INEFFICIENT AUTOMATION

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Automation raises productivity but *displaces workers* and *lowers their earnings*.
Motivation

- Automation raises productivity but **displaces workers** and **lowers their earnings**.
- Increasing adoption has fueled an active **policy debate** (Atkison, 2019; Acemoglu et al, 2020).
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**Tax automation**

Guerreiro et al, 2017; Costinot-Werning, 2018

(i) Govt. has preference for redistribution

(ii) Automation/reallocation are efficient
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Diamond 1965; Dávila et al, 2012; Davila-Korinek, 2018

(i) Dynamic ineff. or pecuniary externalities in IM
(ii) Worker displacement/reallocation absent
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- No **optimal policy** results that take into account **frictions** faced by displaced workers
- Two **literatures** can justify taxing automation → **Reallocation is frictionless or absent**

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Take worker displacement seriously. How should a government respond to automation?

1. Recognize that displaced workers face two important frictions:
   (i) Slow reallocation: workers face mobility barriers and may go through unemployment/retraining.
   Davis-Haltiwanger, 1999; Jacobson et al, 2005; Lee-Wolpin, 2006; Alvarez-Shimer, 2011
   (ii) Imperfect credit markets: workers have limited ability to borrow against future incomes.
   Jappelli et al, 2010; Chetty, 2008

2. Incorporate frictions in a model with endogenous automation and heterogeneous agents.

3. Theoretical results:
   (i) Interaction between frictions gives rise to inefficient automation.
   (ii) Optimal to tax automation when the government lacks instruments to fully alleviate frictions (even with no preference for redistribution).

4. Quantitative: gross flows + idiosyncratic risk → welfare gains from slowing down automation.
Take worker displacement seriously. How should a government respond to automation?

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4. **Quantitative**: gross flows + idiosync. risk → **welfare gains** from slowing down autom.
Contributions to the Literature


- **Policy interventions on efficiency grounds**


- **Normative analysis with incomplete markets**


- **Focus on taxation of automation with labor reallocation frictions**
Environment

Efficient Allocation

Decentralized Equilibrium

Failure of First Welfare Theorem

Optimal Policy

Quantitative Analysis
Continuous time $t \geq 0$
Continuous time $t \geq 0$

Occupations

Workers

Resource constraint $Z c t (x) d \Lambda = G \star \mu A, \mu N; \alpha \phi h \mu h t = Z 1 \{ h (x) = h \} \xi d \pi t$
<table>
<thead>
<tr>
<th>Occupations</th>
<th>Workers</th>
</tr>
</thead>
<tbody>
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Continuous time $t \geq 0$
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### Occupations

- $h = A$ (share $\phi$, degree $\alpha \geq 0$) or $h = N$
- $F^h(\mu) = \begin{cases} F^*(\mu; \alpha) & \text{if } h = A \\ F(\mu) \equiv F^*(\mu; 0) & \text{if } h = N \end{cases}$

### Workers

- $U_0 = E_0 Z \exp(-\rho t) c_1 - \sigma t \, dt$
- Resource constraint $Z c_t(x) d\Lambda = G^* \mu_A, \mu_N; \alpha$
Continuous time $t \geq 0$

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$F^*(1; \alpha) \downarrow$ in $\alpha$ (less labor-intensive)

$F^*(1; \alpha)$ concave in $\alpha$ (automation cost)

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$$h(x) = h$$

$\xi d\pi_t$
Environment

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\[ F^*_\mu (1; \alpha) \downarrow \text{ in } \alpha \text{ (less labor-intensive)} \]

\[ F^* (1; \alpha) \text{ concave in } \alpha \text{ (automation cost)} \]

Final Good Producer

\[ G^* (\mu^A, \mu^N; \alpha) \equiv G \left( \left\{ F^h (\mu^h) \right\} \right) \]

(gross complements)
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**Workers**

$x = \{s, h, \xi\}$ (age, occupation, prod.)

$$\left( \mu^A_t, \mu^N_t \right) = \begin{cases} 1 & \text{in } t = 0 \\ \text{Reallocation afterwards} \end{cases}$$
ENVIRONMENT

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= 1 & \text{in } t = 0 \\
\text{Reallocation} & \text{afterwards}
\end{cases}$$

$$U_0 = \mathbb{E}_0 \left[ \int \exp(-\rho t) \frac{c^1_{t-\sigma}}{1-\sigma} dt \right]$$
**Environment**

**Continuous time** \( t \geq 0 \)

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**Workers**

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\[
\begin{align*}
(\mu^A_t, \mu^N_t) &= 1 \\
\text{Reallocation} & \quad \text{afterwards}
\end{align*}
\]

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U_0 = E_0 \left[ \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \right]
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**Resource constraint**

\[
\int c_t(x) \, d\Lambda = G^* \left( \mu^A, \mu^N; \alpha \right)
\]

\[
\phi^h_t \mu^h_t = \int 1_{\{ h(x) = h \}} \xi \, d\pi_t
\]
Reallocation of existing workers is **costly** (Kambourov-Manovskii, Violante, Costinot-Werning)

1. **Permanent cost**: productivity loss $\theta$ due to skill-specificity

\[
\xi_t = \begin{cases} 
\lim_{\tau \uparrow t} \xi_\tau & \text{if } h'_t(x) = h \\
(1 - \theta) \times \lim_{\tau \uparrow t} \xi_\tau & \text{otherwise}
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Reallocation frictions

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- Reallocation of existing workers is **slow** (Davis-Haltiwanger, Alvarez-Shimer). Two reasons:

  2. **Random opportunities**: Workers can move across occupations with intensity $\lambda$

  3. **Unemployment/retraining spells**: Enter when moving, and exit at rate $\kappa$
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- Arrival of new workers is **slow** (Rebelo et al., Adão et al.). Rate $\chi$. Choose any occupation.
Environment

Efficient Allocation

Decentralized Equilibrium

Failure of First Welfare Theorem

Optimal Policy

Quantitative Analysis
FIRST BEST PROBLEM

Ex post problem

Ex ante problem

\[
\int_0^\infty e^{-\rho t} u'(c_t) N_t \Delta t \, dt = 0
\]

Short unemployment or retraining \(\sim (1 - \theta) YN_t - Y_A t\)

Long unemployment or retraining \(\sim \)
First Best Problem

**Ex post problem**

- Reallocate labor and distribute output
- Close MPLs gap. Stop reallocation at $T_0^{FB}$
  (No OLG case)

**Ex ante problem**
First Best Problem

Ex post problem

- Reallocate labor and distribute output
- Close MPLs gap. Stop reallocation at $T_{FB}^0$ (No OLG case)

\[
\int_{T_{FB}^0}^{+\infty} e^{-\rho t} u' \left( c_t^N \right) \Delta_t dt = 0
\]

where

\[
\Delta_t \equiv (1 - \theta) \left( 1 - e^{-\kappa (t - T_{FB}^0)} \right) \left( Y_t^N - Y_t^A \right)
\]

is the IRF of $Y$ to reallocation

Ex ante problem

Choose degree of automation $\alpha$

Reduce $C_t$ today, expand $Y_t$ tomorrow (No OLG case)
**First Best Problem**

**Ex post problem**

- Reallocate labor and distribute output
- Close MPLs gap. Stop reallocation at $T_{FB}^T$ (No OLG case)

$$\int_{T_{FB}}^{+\infty} e^{-\rho t} u' \left( c_t^N \right) \Delta_t dt = 0$$

**Ex ante problem**

Short unemployment or retraining $\sim (1 - \theta) Y_A^N - Y_A^A$

Long unemployment or retraining

$\Delta_t$

$0$

$t$
**First Best Problem**

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- Reallocate labor and distribute output
- Close MPLs gap. Stop reallocation at $T^\text{FB}_0$ (No OLG case)

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\int_{T^\text{FB}_0}^{+\infty} e^{-\rho t} u' \left( c^N_t \right) \Delta_t dt = 0
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**Ex ante problem**
- Choose degree of automation $\alpha^\text{FB}$
- Reduce $C$ today, expand $Y$ tomorrow

---

Short unemployment or retraining

Long unemployment or retraining
FIRST BEST PROBLEM

Ex post problem

► Reallocate labor and distribute output

► Close MPLs gap. Stop reallocation at $T_{FB}^0$ (No OLG case)

$$\int_{T_{FB}^0}^{+\infty} e^{-\rho t} u' \left( c_t^N \right) \Delta_t dt = 0$$

Short unemployment or retraining $\sim (1 - \theta) Y_N - Y_A$

Long unemployment or retraining

Ex ante problem

► Choose degree of automation $\alpha^{FB}$

► Reduce $C$ today, expand $Y$ tomorrow

$$\int_0^{+\infty} e^{-\rho t} u' \left( c_t^A \right) \Delta^*_t dt = 0$$

where

$$\Delta^*_t \equiv \frac{\partial}{\partial \alpha^*} G^* \left( \mu_t^A, \mu_t^N ; \alpha^{FB} \right)$$

is the IRF of $Y$ to automation (net of cost)
**First Best Problem**

### Ex post problem
- Reallocate labor and distribute output
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Outline

Environment

Efficient Allocation

Decentralized Equilibrium

Failure of First Welfare Theorem

Optimal Policy

Quantitative Analysis
Decentralized Choices

Firms

Workers

Definitions of Equilibrium
**Decentralized Choices**

**Firms**

Choose automation $\alpha$ + labor demand $\mu_t$

$$\max_{\{\alpha, \mu_t\}} \int_0^{+\infty} Q_t \Pi_t (\mu_t; \alpha) \, dt$$

**Workers**

**Assets:** bonds, incomplete markets

Workers not insured against automation risk

$x = \{a, s, h, \xi\}$ (bonds, age, occ., prod.)

$$da_t (x) = [Y^* t (x) + (r_t + \chi) a_t (x) - c_t (x)] \, dt$$

Borrowing friction $a_t (x) \geq a$ for some $a \leq 0$
Firms

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Workers

Choose cons. $c_t$ and labor supply $\mu_t$
Decentralized Choices

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$$a_t (x) \geq a \text{ for some } a \leq 0$$
Decentralized Choices

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$Q_t$: equity priced by unconst. workers

**Workers**

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*Assets*: bonds, incomplete markets

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Environment

Efficient Allocation

Decentralized Equilibrium

**Failure of First Welfare Theorem**

Optimal Policy

Quantitative Analysis
Proposition. (Failure of FWT)

1. The laissez-faire equilibrium is inefficient if and only if reallocation frictions \((\lambda, \kappa)\) and borrowing frictions \((a)\) are such that \(a^* (\lambda, \kappa) < a \leq 0\) for threshold \(a^* (\cdot)\).
Proposition. (Failure of FWT)

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2. The threshold \(a^*(\lambda,\kappa) < 0\) if and only if reallocation is slow \((1/\lambda \text{ or } 1/\kappa > 0)\).
**Proposition.** (Failure of FWT)

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2. The threshold \(a^* (\lambda, \kappa) < 0\) if and only if reallocation is slow \((1/\lambda \text{ or } 1/\kappa > 0)\).

- **Interaction** between reallocation and borrowing frictions is key

- **Efficient cases:** instant realloc. (Costinot-Werning) or no borrowing frictions (Guerreiro et al)
NATURE OF THE INEFFICIENCY

Distortions at the laissez-faire

Workers expect income to improve as they reallocate → Motive for borrowing

Inefficiency
Nature of the Inefficiency

Distortions at the laissez-faire

Inefficiency

Tight constraint

Slow reallocation

Workers expect income to improve as they reallocate → Motive for borrowing
Why Is Automation Inefficient?

▶ Automation. Compare the optimality conditions

(first best)

\[ \int_{0}^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \Delta^*_t \, dt = 0 \]

(laissez-faire)

\[ \int_{0}^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \Delta^*_t \, dt = 0 \]

where \( \Delta^*_t \) is the IRF of \( Y \) to automation.
Why Is Automation Inefficient?

▶ Automation. Compare the optimality conditions

\[
\int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \Delta_t^* dt = 0 \quad \text{and} \quad \int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \Delta_t^* dt = 0
\]

▶ Automation \quad \rightarrow \quad u'(c_{0,t}^A) > u'(c_{0,t}^N) \quad \rightarrow \quad \text{Rationale for redistribution}
Why Is Automation Inefficient?

- **Automation.** Compare the optimality conditions

  (first best) \[
  \int_0^\infty e^{-\rho t} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \Delta_t^* dt = 0
  \]

  (laissez-faire) \[
  \int_0^\infty e^{-\rho t} \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \Delta_t^* dt = 0
  \]

- Automation \(\rightarrow\) \(u'(c_{0,t}^A) > u'(c_{0,t}^N)\) \(\rightarrow\) Rationale for redistribution

- No borrowing constraints \(\rightarrow\) \(\frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} = \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)}\) \(\rightarrow\) Laissez-faire = First best
Why Is Automation Inefficient?

▶ Automation. Compare the optimality conditions

(First best) \hspace{2cm} (laissez-faire)

\[
\int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \Delta_t^* dt = 0 \quad \quad \int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \Delta_t^* dt = 0
\]

▶ Automation \hspace{1cm} \rightarrow \hspace{1cm} u'(c_{0,t}^A) > u'(c_{0,t}^N) \rightarrow \text{Rationale for redistribution}

▶ Borrowing constraints \hspace{1cm} \rightarrow \hspace{1cm} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} < \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \rightarrow \text{Laissez-faire} \neq \text{First best}
Why Is Automation Inefficient?

▶ Automation. Compare the optimality conditions

\[
\int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \Delta_t^* dt = 0 \\
\int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \Delta_t^* dt = 0
\]

▶ Automation  \rightarrow u'(c_{0,t}^A) > u'(c_{0,t}^N) \rightarrow \text{Rationale for redistribution}

▶ Borrowing constraints  \rightarrow \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} < \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} \rightarrow \text{Laissez-faire} \neq \text{First best}

Firms are too patient. Partly overlook that benefits of automation take time to realize.
Environment

Efficient Allocation

Decentralized Equilibrium

Failure of First Welfare Theorem

Optimal Policy

Quantitative Analysis
How should a government respond to automation? Depends on the tools available.
How should a government respond to automation? Depends on the tools available

- Suppose: **tax on automation** $\tau^\alpha + \text{arbitrary transfers/taxes to redistribute**}
How should a government respond to automation? Depends on the **tools** available

- Suppose: **tax on automation** $\tau^\alpha$ + arbitrary transfers/taxes to redistribute
- Wedge between first best and laissez-faire optimality condition

$$\tau^\alpha = \int_0^{+\infty} e^{-\rho t} \left( \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} - \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \right) \Delta_t^* dt$$
How should a government respond to automation? Depends on the tools available

- Suppose: tax on automation $\tau^\alpha +$ arbitrary transfers/taxes to redistribute
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$$\tau^\alpha = \int_0^{+\infty} e^{-\rho t} \left( \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} - \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \right) \Delta_t^* dt$$

When is $\tau^\alpha = 0$? Redistributive tools $\rightarrow$ alleviate borrowing cons. and close MRS gap
How should a government respond to automation? Depends on the tools available

- Suppose: tax on automation $\tau^\alpha +$ arbitrary transfers/taxes to redistribute

- Wedge between first best and laissez-faire optimality condition

$$
\tau^\alpha = \int_0^{+\infty} e^{-\rho t} \left( \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} - \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \right) \Delta_t^* dt
$$

1. **Worker/time-specific lump sum transfers** → implement any first best (SWT holds)

   Informational requirements? (Piketty-Saez, 2013; Guerreiro et al., 2017; Costinot-Werning, 2018)
How should a government respond to automation? Depends on the **tools** available

▶ Suppose: **tax on automation** $\tau^\alpha$ + **arbitrary transfers/taxes to redistribute**

▶ **Wedge between first best and laissez-faire optimality condition**

\[
\tau^\alpha = \int_0^{+\infty} e^{-\rho t} \left( \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} - \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \right) \Delta^*_t dt
\]

2. **Symmetric lump sum transf.** (UBI) $\rightarrow$ govt. borrows for workers $\rightarrow$ restore **efficiency**

Fiscal cost? Govt. debt limits? (Araujo-Woodford, 2015; Daruich-Fernandez, 2020; Guner et al., 2021)
How should a government respond to automation? Depends on the tools available

- Suppose: tax on automation \( \tau^\alpha \) + arbitrary transfers/taxes to redistribute

- Wedge between first best and laissez-faire optimality condition

\[
\tau^\alpha = \int_0^{+\infty} e^{-\rho t} \left( \frac{u'(c_{0,t}^N)}{u'(c_{0,0}^N)} - \frac{u'(c_{0,t}^A)}{u'(c_{0,0}^A)} \right) \Delta^*_t dt
\]

3. Non-linear income taxes or unemp. insurance → help but do not restore efficiency
   Heterogeneity within occupations swamps heterogeneity between occupations (as in quantitative model)
Second best tools: tax automation \textit{(ex ante)} + labor market interventions \textit{(ex post)}

No social insurance for now, reintroduced in quantitative model
Second best tools: tax automation (*ex ante*) + labor market interventions (*ex post*)

No social insurance for now, reintroduced in quantitative model

Tractability: hand-to-mouth workers ($a \to 0$), no OLG ($\chi = 0$)
Constrained Ramsey problem

- **Second best tools**: tax automation \((ex\ ante)\) + labor market interventions \((ex\ post)\)
  
  No social insurance for now, reintroduced in quantitative model

- **Tractability**: hand-to-mouth workers \((a \rightarrow 0)\), no OLG \((\chi = 0)\)

- **Primal problem**: control automation \(\alpha\) and reallocation \(T_0\)

\[
\max_{\{\alpha, T_0, \mu_t, c_t\}} \sum_h \phi^h \eta^h \int_0^{+\infty} \exp(-\rho t) u \left(c_t^h\right) dt
\]

subject to workers’ budget constraints, the law of motion of labor, firms choosing labor optimally, and market clearing.
Government’s optimality conditions to **automate** \((\alpha)\) and **reallocate** \((T_0)\)

\[
\int_{0}^{+\infty} \exp(-\rho t) u'(c_{0,t}^N) \Delta_t^* dt = -\Phi^*(\alpha_{SB}, T_{0}^{SB}, \eta)
\]

\[
\int_{T_0^{SB}}^{+\infty} \exp(-\rho t) u'(c_{0,t}^A) \Delta_t dt = -\Phi(\alpha_{SB}, T_{0}^{SB}; \eta)
\]

\{laissez-faire\}

\{pecuniary externalities\}
Constrained inefficiency

Government’s optimality conditions to automate \((\alpha)\) and reallocate \((T_0)\)

\[
\int_0^{+\infty} \exp(-\rho t) u'(c_{0,t}^N) \Delta_t^* dt = -\Phi^*(\alpha_{SB}, T_{0}^{SB}, \eta)
\]

\[
\int_{T_{0}^{SB}}^{+\infty} \exp(-\rho t) u'(c_{0,t}^A) \Delta_t dt = -\Phi(\alpha_{SB}, T_{0}^{SB}, \eta)
\]

Proposition. (Constrained inefficiency)

Fix weights \(\eta\). Then, there is always a small perturbation of the technology \(G^*(\cdot)\) such that either \(\Phi^*(\cdot) \neq 0\) or \(\Phi(\cdot) \neq 0\) — i.e., the equilibrium is generically constrained inefficient.
No pref. for redistribution: weights $\eta^{\text{effic}}$ so that distributional terms cancel out

Guarantee that the government would not distort an efficient allocation for redistributive reasons
No pref. for redistribution: weights $\eta^{\text{effic}}$ so that distributional terms cancel out

Guarantee that the government would not distort an efficient allocation for redistributive reasons

(second best) \hspace{1cm} (laissez-faire)

$$
\int_{0}^{+\infty} e^{-\rho t} \sum_{h} \phi^{h} \eta^{h,\text{effic}} \frac{u'(c^{h}_{0,t})}{u'(c^{h}_{0,0})} \Delta^{*}_{t} dt = 0
$$

$$
\int_{0}^{+\infty} e^{-\rho t} \frac{u'(c^{N}_{0,t})}{u'(c^{N}_{0,0})} \Delta^{*}_{t} dt = 0
$$
Taxing automation on efficiency grounds

No pref. for redistribution: weights $\eta_{\text{effic}}$ so that distributional terms cancel out

Guarantee that the government would not distort an efficient allocation for redistributive reasons

(second best) \hspace{1cm} (laissez-faire)

$$\int_0^{+\infty} e^{-\rho t} \sum_h \phi^h \eta^h,\text{effic} \frac{u'(c^h_{0,t})}{u'(c^h_{0,0})} \Delta_t^* dt = 0$$
$$\int_0^{+\infty} e^{-\rho t} \frac{u'(c^N_{0,t})}{u'(c^N_{0,0})} \Delta_t^* dt = 0$$

1. The response of output to automation $\Delta_t^*$ is back-loaded

Figure
**TAXING AUTOMATION ON EFFICIENCY GROUNDS**

- **No pref. for redistribution:** weights $\eta^{\text{effic}}$ so that distributional terms cancel out

  Guarantee that the government would not distort an efficient allocation for redistributive reasons

\[
\int_0^{+\infty} e^{-\rho t} \sum_h \phi^h \eta^{h,\text{effic}} \frac{u'(c^h_{0,t})}{u'(c^h_{0,0})} \Delta^*_t dt = 0
\]

\[
\int_0^{+\infty} e^{-\rho t} \frac{u'(c^N_{0,t})}{u'(c^N_{0,0})} \Delta^*_t dt = 0
\]

1. The response of output to automation $\Delta^*_t$ is **back-loaded**

2. **Government** is *more impatient* than the firm — priced by unconstrained workers only
Taxing automation on efficiency grounds

▶ No pref. for redistribution: weights $\eta^{\text{effic}}$ so that distributional terms cancel out

Guarantee that the government would not distort an efficient allocation for redistributive reasons

(second best) \hspace{2cm} (laissez-faire)

\[
\int_0^{+\infty} e^{-\rho t} \sum_h \phi^h \eta^{h,\text{effic}} \frac{u'(c_{0,t}^h)}{u'(c_{0,0}^h)} \Delta^*_t \, dt = 0
\]

\[
\int_0^{+\infty} e^{-\rho t} \frac{u'(c_{0,0}^N)}{u'(c_{0,0}^N)} \Delta^*_t \, dt = 0
\]

1. The response of output to automation $\Delta^*_t$ is back-loaded

2. Government is more impatient than the firm — priced by unconstrained workers only

$\rightarrow$ Optimal to tax automation on efficiency grounds
**Taxing automation on efficiency grounds**

- **No pref. for redistribution**: weights $\eta^{\text{effic}}$ so that distributional terms cancel out
  
  Guarantee that the government would not distort an efficient allocation for redistributive reasons

  (second best) 
  
  $\int_{0}^{+\infty} e^{-\rho t} \sum_{h} \phi^{h} \eta^{h,\text{effic}} \frac{u'(c_{0,t}^{h})}{u'(c_{0,0}^{h})} \Delta^{*}_t dt = 0$

  (laissez-faire)
  
  $\int_{0}^{+\infty} e^{-\rho t} \frac{u'(c_{0,t}^{N})}{u'(c_{0,0}^{N})} \Delta^{*}_t dt = 0$

---

**Taxing automation** prevents excessive investment and raises consumption early on in the transition, precisely when displaced workers are borrowing-constrained.
Active labor market interventions might not be available (Heckman et al., Card et al.)
Active labor market interventions might not be available (Heckman et al., Card et al.)

The government uses automation (α) as a proxy for reallocation ($T_0$)

$$\int_{0}^{+\infty} e^{-\rho t} \sum_h \phi^h \eta^h \frac{u'(c^h_{0,t})}{u'(c^h_{0,0})} \left( \Delta^*_t + T'_0 (\alpha^{SB}) \Delta_t \right) dt = 0$$

so that

Short unempl/retraining spells (1/κ low) $\rightarrow$ tax α more

Long unempl/retraining spells (1/κ high) $\rightarrow$ tax α less
EXTENSION II: EQUITY CONCERNS

Efficiency

MRS^A = MRS^N

LF = SB^{effic}

FB^{utilit}

SB^{utilit}

Automation ↓

SB^{effic}

Automation ↓

Equity

MU^A = MU^N
Extension III: Gradual Automation

- Tax capital in the long-run → improve insurance or prevent dynamic inefficiency
  (Aiyagari, 1995; Chamley, 2001; Conesa et al., 2009; Dávila et al., 2021; Aguiar et al.; 2021)
Extension III: Gradual Automation

- Tax capital in the long-run → improve insurance or prevent dynamic inefficiency
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- Rationale for taxing automation is distinct
  1. Does not rely on uninsured income risk (or overlapping generations)
  2. Tax only during the transition, not in long-run once labor reallocation is complete
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- To clarify 2., extend model so that automation takes place gradually

\[
\begin{align*}
d\alpha_t &= (x_t - \delta \alpha_t) \, dt; \\
Y_t &= G^*(\mu_t; \alpha_t) - x_t \alpha_t - \Omega \left(\frac{x_t}{\alpha_t}\right) \alpha_t
\end{align*}
\]

Law of motion

Output net of investment costs
Extension III: Gradual Automation

▶ Tax capital in the long-run → improve insurance or prevent dynamic inefficiency
(Aiyagari, 1995; Chamley, 2001; Conesa et al., 2009; Dávila et al., 2021; Aguiar et al.; 2021)

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1. Does not rely on uninsured income risk (or overlapping generations)
2. Tax only during the transition, not in long-run once labor reallocation is complete

▶ To clarify 2., extend model so that automation takes place gradually

\[
d\alpha_t = (x_t - \delta \alpha_t) \, dt; \quad Y_t = G^* (\mu_t; \alpha_t) - x_t \alpha_t - \Omega (x_t/\alpha_t) \alpha_t
\]

Law of motion \quad Output net of investment costs

▶ Workers are unconstrained in the long-run \( \Rightarrow \alpha_t^{LF}/\alpha_t^{FB} \to 1 \) as \( t \to +\infty \)
Environment

Efficient Allocation

Decentralized Equilibrium

Failure of First Welfare Theorem

Optimal Policy

Quantitative Analysis
Firm

task-based framework – Acemoglu-Autor

\[ y^h_t = F\left(\mu^h_t; \alpha^h_t\right) = A^h \left(\varphi^h \alpha^h_t + \mu^h_t\right)^{1-\eta} \]

quadratic adjustment costs – \(\omega \left(x_t/\alpha_t\right)^2 \alpha_t\)

\[ d\alpha^A_t = (x_t - \delta \alpha^A_t) \, dt \quad \alpha^N_t = 0 \]
Quantitative Model

Firm

task-based framework – Acemoglu-Autor

\[ y_t^h = F \left( \mu_t^h; \alpha_t^h \right) = A^h \left( \phi^h \alpha_t^h + \mu_t^h \right)^{1-\eta} \]

quadratic adjustment costs – \( \omega (x_t/\alpha_t)^2 \alpha_t \)

\[ d\alpha_t^A = (x_t - \delta \alpha_t^A) \, dt \quad \alpha_t^N = 0 \]

Workers

gross flows – Kambourov-Manovskii

\[ S_t (x) = \frac{(1 - \phi) \exp \left( \frac{V_t^N (x'(N; x))}{\gamma} \right)}{\sum_{h'} \phi^{h'} \exp \left( \frac{V_t^{h'} (x'(h'; x))}{\gamma} \right)} \]

uninsured risk – Huggett-Aiyagari

\[ dz_t^I = -\rho z_t^I dt + \sigma z dW_t \]

\[ z_t^P = (1 - \theta) z_{t-} \text{ when moving} \]
Quantitative Model

Firm

task-based framework – Acemoglu-Autor

\[ y_t^h = F\left( \mu_t^h; \alpha_t^h \right) = A^h \left( \phi^h \alpha_t^h + \mu_t^h \right)^{1-\eta} \]

quadratic adjustment costs – \( \omega \left( \frac{x_t}{\alpha_t} \right)^2 \alpha_t \)

\[ d\alpha_t^A = \left( x_t - \delta \alpha_t^A \right) dt \quad \alpha_t^N = 0 \]

Workers

gross flows – Kambourov-Manovskii

\[ S_t(x) = \frac{(1 - \phi) \exp \left( \frac{V_t^{N}(x'(N;x))}{\gamma} \right)}{\sum_{h'} \phi^{h'} \exp \left( \frac{V_t^{h'}(x'(h';x))}{\gamma} \right)} \]

uninsured risk – Huggett-Aiyagari

\[ dz_t^T = -\rho_z z_t^T dt + \sigma_z dW_t \]

\[ z_t^P = (1 - \theta) z_{t,-}^P \text{ when moving} \]

Calibration

internal (7) and external (14)
Automation, Reallocation and Inequality

Automation

- Laissez-faire
- Automation Tax

Share of workers in $h = A$

Wages

- Automated
- Non-Automated

Share of HtM
Objective: The government maximizes

\[ W(\eta) \equiv \int_{-\infty}^{+\infty} \int \eta_t(x) V_{t}^{\text{birth}}(x) d\pi_t(x) \, dt \]

Second best: Choose \( \{\tau_t^x\} \) on investment, rebated to firm owners.
Workers displaced by automation would like to borrow as they reallocate slowly.
TAKEAWAYS

▶ Workers displaced by automation would like to borrow as they reallocate slowly

▶ Borrowing constraints create wedge between interest rate and MRS of workers
Takeaways

▶ Workers **displaced** by automation would like to borrow as they **reallocate slowly**

▶ **Borrowing constraints** create wedge between **interest rate** and **MRS** of workers

▶ **Firms** are effectively **too patient** when investing in automation
Takeaways

- Workers displaced by automation would like to borrow as they reallocate slowly
- Borrowing constraints create wedge between interest rate and MRS of workers
- Firms are effectively too patient when investing in automation

The government should slow down automation on efficiency grounds, even when it has no preference for redistribution
Competitive equilibrium. Set of

1. Allocation for consumption \( \{c_t\} \) and labor supplies \( \{\mu_t, \Theta_t\} \), and automation \( \alpha \)
2. Interest rate \( \{r_t\} \), wages \( \{w_t^A, w_t^N\} \) and profits \( \{\Pi_t\} \)

such that

1. Workers consume, save and move optimally given prices
2. Representative firm chooses automation and hires labor optimally given prices
3. Labor markets clear and resource constraint holds
Distortions at the laissez-faire

- Consumption (PE)
- Reallocation (PE)
- Slow reallocation
- Tight constraint

Distributional effects

- Constraint not binding
- Constraint slack for all $t > T_0$
- Constraint binds for some $t > T_0$

Prod. inefficiency

Stopping time with $a \to -\infty$
Response of output to automation

Output gains $(\alpha, -\mu)$ are complements

Crowding out

$\Delta_t^*$
Incomes:

\[ Y_t (x) = T_t \left( \xi \exp(z) w_t^n + \exp(z) \Pi_t \right) \]

where \( T_t (y) = y - \psi_0 y^{1-\psi_1} \) captures the non-linear tax schedule.

Assets:

Workers trade riskless bonds, and annuities (Blanchard-Yaari)

Fiscal policy:

Constant government spending and debt to GDP, adjusts taxes

Resource constraint:

\[ \int a_t (x) d\pi_t = -B_t, \]
## Table 1: External Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Calibration</th>
<th>Target / Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>EIS (inverse)</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>$\chi$</td>
<td>Death rate</td>
<td>1/50</td>
<td>Average working life of 50 years</td>
</tr>
<tr>
<td>$1 - \eta$</td>
<td>Initial labor share</td>
<td>0.64</td>
<td>1970 labor share (BLS)</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Depreciation rate</td>
<td>0.1</td>
<td>Graetz-Michaels (2018)</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Elasticity of substitution across occs.</td>
<td>0.75</td>
<td>Buera-Kaboski (2011)</td>
</tr>
<tr>
<td>$1/\kappa$</td>
<td>Average unemployment duration</td>
<td>1/3.2</td>
<td>Alvarez-Shimer (2011)</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Productivity loss from relocation</td>
<td>0.18</td>
<td>Kambourov-Manovskii (2009)</td>
</tr>
<tr>
<td>$a$</td>
<td>Borrowing limit</td>
<td>0</td>
<td>Auclert et al (2018)</td>
</tr>
<tr>
<td>$\phi_0, \phi_1, -B/Y$</td>
<td>Government</td>
<td>0.35, 0.18, 0.26</td>
<td>Heathcote et al (2017), Kaplan et al (2018)</td>
</tr>
<tr>
<td>$\rho, \sigma, b$</td>
<td>Income</td>
<td>0.023, 0.102, 0.4</td>
<td>Floden-Lindé (2001), Shimer (2005)</td>
</tr>
</tbody>
</table>
**Table 2: Internal Calibration**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Calibration</th>
<th>Target / Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>Discount rate</td>
<td>0.148</td>
<td>2% real interest rate</td>
</tr>
<tr>
<td>$A^A, A^N$</td>
<td>Productivities</td>
<td>0.89, 1.23</td>
<td>Initial output (1)</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Adjustment cost</td>
<td>2</td>
<td>Half-life of automation</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Fraction of automated occupations</td>
<td>0.53</td>
<td>Routine occs. share 1970</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Mobility hazard</td>
<td>0.42</td>
<td>Occupational mobility 1970</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Fréchet parameter</td>
<td>0.053</td>
<td>Elasticity of labor supply</td>
</tr>
</tbody>
</table>