Should Robots Be Taxed?

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Should robots be taxed?

- Will a rise in automation increase income inequality by eliminating the jobs of routine workers?
  - Cortes, Jaimovich, and Siu (2017)
  - Acemoglu and Restrepo (2017)
- Is there a role for policy?
- Develop model with heterogeneous households: routine and non-routine.
- Perform optimal policy exercises.

Outline

1. Model of automation
   - Static model (paper develops dynamic model)
2. Equilibrium with current tax system (status-quo equilibrium)
3. First-best solution
4. Mirrleesian second-best solution
5. Optimal policy with simple income taxes
6. Welfare comparison
7. Endogenous occupational choice
8. Relation to public finance literature
9. Conclusion

Model

Model of automation

- Two types of households: π_r routine and π_n non-routine households.
- Preferences
$$U_j = u(c_j, l_j) + v(G),$$
- routine $j = r$ and non-routine $j = n$.
- $c_j =$ consumption, $l_j =$ hours worked, $G =$ government spending.
- Budget constraint
$$c_j \leq w_j l_j - T(w_j l_j),$$
- $w_j =$wage rate worker type $j = r, n$,
- $T(\cdot) =$ income tax schedule.

Robot producers

- Robots are an intermediate input. Final good producers can use robots in tasks $i \in [0,1]$.
- Robots for each task i are produced by competitive firms.
- Cost of producing a robot ϕ units of output. Identical across tasks.

- Problem of firm that produces robots to automate task i is

$$\pi_i = \max_{x_i} p_i x_i - \phi x_i.$$

- It follows that

$$p_i = \phi.$$

Final good producers

- A representative firm hires non-routine labor (N_n).
- For each task i, hire routine labor (n_i) or buy intermediate goods (x_i) which we refer to as robots.
- Production function:

$$Y = A \left[\int_0^m x_i^\rho di + \int_m^1 n_i^\rho di \right]^{\frac{1-\alpha}{\rho}} N_n^\alpha,$$

  - CES aggregator for tasks and Cobb-Douglas in tasks and non-routine labor.
  - Each task may be produced by robots or routine workers (perfect substitution).
  - Since tasks are symmetric, assume first m are automated, and last $(1-m)$ use routine workers.

Final good producers

- Representative firm problem is to choose $\{x_i, n_i, m, N_n\}$ to maximize

$$\pi = Y - w_n N_n - w_r \int_m^1 n_i di - \int_0^m (1+\tau_x)\phi x_i di.$$

- τ_x = linear tax on robots.

Final good producers

- $x_i = x$ constant in $[0, m]$
- $n_i = n$ constant in $(m, 1]$
- With automation, $w_r = (1 + \tau_x)\phi$
- With automation the levels of routine labor and robots are the same: $x = n$

Government

- Government chooses
  - Income taxation, $T(\cdot)$.
  - Tax on robots, τ_x.
  - Government spending, G.

- Budget constraint:

$$G \leq \pi_r T(w_r N_r) + \pi_n T(w_n N_n) + \int_0^m \tau_x \phi x_i di.$$

  - Tax schedule is the same for both types of workers.

Market clearing

- Routine labor:

$$\int_m^1 n_i di \equiv N_r = \pi_r l_r,$$

$$N_n = \pi_n l_n.$$

- Output market:

$$\pi_r c_r + \pi_n c_n + G \leq A \left[\int_0^m x_i^\rho di + \int_m^1 n_i^\rho di \right]^{\frac{1-\alpha}{\rho}} N_n^\alpha - \int_0^m \phi x_i di.$$

  - Cost of robot production subtracted from final output.

Competitive equilibrium

- The income share of total production of non-routine workers is the same as with a Cobb-Douglas production function

$$\frac{w_n N_n}{Y} = \alpha.$$

- But for routine workers it is multiplied by $(1 - m)$

$$\frac{w_r N_r}{Y} = (1 - \alpha)(1 - m).$$

- An increase in automation increases pre-tax income inequality
  - Reduces the share of routine workers,
  - Keeps constant share of non-routine workers.

No automation

- No automation if

$$w_r < (1 + \tau_x)\phi$$

- In this case: $m = 0$ and $x = 0$
- Also,

$$w_n N_n = \alpha Y$$
$$w_r N_r = (1 - \alpha) Y$$
$$Y = A N_r^{1-\alpha} N_h^{\alpha}$$

With automation

- With automation

$$w_r = (1 + \tau_x)\phi$$

- Total routine labor supplied is split equally by $1 - m$ non-automated tasks:

$$N_r = (1 - m)n_i, \text{ for } i \in (m, 1],$$

- Robots in the first m tasks are used at the same level.

- Equilibrium level of automation is

$$m = 1 - \left[\frac{(1 + \tau_x)\phi}{(1 - \alpha)A}\right]^{1/\alpha} \frac{N_r}{N_n}.$$

With automation

- Wage rates are given by technological parameters (independent of preferences)

$$w_n = \alpha \frac{A^{1/\alpha}(1-\alpha)^{\frac{1-\alpha}{\alpha}}}{\left[(1+\tau_x)\phi\right]^{\frac{1-\alpha}{\alpha}}},$$

$$w_r = (1+\tau_x)\phi.$$

  - Tax on robots increases wage of routine, but decreases wage of non-routine.
  - In that way, this instrument affects the relative wage.

Status-quo equilibrium

Status-quo equilibrium

- Calibrate sequence of static economies $2000 - 2150$.
- Heathcote, Storesletten and Violante (2014) propose after-tax income function

$$
\begin{aligned}
y(w_j l_j) &= \lambda (w_j l_j)^{1-\gamma}, \\
T(w_j l_j) &= w_j l_j - \lambda (w_j l_j)^{1-\gamma}.
\end{aligned}
$$

  - λ controls the level of taxation (higher λ implies lower average taxes).
  - γ controls the progressivity of the tax code ($\gamma > 0$ implies progressivity).

- HSV estimates using PSID data
  - $\gamma = 0.181$ (income taxes close to linear),
  - $R^2 = 0.91$.

Status-quo equilibrium

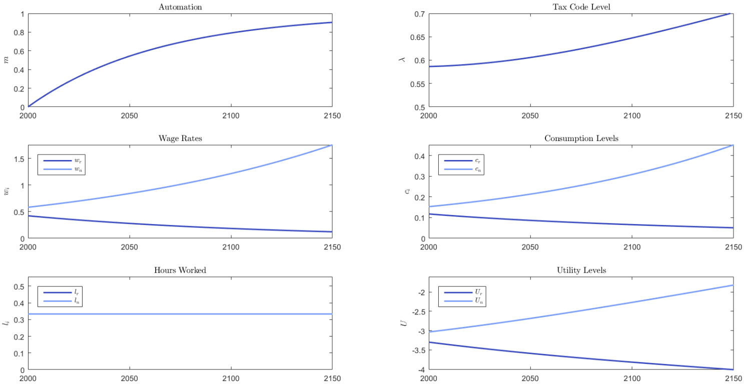
- Functional form for utility function:
  - $U_j = \log(c_j) + \zeta \frac{l_j^{1+\nu}}{1+\nu} + \chi \log(G)$.
  - Choose $\zeta = 10.63$, which implies $l_j = 1/3$, and Frisch elasticity $\nu = 1/0.75$ (Chetty et al., 2011).
  - $\chi = 0.233$.

- Policy:
  - Government sets its spending to 18.9 percent of net output.
  - Sets $\gamma = 0.181$ and adjusts λ to balance budget.
  - Robots are not taxed, $\tau_x = 0$.

- Production parameters:
  - Normalize $A = 1$
  - Set $\alpha = 0.53$ and $\pi_r = 0.55$ (Chen, 2016)
  - $\phi_t = \phi_0 e^{-g_\phi \times t}$, $\phi_0 = 0.42$ and $g_\phi = 0.01$ to match Acemoglu and Restrepo (2018).

Status-quo equilibrium

Figure 1: Status-Quo Equilibrium



- Only non-routine workers benefit from automation.
- Consumption of routine workers goes to zero.
- Full automation never occurs.

First-best allocation

First-best allocation

- Planner maximizes average utility

$$V = \pi_r U_r + \pi_n U_n,$$

  - Possible interpretation: ex-ante, workers do not know whether they are routine or non-routine, planner maximizes expected utility.

- subject to resource constraints

$$\pi_r c_r + \pi_n c_n + G \leq Y - \phi \int_0^m x_i di,$$

$$Y = A \left[\int_0^m x_i^\rho di + \int_m^1 n_i^\rho di \right]^{\frac{1-\alpha}{\rho}} (\pi_n l_n)^\alpha,$$

$$\int_m^1 n_i di = \pi_r l_r.$$

First-best allocation

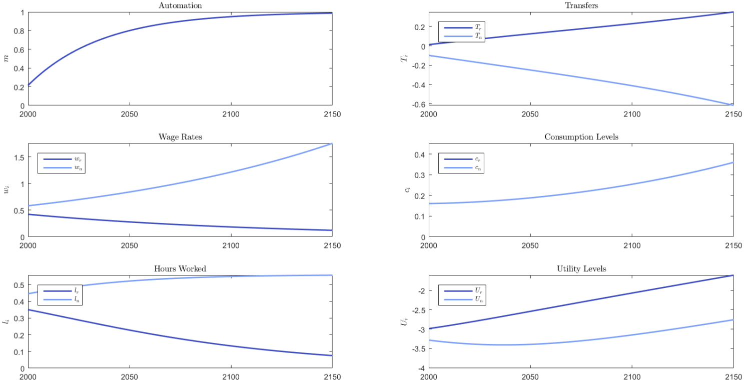
- Agents have equal consumption in the first best.
- More productive agents work more.

⇒ When types are not observable, this allocation cannot be implemented

  - High productivity agents would pretend to be low productivity.

First-best allocation

Figure 2: First Best



- Routine workers have higher utility than non-routine.
- Routine workers always benefit from automation.
- Non-routine workers eventually benefit.

First-best allocation

- While interesting as a benchmark, the first best is not implementable when there are restrictions on the tax system.
- For that reason we will turn to plans that satisfy restrictions:
  - Informational restrictions, in the spirit of Mirrlees (1971);
  - Instrument restrictions, in the tradition of Ramsey (1927).

Mirrleesian optimal taxation

Mirrleesian optimal taxation

- Government does not observe agent's type or labor supply.
- Government observes an agent's total income
  - Optimal non-linear income taxation
- Robot taxes are assumed to be proportional, τ_x.
  - Guesnerie (1995): non-linear taxes on intermediate inputs create arbitrage opportunities. Difficult to implement.

Mirrleesian optimal taxation

- In Mirrlees (1971) differences in agents' productivities are exogenous.
- In our model, productivity differences are endogenous and depend on τ_x.
- Key question: is it optimal to distort production decisions by taxing the use of robots to redistribute income from non-routine to routine workers to increase social welfare?

Mirrleesian optimal taxation

- Planner's problem:

$$W(\tau_x) \quad = \quad \max \pi_r \left[u(c_r, l_r) + v(G)\right] + \pi_n \left[u(c_n, l_n) + v(G)\right],$$

subject to resource constraint

$$\pi_r c_r + \pi_n c_n + G \leq w_n \pi_n l_n \frac{\tau_x + \alpha}{\alpha(1+\tau_x)} + \frac{w_r \pi_r l_r}{1+\tau_x}.$$

and two incentive compatibility (IC) constraints

$$u(c_n, l_n) \geq u(c_r, w_r l_r / w_n),$$
$$u(c_r, l_r) \geq u(c_n, w_n l_n / w_r).$$

- Optimal choice of τ_x requires $W'(\tau_x) = 0$.

Mirrleesian optimal taxation

Proposition

In the optimal plan, when automation is incomplete ($m < 1$) robot taxes are strictly positive ($\tau_x > 0$).

- Increasing τ_x generates a first-order gain from loosening the informational restriction of the non-routine worker:

$$u(c_n, l_n) \geq u(c_r, w_r l_r / w_n).$$

- If $\tau_x < 0$, a marginal increase in τ_x is also in the direction of production efficiency.
- If $\tau_x = 0$, a marginal increase in τ_x induces output losses, but only second order.
- A planner that chooses $\tau_x \leq 0$ can always improve its objective with a marginal increase in τ_x.

Mirrleesian optimal taxation - with full automation

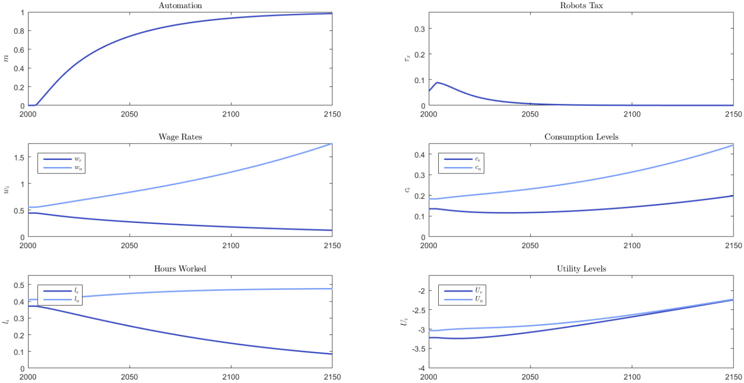
- With full automation, $Y_r = 0$ and $m = 1$, the IC of the non-routine worker becomes

$$u(c_n, l_n) \geq u(c_r, 0)$$

- Robot taxes no longer affect this constraint.
- Routine and non-routine workers have the same utility.

Mirrleesian optimal taxation

Figure 3: Mirrleesian Optimal Taxation



- Modest levels of robot taxes. These become zero once routine workers are replaced by robots.
- Asymptotic full automation. Agents have the same utility.

Simple income tax systems

Simple taxes

- The Mirrleesian plan may be a big deviation from the income tax systems that we observe in actual economies.
- How close to the Mirrleesian second best can an empirically plausible tax function take us?
- Is there a simple modification of such tax system that would generate a large improvement?

$\Rightarrow$ Restrictions on instruments - Ramsey tradition

Simple taxes

- Optimal tax policy when the tax schedule has form proposed by Heathcote, Storesletten and Violante (2014)

$$T(w_j l_j) = w_j l_j - \lambda (w_j l_j)^{1-\gamma},$$

- With this formulation the ratio of consumptions is

$$\frac{c_r}{c_n} = \left[\frac{(1-\alpha)(1-m)}{\alpha} \frac{\pi_n}{\pi_r} \right]^{1-\gamma}.$$

- Two ways to make ratio c_r / c_n closer to one.
  - Raise τ_x which leads to a fall in the level of automation, m .
    - ★ Away from production efficiency.
  - Make γ closer to one, i.e. make the tax system more progressive.
    - ★ Reduces incentives to work.

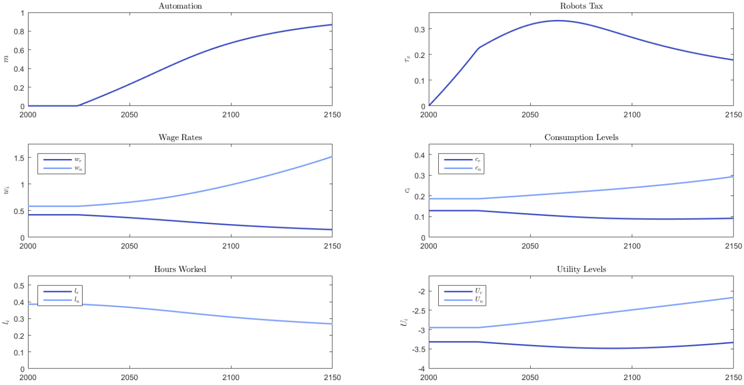
Simple taxes

$$\frac{c_r}{c_n} = \left[\frac{(1-\alpha)(1-m)}{\alpha} \frac{\pi_n}{\pi_r} \right]^{1-\gamma}.$$

- The planner will balance making the system more progressive and distorting m downwards.
- Full automation is never optimal.
  - That would lead the routine worker to consume zero.

Simple taxes

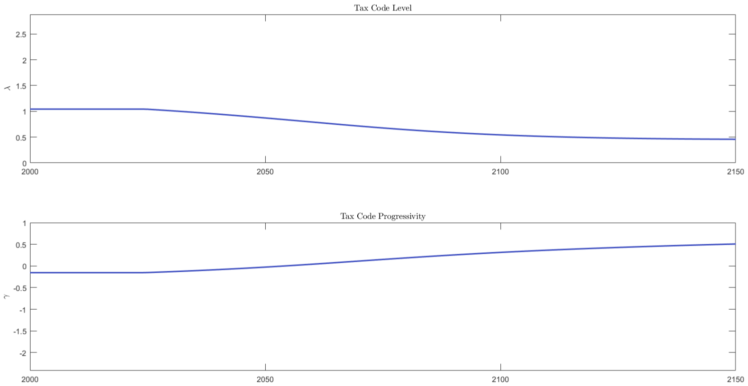
Figure 4: Simple Taxes - Panel A



- High taxes on robots = high production distortions.
- Both agents eventually benefit from automation.
- Full automation never occurs.

Simple taxes

Figure 4: Simple Taxes - Panel B



Simple taxes with lump-sum transfers

- The previous tax system leads to very high taxation of robots, large production ineficiency.
- Simple modification: allow for lump-sum rebates, Ω.

$$T(w_j l_j) = w_j l_j - \lambda (w_j l_j)^{1-\gamma} - \Omega.$$

- In this case, the ratio of consumptions is given by

$$\frac{c_r - \Omega}{c_n - \Omega} = \left[\frac{(1-\alpha)(1-m)}{\alpha} \frac{\pi_n}{\pi_r} \right]^{1-\gamma},$$

Simple taxes with lump-sum transfers

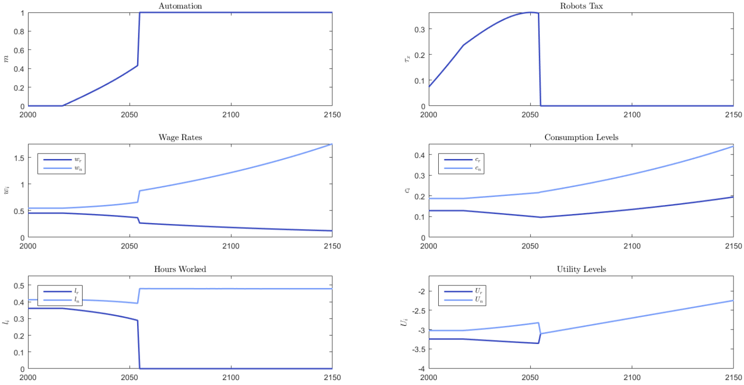
$$\frac{c_r - \Omega}{c_n - \Omega} = \left[\frac{(1-\alpha)(1-m)}{\alpha} \frac{\pi_n}{\pi_r} \right]^{1-\gamma},$$

- Lump-sum rebate helps redistributing income
- Agents receive income even if they do not work

$\Rightarrow$ Full automation is possible.

Simple taxes with lump-sum transfers

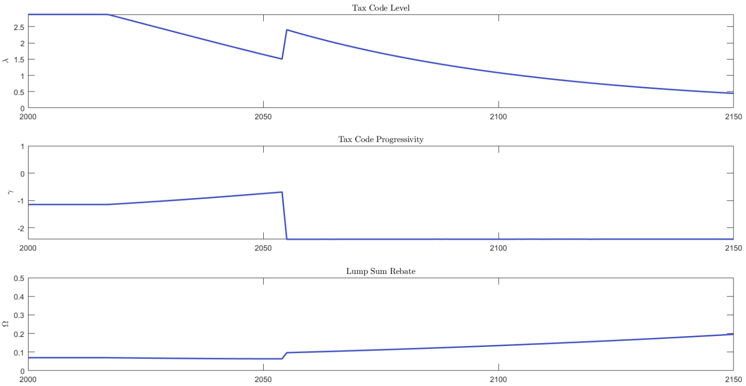
Figure 5: Simple Taxes & Lump Sum Rebate - Panel A



- Full automation is recovered.
- Robot taxes are zero after full automation (since $l_r = 0$ robot taxes do not help redistribution).

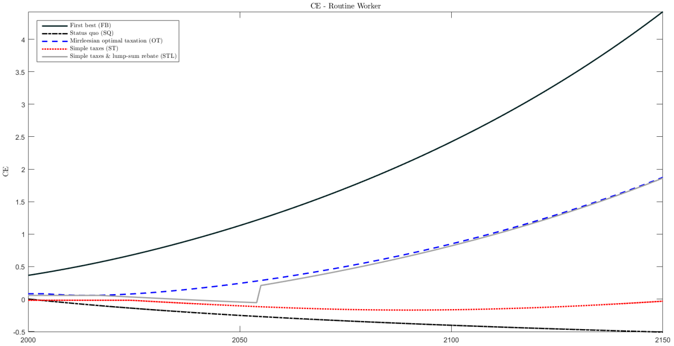
Simple taxes with lump-sum transfers

Figure 5: Simple Taxes & Lump Sum Rebate - Panel B



Welfare comparison - routine workers

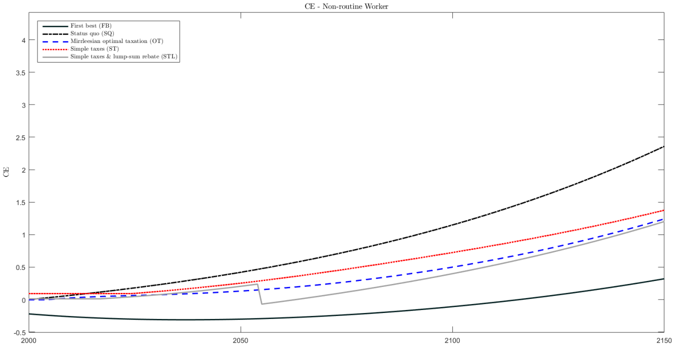
Figure 7: Consumption Equivalent - Panel A



- How much would we have to increase consumption in the status-quo with $m = 0$?
- Status-quo is the only equilibrium where they are always hurt by further automation.

Welfare comparison - non-routine workers

Figure 7: Consumption Equivalent - Panel B



- Best equilibrium is status-quo, they are the only ones to benefit from decreasing automation costs.
- Apart from first best they are always better off by further automation.
- First-best planner can induce non-routine to work more, and temporarily lose with automation.

Endogenous occupational choice

Endogenous occupational choice

- Suppose now that agents can move between occupations.
  - Saez (2004), Rothschild and Scheuer (2013), Gomes, Lozachmeur, and Pavan (2017)
- Household type θ has preferences over the two occupations.

$$u(c_\theta, l_\theta) + g(G) - \mathcal{O}_\theta \theta.$$

- $\mathcal{O}_\theta = 1$ if household becomes non-routine, and $\mathcal{O}_\theta = 0$ otherwise.
  - If $\theta < 0$ the household prefers non-routine occupations.
  - If $\theta > 0$ the household prefers routine occupations.
- The agent receives the wage w_n if assigned to a non-routine occupation and w_r if routine.

Endogenous occupational choice

- Agents choose both their occupation and the number of hours worked.
- There are two incentive constraints:
  - Labor supply IC
    $$u(c_\theta, l_\theta) \geq u\left(c_{\theta'}, \frac{w_{\theta'}}{w_\theta} l_{\theta'}\right).$$
  - Occupational choice IC
    $$u(c_\theta, l_\theta) - \mathcal{O}_\theta \theta \geq u(c_{\theta'}, l_{\theta'}) - \mathcal{O}_{\theta'} \theta.$$

Endogenous occupational choice

- In the optimum, agents that choose the same occupation have the same levels of consumption and hours of work.
- The occupational choice IC is summarized by a threshold rule

$$\theta^* = u(c_n, l_n) - u(c_r, l_r).$$

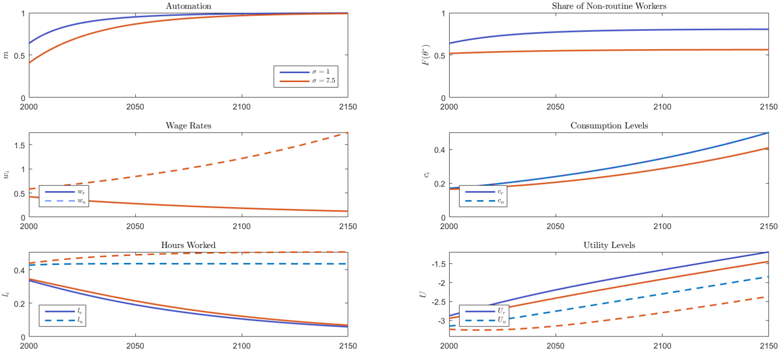
  - Agents with $\theta > \theta^*$ choose to be routine workers.
  - Agents with $\theta \leq \theta^*$ become non-routine.

Endogenous occupational choice

- We assume that θ is drawn from a normal distribution with mean zero and standard deviation σ.
- Half of the population prefers non-routine work.
- The other half prefers routine work.

Endogenous occupational choice - First best

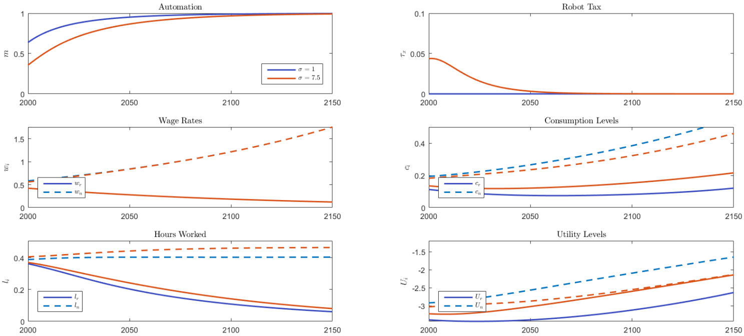
Figure 8: First Best with Occupational Choice



- For lower σ: more agents become non-routine.
- For lower σ: everyone works less and has higher consumption.

Endogenous occupational choice - Mirrlees Optimal Taxes

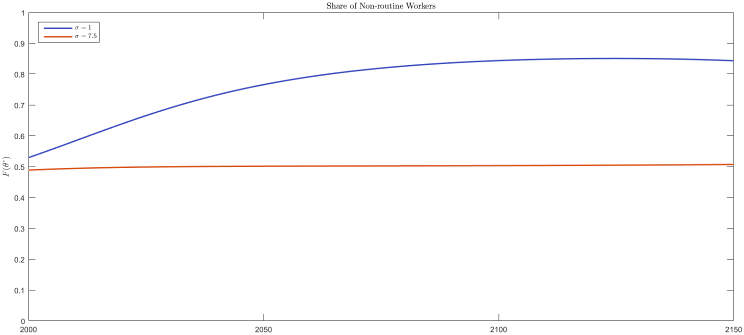
Figure 9: Mirrlees Optimal Taxation with Occupational Choice (Panel A)



- When occupation switching costs are lower: redistribute by inducing more agents to become non-routine.
- There is less of a need to resort to robot taxes.
- Worse deal for the remaining routine.

Endogenous occupational choice - Mirrlees Optimal Taxes

Figure 9: Mirrlees Second Best with Occupational Choice (Panel B)



- With $\sigma = 1$, redistribution by moving agents to non-routine $\Rightarrow$ More non-routine than in first best.
- With $\sigma = 2$, direct redistribution and more robot taxes $\Rightarrow$ Less non-routine than in first best.

Back to taxation of intermediate goods

Back to taxation of intermediate goods

- Diamond & Mirrlees (1971)
  - Assumes that government can tax different goods at different rates.
  - In our model this assumption would allow taxing routine and non-routine workers at different rates.
  - When direct tax discrimination is not possible, robots will be taxed provided this helps treating different agents differently.

- Atkinson & Stiglitz (1976)
  - Assumes that labor types are perfect substitutes.
  - This implies that intermediate goods do not interact differently with different labor types.
  - These assumptions do not hold in our model.
    - ★ Robots are substitutes for routine workers and complements for non-routine workers.
  - Naito (1999), Scheuer (2014), and Jacobs (2015)

Robots as capital

- Robots are durable goods.
- Taxing robots creates intertemporal distortions, in addition to production inneficiency.
- Intertemporal distortions might be optimal for reasons orthogonal to the ones studied in this paper:
  - To confiscate the initial stock, if the set of tax instruments is limited.
  - Because the elasticities of the marginal utility of consumption and labor are time varying.
  - With idiosyncratic risks, there may be insurance motives.
- As a capital good, robots would be taxed by a capital income tax without full deduction of investment.
  - South Korea will limit tax incentives for investment in automated machines, as part of a revision of tax laws. Effective begining of 2018.

Conclusions

- With current U.S. tax system, a sizable fall in automation costs leads to a large rise in income inequality.
  - Routine-worker wages fall to make them competitive with automation.
  - Only non-routine workers benefit from advances in automation.
  - Full automation never occurs: routine workers always supply labor as their income and consumption approach zero.
- Inequality can be reduced by raising marginal tax rates paid by high-income individuals and by taxing robots to raise the wages of routine workers.
  - Eventually both agents benefit from advances in automation.
  - Full automation never occurs.
  - This solution involves a substantial efficiency loss.

Conclusions

- Mirrleesian optimal income tax can reduce inequality at a smaller efficiency cost.
  - Lower taxes on robots.
- Simple approach with large gains: amend tax system to include lump-sum rebates.
  - Solution gets closer to Mirrleesian solution.
  - When costs of automation are sufficiently low, routine workers stop working and live off transfers.
  - Still requires taxing robots

Conclusions

- With endogenous occupational choice:
  - The planner can switch agents between occupations to redistribute.
  - For lower switching costs:
    - More agents change to non-routine occupations.
    - There is less of a role for robot taxes.
  - Short vs. long run.