2}} (b_t Z_{d,t})^{\frac{\sigma_2-1}{\sigma_2}} \right]^{\frac{\sigma_2}{\sigma_2-1}},$$

$$H_t = \left[f^{\frac{1}{\sigma_3}} S_{d,t}^{\frac{\sigma_3-1}{\sigma_3}} + (1-f)^{\frac{1}{\sigma_3}} K_{d,t}^{\frac{\sigma_3-1}{\sigma_3}} \right]^{\frac{\sigma_3}{\sigma_3-1}}.$$

σ_1 is elasticity of substitution between composite inputs H and V, σ_2 is elasticity of substitution between robots and unskilled workers, and σ_3 is elasticity of substitution between capital and skilled workers. For simplicity, we assume that public spending on infrastructure is equal to public spending on education.

The firm maximizes its profit by choosing capital, robots, and two types of labor. Thus, the problem of the firm is

$$\max_{K_d, Z_d, S_d, L_d} \theta_t Q_t - r_{K,t} K_{d,t} - r_{Z,t} Z_{d,t} - w_{S,t} S_{d,t} - w_{L,t} L_{d,t},$$

Where $\theta \leq 1$ is the price of intermediate goods, r_K is the rental rate of capital, r_Z is the rental rate of robots, w_S is the wage rate for skilled workers, and w_L is the wage rate for unskilled workers. The first-order conditions are

$$\theta_t \frac{\partial Q_t}{\partial K_{d,t}} = r_{K,t}, \theta_t \frac{\partial Q_t}{\partial Z_{d,t}} + Q_t \frac{\partial \theta_t}{\partial Z_{d,t}} = r_{Z,t},$$

$$\theta_t \frac{\partial Q_t}{\partial S_{d,t}} + Q_t \frac{\partial \theta_t}{\partial S_{d,t}} = w_{S,t}, \theta_t \frac{\partial Q_t}{\partial L_{d,t}} + Q_t \frac{\partial \theta_t}{\partial L_{d,t}} = w_{L,t}$$

Further elaboration reduces the above to the following relatively simple conditions.

$$\theta_t \frac{\partial Q_t}{\partial K_{d,t}} = r_{K,t}, \theta_t \frac{\partial Q_t}{\partial Z_{d,t}} \left[1 - \frac{x}{s_{Z,t}} \right] = r_{Z,t},$$

$$\theta_t \frac{\partial Q_t}{\partial S_{d,t}} \left[1 + \frac{x}{s_{S,t}} \frac{S_{d,t}}{S_{d,t} + L_{d,t}} \right] = w_{S,t}, \theta_t \frac{\partial Q_t}{\partial L_{d,t}} \left[1 + \frac{x}{s_{L,t}} \frac{L_{d,t}}{S_{d,t} + L_{d,t}} \right] = w_{L,t}$$

We will see higher demand for robots, but lower demand for both skilled and unskilled labor. Endogenous mark-up adds additional wedge between the return of the production factor (e.g., interest rates and wages) and its marginal product on top of mark-up θ. The additional wedge relates to the assumptions that: (i) wholesalers are owned by capitalists; and (ii) wholesalers' profit positively depend on the mark-up. Since higher robot density raises mark-up, the additional wedge (difference between the marginal product and factor price, not explained by the level of mark-up) for robots is smaller than one, while that for two types of labor is larger than one (because the contribution of labor to wholesalers, $(1 - \theta)Q_t$, is transferred to capitalists (i.e., workers cannot get their contribution).

In equilibrium, the profit of the competitive firm must be zero:

$$\pi_t \equiv \theta_t Q_t - r_{K,t} K_{d,t} - r_{Z,t} Z_{d,t} - w_{S,t} S_{d,t} - w_{L,t} L_{d,t} = 0.$$

C. Workers' Problems

Following Berg et al., (2018), we assume that workers consume all of their income. The representative skilled worker's utility function is guven by preference developped by Greenwood et al., (1988):

$$U(C_S, S) = \frac{1}{1 - \sigma_S} \left(C_{S,t} - \Phi_S \frac{S_t^{1+\mu_S}}{1 + \mu_S} \right)^{1-\sigma_S},$$

where C_S is skilled worker's consumption and S is labor supply. $\Phi_S > 0$ measures the disutility of working and μ_S is the inverse of Frisch elasticity.

The budget constraint of the skilled worker is

$$(1 + \tau_c)C_{S,t} = (1 - \tau_{w_S}) w_{S,t} S_t + \kappa.$$

τ_c is the consumption tax rate, τ_{w_S} is the income tax rate on skilled workers' income, and κ is the universal limp-sum transfer. The skilled worker chooses C_S and S to maximize the utility function subject to the above budget constraint.

Similar to the skilled worker, the unskilled worker's problem can be written as

$$\max_{C_L,L} U(C_L, L) = \frac{1}{1 - \sigma_L}\left(C_{L,t} - \Phi_L \frac{L_t^{1+\mu_L}}{1 + \mu_L}\right)^{1-\sigma_L},$$

subject to

$$(1 + \tau_c)C_{L,t} = (1 - \tau_{w_L})w_{L,t}L_t + \kappa + s_L,$$

where τ_{w_L} is the income tax rate on unskilled workers' income, s_L is the trageted transfer to unskilled workers.

The first order conditions are

$$\Phi_L L_t^{\mu_L} = \frac{1 - \tau_{w_L}}{1 + \tau_c} w_{L,t}$$

$$\Phi_S S_t^{\mu_S} = \frac{1 - \tau_{w_S}}{1 + \tau_c} w_{S,t}$$

D. Problems of the Owners of Capital

The representative capitalist chooses consumption C, investment in capital I_K, and investment in robots I_Z to maximize

$$\max_{C, I_K, I_Z} \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma_C}}{1 - \sigma_C}$$

subject to

$$(1 + \tau_c)C_t + I_{K,t} + I_{Z,t}$$
$$= (1 - \tau)\left[r_{K,t}K_t + r_{Z,t}Z_t\right] + (1 - \tau_\theta)(1 - \theta)\frac{Q_t}{N_C} + \kappa - \tau_Z Z_t - \tau_{KZ}(K_t + Z_t)$$
$$- \tau_{Capitalist},$$

$$K_{t+1} = (1 - \delta_K)K_t + I_{K,t},$$

and

$$Z_{t+1} = (1 - \delta_Z)Z_t + I_{Z,t},$$

where β is the discount factor, δ_K is the depreciation rate of capital, δ_Z is the depreciation rate of robot, τ is the capital income tax rate, τ_θ is the tax rate on mark-up, τ_Z is the robot tax rate, τ_{KZ} is the wealth tax rate, and $\tau_{Capitalist}$ is the lump-sum tax on capitalist' income. We assume $\tau_\theta = \tau$.

The marginal conditions of capitalists' savings in the endogenous mark-up model are identical to that with exogenous mark-up. Intuitively speaking, given other conditions, this observation reflects the zero-sum feature of profit sharing based on mark-up at the first order. Since wholesalers are entirely owned by capitalists, mark-up does not have the first order effect on the overall return of savings once profit transfer from the wholesalers is counted, suggesting no change in the two Euler equations.

$$\frac{\lambda_t}{\beta\lambda_{t+1}} = (1-\tau)\frac{\partial Q_{t+1}}{\partial K_{d,t+1}} + (1-\delta_K), \frac{\lambda_t}{\beta\lambda_{t+1}} = (1-\tau)\frac{\partial Q_{t+1}}{\partial Z_{d,t+1}} - \tau_Z + (1-\delta_Z)$$

and in the initial steady state:

$$1 = \beta\left[(1-\tau)\frac{\partial Q}{\partial K_d} + 1 - \delta_K\right], 1 = \beta\left[(1-\tau)\frac{\partial Q}{\partial Z_d} + 1 - \delta_Z - \tau_Z\right]$$

They do not explicitly include mark-up ($\theta < 1$).

However, this does not warrant robots-unskilled labor and traditional capital-skilled labor ratios with endogenous mark-up identical to those with exogenous mark-up in the steady state. This is a direct result of the four marginal conditions of the intermediate good firm. Different from the case of exogenous mark-up, the ratio of the rate of return to robots and traditional capital include the elasticity of mark-up.

E. Government

The government budget constraint is given by

$$G + \sum_{i=L,S,C} N_i\kappa + N_L s_L + N_C \alpha\tau(I_{K,t} + I_{Z,t})$$
$$= N_C\left[\tau\{r_{K,t}K_t + r_{Z,t}Z_t\} + \tau_c C_t + \tau_Z Z_t + \tau_{KZ}(K_t + Z_t) + \tau_{Capitalist}\right] + \tau_\theta(1-\theta)Q_t$$
$$+ N_S\left[\tau_w w_{S,t}S_t + \tau_c C_{S,t}\right] + N_L\left[\tau_w w_{L,t}L_t + \tau_c C_{L,t}\right].$$

F. Market Clearing Conditions

The goods market is in equilibrium when the supply by the firms equals the demand by capitalists, workers, and government:

$$Q_t = N_c\left(C_t + I_{K,t} + I_{Z,t}\right) + N_s C_{S,t} + N_L C_{L,t} + G_t.$$

The labor markets are in equilibrium when the labor demand is equal to the labor services supplied by workers:

$$S_{d,t} = N_S S_t,$$

and

$$L_{d,t} = N_L L_t.$$

Similarly, the capital and robot markets are in equilibrium when

$$K_{d,t} = N_C K_t,$$

and

$$Z_{d,t} = N_C Z_t.$$

G. Calibration

The model is calibrated to match the U.S. economy. Our calibration strategy closely follows Berg et al., (2018) and therefore we keep the description here to be brief.

We choose the model period to be one year and set the steady-state discount rate at 0.5 percent, or discount factor $\beta = 0.995$. We assume that the depreciation rates are the same between capital and robots. The depreciation rate is set at 0.05.

As for the production function, the shares of composite input H, unskilled labor, and skilled labor are calibrated to target the capital income share of 0.35, unskilled income share of 0.31, the skilled income share of 0.30, and the robot income share of 0.04. This yields $a = 0.77$, $e = 0.99$, and $f = 0.09$. Following Berg et al., (2018), we set the elasticity of substitution between H and V to be 0.67 and the elasticity of substation between skilled labor and capital to be 0.34. Following Berg et al., (2018), the elasticity of substitution between unskilled labor and robots is set to be 2.5, which satisfies the empirical observation by DeCanio (2016).

We set $\mu_L = 2$ and $\mu_S = 2$, which are taken from intensive margin by Chetty et al., (2011). This means that Frisch elasticity of both unskilled and skilled labor is 0.5, which is the middle of the range suggested in the literature. Disutility of working for unskilled worker is set by targeting the steady-state working hours to be 1/3 (i.e., eight hours per day). Observed wage dispersion between skilled and unskilled workers, $\frac{w_S}{w_L} = 2$, is used to pin down the parameter of the skilled worker's disutility of working.

Population is normalized to one. The population share of capitalists is 1 percent. The share of skilled workers to total workers depends on public spending on education $\phi = \phi_0 G^\gamma$. IMF (2018) reports that a 4 percentage points shift from unskilled to medium/high skilled workers costs 1-3 percent of GDP, based on education costs in the U.S. Based on this, we set $\gamma = 0.22$. We calibrate ϕ_0 by targeting the share of unskilled workers of 55 percent, which is reported by Acemoglu and Autor (2011). Education spending also affects the level of TFP. Thus, we assume that $A = A_0 (\frac{G}{Y})^\xi$ where ξ is the elasticity of TFP to education spending. As there are no direct empirical counterpart of ξ, we postulate that one percentage point increase in education spending raises TFP by one percent. The parameter A_0 is set to normalize output to be one.

We now turn to the policy parameters. Based on the U.S. data, we set the rates of capital and wage income tax to target the tax revenue to GDP ratio of 13 percent. Public spending on education is set to be 0.041 consistent with the U.S. data. Tables 1 and 2 summarize the parameter values in the baseline simulation for the constant mark-up model and the endogenous mark-up model, respectively.

Table 1. Structural Parameters in Calibration for the Exogenous Mark-up Model

Parameter	Description	Value	Source or Anchor
σ_1	Elasticity of substitution between composite capital and composite labor	0.67	Berg et al., (2018)
σ_2	Elasticity of substitution between unskilled labor and robots	2.5	Berg et al., (2018)
σ_3	Elasticity of substitution between skilled labor and capital	0.335	Berg et al., (2018)
a	Share parameter of composite labor in production	0.803	Berg et al., (2018)
e	Share parameter of unskilled labor in composite labor	0.997	Berg et al., (2018)
f	Share parameter of skilled labor in composite capital	0.057	Berg et al., (2018)
σ_S	The inverse of intertemporal elasticity of substitution for skilled workers	2	Berg et al., (2018)
σ_L	The inverse of intertemporal elasticity of substitution for unskilled workers	2	Berg et al., (2018)
μ	The inverse of Frisch elasticity of unskilled labor supply	2	Chetty et al., (2011)
μ_s	The inverse of Frisch elasticity of skilled labor supply	2	Chetty et al., (2011)
Φ_L	Disutility of unskilled work	11.2	L=1/3 (i.e., eight hours)
Φ_S	Disutility of skilled work	64.3	w_s/w_l=2
β	Discount factor	$1/(1 + 0.005)$	Berg et al., (2018)
δ_K	Depreciation rate of capital	0.05	Berg et al., (2018)
δ_Z	Depreciation rate of robots	0.05	Berg et al., (2018)
$\emptyset_0$	Parameter for population share function	0.909	Acemoglu and Autor (2011)
ξ	Elasticity of TFP to education spending	0.22	IMF (2018)
A_0	Initial total factor productivity	0.278	Berg et al., (2018)
τ	Baseline tax rate (factor income and profit of wholesalers)	0.13	U.S. data
ϵ	The elasticity of substitution (implied mark-up is 1.19)	6.263	Barkai (2020)

Table 2. Structural Parameters in Calibration for the Endogenous Mark-up Model

| Parameter	Description	Value	Source or Anchor
σ_1	Elasticity of substitution between composite capital and composite labor	0.67	Berg et al., (2018)
σ_2	Elasticity of substitution between unskilled labor and robots	2.5	Berg et al., (2018)
σ_3	Elasticity of substitution between skilled labor and capital	0.335	Berg et al., (2018)
a	Share parameter of composite labor in production	0.816	Berg et al., (2018)
e	Share parameter of unskilled labor in composite labor	0.996	Berg et al., (2018)
f	Share parameter of skilled labor in composite capital	0.051	Berg et al., (2018)
σ_S	The inverse of intertemporal elasticity of substitution for skilled workers	2	Berg et al., (2018)
σ_L	The inverse of intertemporal elasticity of substitution for unskilled workers	2	Berg et al., (2018)
μ	The inverse of Frisch elasticity of unskilled labor supply	2	Chetty et al., (2011)
μ_s	The inverse of Frisch elasticity of skilled labor supply	2	Chetty et al., (2011)
Φ_L	Disutility of unskilled work	11.2	L=1/3 (i.e., eight hours)
Φ_S	Disutility of skilled work	64.3	w_s/w_l=2
β	Discount factor	$1/(1+0.005)$	Berg et al., (2018)
δ_K	Depreciation rate of capital	0.05	Berg et al., (2018)
δ_Z	Depreciation rate of robots	0.05	Berg et al., (2018)
$\emptyset_0$	Parameter for population share function	0.909	Acemoglu and Autor (2011)
ξ	Elasticity of TFP to education spending	0.22	IMF (2018)
A_0	Initial total factor productivity	0.241	Berg et al., (2018)
τ	Baseline tax rate (factor income and profit of wholesalers)	0.13	U.S. data
x	Elasticity of mark-up with respect to the robot density	0.045	U.S. data
m_0	Parameter in the mark-up function (implied mark-up is 1.19)	0.880	Barkai (2020)

II. WELFARE COMPARISON BASED ON THE UTILITY FUNCTIONS OF THE AGENTS

This Annex presents welfare analysis based on social welfare derived from the utility function in the model. Social welfare in the Annex is defined as the average of utility of the three agents (capitalists, unskilled workers and skilled workers), weighted by their population shares in Annex I. With the specification, social welfare is described by consumption of the three agents and labor supply of the two types of workers, in contrast to the discussion in the main text of the paper that depends solely on disposable income.

This Annex is organized as follows. First, it presents the evolution of social welfare under the baseline. The evolution suggests that we could omit capitalists in discussing social welfare, because of their small population weight (one percent) as well as very low marginal utility of their consumption. The latter reflects the already very high level of per capita consumption of capitalists in the initial state, relative to skilled and unskilled workers. This finding support the second criterion in Section V. The second, third and fourth sections present the impact of the policy packages on social welfare (<u>measured as the deviations from the baseline</u>). Again, we will see the irrelevance of the utility of capitalists in our welfare discussion.

A. Social Welfare under the Baseline

The evolution of social welfare under the baseline is broadly in line with that in Section V. Technological progress of automation reduces social welfare, only compensated in the long run. The decline of social welfare is almost entirely driven by lower utility of unskilled workers due to their lower disposable income. Positive effect of lower labor supply (more leisure) on utility does not sufficiently compensate lower disposable income. As time goes, accumulated traditional

Social Welfare. Baseline
(Period average change relative to the inistial steady state, percent)

capital and robots raise demand for skilled workers. Higher disposable income of skilled workers increases their utility. Also, accumulation of traditional capital somewhat improves utility of unskilled workers, in the long run, after the rebound of their disposable income (around 20 years).
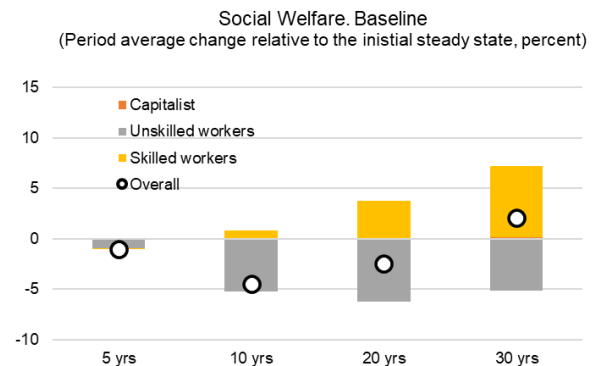
Capitalists does not quantitatively affect social welfare under the baseline. This is a very striking finding that supports our strategy of comparing social welfare in the paper: omitting capitalists in welfare discussions. This reflects a small pupulation share of capitalists (one percent) and very small marginal impact of their consumption on utility because their consumption level is already substantially higher than workers in the initial state.

B.   Social Welfare under the Tax-and-Redistribution Packages

**Raising the tax on capital income to finance targeted transfer to unskilled workers: better than the baseline**. Social welfare improves from the baseline throuought the period, due to higher disposable income of unskilled workers as a result of redistribution. Utility of skilled workers somewhat decreases, reflecting their lower disposable income than the baseline. Again, the contribution of capitalists is negligible, due to their small pupulation share as well as small marginal

Social Welfare. Raising Tax on Capital Income
(Period average change relative to the baseline, percentage)

impact of the policy package on their utility. In a nutshell, since capital is inelastically supplied in the short run, policymakers may find it optimal to raise the tax rate for high income groups, who rely more heavily on capital income (Bakis et al., 2015).
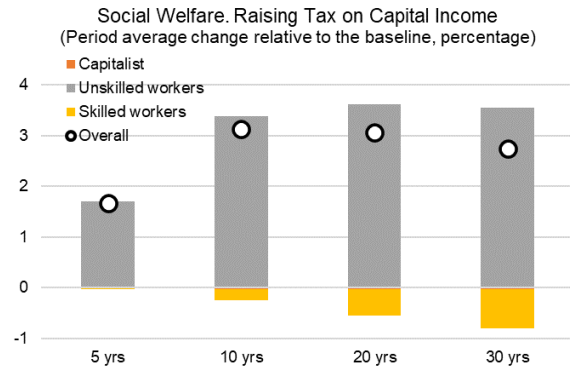
Introducing a consumption tax to finance targeted transfer to unskilled workers: better than the previous two packages in the long run and the baseline but worse than raisign a tax on capital income in the short run. Again, less hurting production efficiency by this package does not translate into social welfare improvement relative to the package to raise a capital income tax to finance the targeted transfer in the short run. This is because additional tax burden imposed on skilled workers offsets the benefit of net

Social Welfare. Consumption Tax
(Period average change relative to the baseline, percentage)

income transfer to unskilled workers despite the positive effect on higher output.
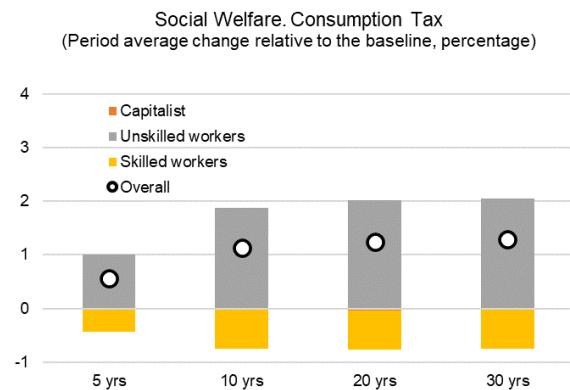
**Imposing a tax on stock of robots to finance targeted transfer to unskilled workers: substantial improvement in social welfare.** The substantial improvement reflects higher disposable income of unskilled workers throughout the peiod, due to the shift of demand from robots to unskilled labor on top of the targeted income transfer to them. Also, increased demand for skilled labor in response to the shift of investment from robots to traditional capital raises utility of skilled

Social Welfare. Robot Tax
(Period average change relative to the baseline, percentage)

workers from the baseline during the first five years. However, in the long run, high cost of taxing robots on output weighs on demand for skilled workers, reducing their utility below the baseline.
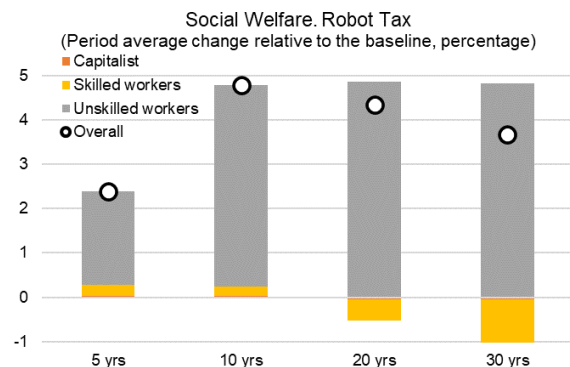
Introducing a wealth tax to finance targeted transfer to unskilled workers: generate welfare gain similar to raising a tax on capital income. As in Section IV, we consider a tax on total physical capital (i.e., wealth). The package with a tax on total physical capital (i.e., wealth tax) has welfare impact very similar to that of capital income tax-fianced transfer policy. This is in line with the observation in Section IV-B.
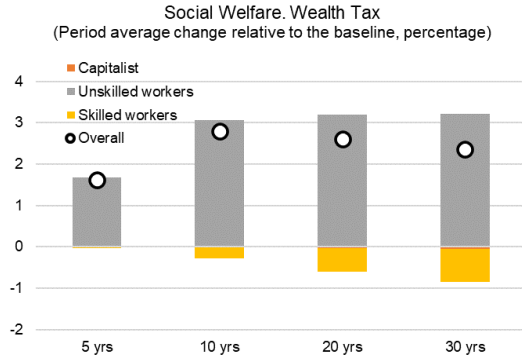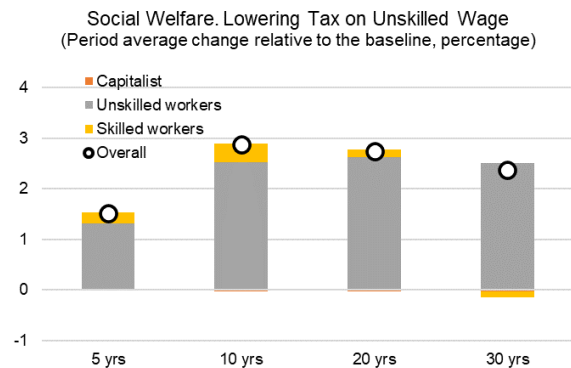
Raising the tax on mark-up to finance targeted transfer to unskilled workers: stable large social welfare improvement from the baseline. Social welfare improves from the baseline throuought the period, due to higher disposable incomes of unskilled workers as a result of redistribution. The degree of social welfare improvement is similar to capital income taxation in the short run, while it is better in the long run due to less distortionary impact on capital accumulation.
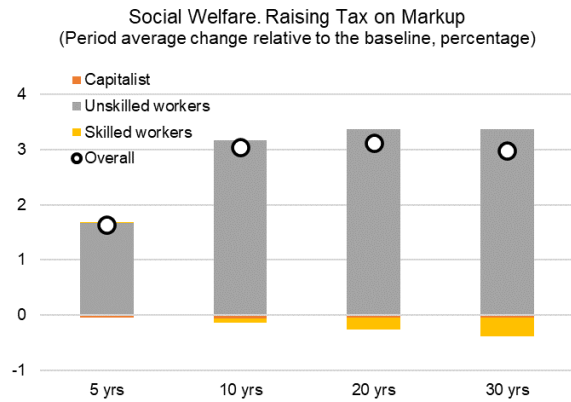
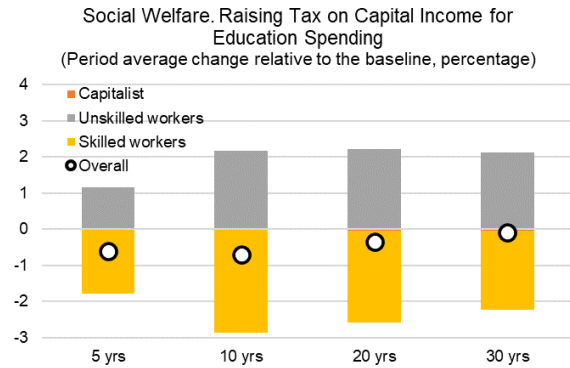**Raising a capital income tax to finance a tax cut of unskilled wage income: more improvement in social welfare than targeted transfer.** Stronger unskilled disposable income (by stronger labor supply and after-tax wage) by the tax cut makes their positive contribution to social welfare larger than the package with targeted transfer. For skilled workers, the reduced labor demand increases their utility in the short run. However, skilled workers worse off in the long run reflecting the continued use of unskilled labor instead of robots by the tax cut.

Social Welfare. Wealth Tax
(Period average change relative to the baseline, percentage)

Social Welfare. Raising Tax on Markup
(Period average change relative to the baseline, percentage)

Social Welfare. Lowering Tax on Unskilled Wage
(Period average change relative to the baseline, percentage)

C. Social Welfare under the Tax-and-Invest Package

Raising a capital income tax to finance education spending to switch unskilled to skilled workers: improved efficiency does not translate into social welfare. The shift raises disposable income of unskilled workers. On the other hand, as discussed in Section V, the package reduces disposable income of skilled workers because the package makes them abundant in the labor market, reducing their wages. The overall net effect on social welfare is negligible with the specification of

Social Welfare. Raising Tax on Capital Income for Education Spending
(Period average change relative to the baseline, percentage)

the model in the paper. Readers may think this result is odd, because overall output with this package is better than the package raising a capital income tax and using its receipt as targeted transfer to unskilled workers (Section IV). Some of the improved economic efficiency by the education spending is shared by capitalists through improved marginal product of capital. But its impact on social welfare is very small (or negligible), because of their very low population share and very small marginal impact of their consumption as well as the offsetting negative impact of higher tax burden on capital.

D. Social Welfare under Rigid Unskilled Wage Policy

Rigid unskilled wage (with fixing it at the initial level): Medium-term social welfare deteriorates with large cost to skilled workers. Social welfare declines especially in the medium term, driven by skilled workers. While the utility of unkilled workers improve with this package, the improvement reflects lower labor supply because as in Section V their disposable income is substantially lower than the baseline. This is not captured by the three criteria in Section V.

Social Welfare. Rigid Unskilled Wage
(Period average change relative to the baseline, percentage)