INEFFICIENT AUTOMATION

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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)

- No optimal policy results that take into account frictions faced by displaced workers

- Two literatures can justify taxing automation:
  1. Reallocation is frictionless or absent: Tax automation
     - Guerreiro et al 2017; Costinot-Werning 2018
   1. Govt. has preference for redistribution
   1. Automation/reallocation are efficient
     - Tax capital (long-run): Aiyagari 1995; Conesa et al. 2002
     1. Improve efficiency in economies with IM
     1. Worker displacement/reallocation absent

- Take worker displacement seriously. How should we respond to automation?
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- **Tax automation**
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(ii) Govt. has preference for redistribution

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Motivation

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**Tax automation**
Guerreiro et al 2017; Costinot-Werning 2018

**Tax capital (long-run)**
Aiyagari 1995; Conesa et al. 2002

Take worker displacement seriously. **How should we respond to automation?**
1. Recognize that displaced workers face two important frictions:
   (i) **Slow reallocation**: workers face mobility barriers and may go through unempl./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; Landais-Spinnewijn, 2021
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2. Incorporate frictions in a model with endog. automation and heterogeneous agents
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3. **Theory (second best)**: gov't can tax automation but lacks tools to alleviate frictions
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2. Incorporate frictions in a model with endogenous automation and heterogeneous agents

3. **Theory (second best)**: gov't can tax automation but lacks tools to alleviate frictions
   (i) Equilibrium is (generically) constrained inefficient and automation is excessive
       Conflict between how firms and displaced workers value the effects of automation → Pareto improvement
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   (ii) Optimal to **slown down automation** automation on efficiency grounds

4. **Quantitative**: gross flows + idiosync. risk → Optimal **speed** of automation + **welfare**
Continuous time $t \geq 0$
Firms

Continuous time $t \geq 0$

Occupations
Firms

Continuous time $t \geq 0$

Occupations

$h = A \text{ (degree } \alpha \geq 0) \text{ or } h = N$
Continuous time $t \geq 0$

Occupations

$h = A$ (degree $\alpha \geq 0$) or $h = N$

$$y^A = F(\mu^A, \alpha), \quad y^N = F^*(\mu^N) \equiv F(\mu^N, 0)$$
Firms

Continuous time $t \geq 0$

Occupations

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$y^A = F(\mu^A, \alpha), \quad y^N = F^*(\mu^N) \equiv F(\mu^N, 0)$

Final good producer

$G^*(\mu^A, \mu^N; \alpha) \equiv G\left(\left\{y^h\right\}\right) - C(\alpha)$
Firms

Continuous time $t \geq 0$

**Occupations**

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**Final good producer**

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

**Automation**

\[ \partial_A G^* (\mu^A, \mu^N; \alpha) \downarrow \text{ in } \alpha \text{ (labor-displacing)} \]

\[ G^* (\mu^A, \mu^N; \alpha) \text{ concave in } \alpha \text{ (costly)} \]
Firms

Continuous time $t \geq 0$

**Occupations**

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**Final good producer**

$$G^* (\mu^A, \mu^N; \alpha) \equiv G \left( \left\{ y^h \right\} \right) - C(\alpha)$$

**Profit maximization**

$$\max_{\alpha \geq 0} \int_0^{+\infty} Q_t \Pi_t (\alpha) \, dt$$
Continuous time $t \geq 0$

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$$G^* (\mu^A, \mu^N; \alpha) \equiv G \left( \{y^h\} \right) - C(\alpha)$$

**Profit maximization**

$$\max_{\alpha \geq 0} \int_0^{+\infty} Q_t \Pi_t(\alpha) \, dt$$

$$\Pi_t(\alpha) \equiv \max_{\mu^A, \mu^N \geq 0} G^* (\mu^A, \mu^N; \alpha) - \mu^A w^A_t - \mu^N w^N_t$$
Example. Production function based on Acemoglu-Restrepo (2018)
Example. Production function based on Acemoglu-Restrepo (2018)

Occupations $h = A \text{ (mass } \phi \text{)}$ or $h = N \text{ (mass } 1 - \phi \text{)}$

Aggregate production function $G^\star_{\mu A, \mu N}; \alpha = \phi \alpha + \mu A \nu - 1 \nu + (1 - \phi) \mu N \nu - 1 \nu - \delta \alpha$, where $\delta$ is the marginal cost of automation.
Example. Production function based on Acemoglu-Restrepo (2018)

Occupations $h = A$ (mass $\phi$) or $h = N$ (mass $1 - \phi$)

Occupational technologies

$$y^A = \alpha + \mu^A \quad \text{and} \quad y^N = \mu^N$$
Example. Production function based on Acemoglu-Restrepo (2018)

Occupations $h = A$ (mass $\phi$) or $h = N$ (mass $1 - \phi$)

Occupational technologies

$$y^A = \alpha + \mu^A \quad \text{and} \quad y^N = \mu^N$$

Aggregate production function

$$G^* (\mu^A, \mu^N; \alpha) = \left[ \phi \left( \alpha + \mu^A \right)^{\frac{\nu-1}{\nu}} + (1 - \phi) \left( \mu^N \right)^{\frac{\nu-1}{\nu}} \right]^\frac{\nu}{\nu-1} - \delta \alpha,$$

where $\delta$ is the marginal cost of automation.
Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \]
Workers

Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \]

Initial allocation

\[
\left\{
\begin{array}{l}
\mu^A_t, \mu^N_t \Rightarrow \frac{1}{2} \quad \text{in } t = 0 \\
\text{Reallocation afterwards}
\end{array}
\right.
\]
Workers

Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \]

Initial allocation

\[ (\mu^{A}_t, \mu^{N}_t) \begin{cases} = 1/2 \text{ in } t = 0 \\ \text{Reallocation afterwards} \end{cases} \]

Budget constraint

\[ da_t^h = [\gamma_t^{h,*} + r_t a_t^h - c_t^h] dt \]
Workers

Preferences

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

Initial allocation

\[ \begin{align*}
(\mu_t^A, \mu_t^N) & = 1/2 \quad \text{in } t = 0 \\
\text{Reallocation} & \text{ afterwards}
\end{align*} \]

Budget constraint

\[ da_t^h = \left[ Y_t^{h,*} + r_t a_t^h - c_t^h \right] dt \]

Two frictions

1. Reallocation (neoclassical)
Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \]

Initial allocation

\[ (\mu_t^A, \mu_t^N) \begin{cases} 
= 1/2 & \text{in } t = 0 \\
\text{Reallocation afterwards} & 
\end{cases} \]

Budget constraint

\[ da_t^h = \left[ \mathcal{Y}_t^{h,*} + r_t a_t^h - c_t^h \right] dt \]

Two frictions

1. Reallocation (neoclassical)
   - Random opportunities arrive at rate \( \lambda \)
Workers

Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_1^{1-\sigma}}{1-\sigma} dt \]

Initial allocation

\[ (\mu^A_t, \mu^N_t) \begin{cases} 1/2 & \text{in } t = 0 \\ \text{Reallocation} & \text{afterwards} \end{cases} \]

Budget constraint

\[ da^h_t = \left[ \gamma^h_t + r^h_t a^h_t - c^h_t \right] dt \]

Two frictions

1. Reallocation (neoclassical)
   - Random opportunities arrive at rate \( \lambda \)
   - Unempl. / retrain. exit at rate \( \kappa \)
Workers

Preferences

\[ U_0 = \int \exp(-\rho t) \frac{c_t^{1-\sigma}}{1-\sigma} dt \]

Initial allocation

\( (\mu_t^A, \mu_t^N) \)

\[ \begin{align*}
\left\{ 
\begin{array}{l}
= 1/2 \\
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Budget constraint

\[ da_t = \left[ \mathcal{Y}_t^{h,*} + r_t a_t^h - c_t^h \right] dt \]

Two frictions

1. Reallocation (neoclassical)
   - Random opportunities arrive at rate \( \lambda \)
   - Unempl. / retrain. exit at rate \( \kappa \)
   - Productivity loss \( \theta \)
**Workers**

**Preferences**

\[ U_0 = \int \exp(-\rho t) \frac{c_1^{1-\sigma}}{1-\sigma} dt \]

**Initial allocation**

\[ (\mu_t^A, \mu_t^N) = \begin{cases} \frac{1}{2} & \text{in } t = 0 \\ \text{Reallocation afterwards} & \end{cases} \]

**Budget constraint**

\[ da_t^h = [\gamma_t^h + r_t a_t^h - c_t^h] dt \]

**Two frictions**

1. **Reallocation** (neoclassical)
   - Random opportunities arrive at rate \( \lambda \)
   - Unempl. / retrain. exit at rate \( \kappa \)
   - Productivity loss \( \theta \)

2. **Borrowing**

\[ a_t^h \geq a \text{ for some } a \leq 0 \]
Resource constraint:

\[
\frac{1}{2} \sum_h c_t^h = G^*(\mu^A_t, \mu^N_t; \alpha)
\]
Resource constraint:

\[
\frac{1}{2} \sum_h C_t^h = G^* (\mu_t^A, \mu_t^N; \alpha)
\]

Labor markets:

\[
w_t^h = G_h (\mu_t^A, \mu_t^N; \alpha) \quad \text{for each } h = A, N
\]
Resource constraint:

$$\frac{1}{2} \sum_{h} c_{t}^{h} = G^{*} (\mu_{t}^{A}, \mu_{t}^{N} ; \alpha)$$

Labor markets:

$$w_{t}^{h} = G_{h} (\mu_{t}^{A}, \mu_{t}^{N} ; \alpha) \quad \text{for each } h = A, N$$

No arbitrage:

$$Q_{t} = \exp \left( - \int_{0}^{t} r_{s} ds \right)$$
Resource constraint:
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\frac{1}{2} \sum_h c_t^h = G^* (\mu_t^A, \mu_t^N; \alpha)
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No arbitrage:
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Q_t = \exp \left( - \int_0^t r_s ds \right)
\]

All agents act competitively.
Environment

Laissez-Faire

Optimal Policy

Quantitative Analysis
Laissez-faire: Reallocation

- Wages $w_t^A < w_t^N$ due to automation
Laissez-faire: Reallocation

- Wages $w^A_t < w^N_t$ due to automation
- Reallocation from $h = A \rightarrow h = N$
Laissez-faire: Reallocation

- Wages $w_t^A < w_t^N$ due to automation
- Reallocation from $h = A \rightsquigarrow h = N$
- Stop reallocating at $T^{LF}$

\[
\int_{T^{LF}}^{+\infty} e^{-\rho t} u' (c_t^A) \Delta_t \, dt = 0
\]

where

\[
\Delta_t \equiv (1 - \theta) \left( 1 - e^{-\kappa(t - T^{LF})} \right) \frac{w_t^N - w_t^A}{w_t^N - w_t^A}
\]

denotes the output gains from reallocation
Workers expect income to improve as they reallocate
Workers expect income to improve as they reallocate → Motive for borrowing
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Laissez-faire: Binding borrowing constraints

Two benchmarks: instant realloc. (Costinot-Werning) or no borrowing frictions (Guerreiro et al)
**Laissez-faire: Binding borrowing constraints**

**Labor incomes**

- \( \hat{Y}_t^A \) (red line)
- \( \hat{Y}_t^N \) (blue line)

**Borrowing constraints**

- Borrowing constrained
- \( a^*(\lambda) \)
- Tight constraint
- \( a \uparrow \)
- Slow reallocation

**Evidence:** Earnings partially recover (Jacobson et al) + Imperfect cons. smoothing (Landais-Spinnewijn)
Firm automation choice $\alpha^{LF}$: trades off cost $C(\alpha)$ with increase in output.
Laissez-faire: Automation

- Firm automation choice $\alpha^{LF}$: trades off cost $C(\alpha)$ with increase in output
- Optimality condition

$$\int_0^{+\infty} Q_t \Delta^*_t dt = 0$$

where

$$\Delta^*_t \equiv \frac{\partial}{\partial \alpha} G^*(\mu^A_t, \mu^N_t; \alpha^{LF})$$

denotes the output gains (net of cost) from automation, and

$$Q_t = \exp \left( - \int_0^t r_s ds \right) = \exp \left( -\rho t \right) \frac{u'(c^N_t)}{u'(c^N_0)}$$

since non-automated workers are unconstrained (savers).
Environment

Laissez-Faire

Optimal Policy

Quantitative Analysis
Constrained Ramsey problem

How should a government respond to automation?

First best tools: lump sum transfers (directed, UBI)

Info requirements? Fiscal cost? (Guerreiro et al., 2017; Costinot-Werning, 2018, Guner et al., 2021)

Primal problem: The government maximizes the social welfare function

\[ U = \sum_{h} \eta U_{h} + \int_{0}^{\infty} \exp(-\rho t) u_c c_{ht} \, dt \]

by choosing \( \alpha, T, \mu, A_t, \mu_N, c_A, c_N \) subject to workers choosing consumption optimally, the law of motion of labor, firms choosing labor optimally, and market clearing.
How should a government respond to automation?

- Depends on the tools available

First best tools: lump sum transfers (directed, UBI)

Info requirements? Fiscal cost? (Guerreiro et al., 2017; Costinot-Werning, 2018, Guner et al., 2021)

Primal problem:
The government maximizes the social welfare function

$$U = \sum_{h} \eta \ln h + \int_{0}^{\infty} \exp(-\rho t) u c h t \, dt$$

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How should a government respond to automation?

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How should a government respond to automation?

- Depends on the tools available

- **Second best tools:** tax automation + active labor market interventions
  
  E.g., South Korea’s reduction in automation tax credit in manuf; Geneva’s tax on automated cashiers.
Constrained Ramsey problem

How should a government respond to automation?

- Depends on the **tools** available

- **Second best tools**: tax automation + active labor market interventions
  E.g., South Korea’s reduction in automation tax credit in manuf; Geneva’s tax on automated cashiers.

- **Primal problem**: The government maximizes the social welfare function

\[
\mathcal{U} \equiv \sum_h \eta^h \int_0^{+\infty} \exp(-\rho t) u\left(c^h_t\right) dt
\]

by choosing \(\{\alpha, T, \mu_t^A, \mu_t^N, c_t^A, c_t^N\}\) subject to workers choosing consumption optimally, the law of motion of labor, firms choosing labor optimally, and market clearing.
Consider a perturbation $\delta \alpha$ starting from the laissez-faire. Welfare change

$$\frac{\delta U}{\delta \alpha} = \eta^N u' \left( c^N_0 \right) \times \int_0^{+\infty} \exp(-\rho t) \frac{u' \left( c^N_t \right)}{u' \left( c^N_0 \right)} \times \left( \Delta^*_t + \Sigma^N_{t,*} \right) dt$$

$$+ \eta^A u' \left( c^A_0 \right) \times \int_0^{+\infty} \exp(-\rho t) \frac{u' \left( c^A_t \right)}{u' \left( c^A_0 \right)} \times \left( \Delta^*_t + \Sigma^A_{t,*} \right) dt$$

where $\Delta^*_t$ is aggregate term and $\Sigma^A_{t,*} + \Sigma^N_{t,*} = 0$ are distributional terms.
Consider a perturbation $\delta \alpha$ starting from the laissez-faire. Welfare change

$$\frac{\delta U}{\delta \alpha} = \eta^N u'(c_0^N) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c_t^N)}{u'(c_0^N)} \left( \Delta^* t + \Sigma^N, t \right) dt$$

$$+ \eta^A u'(c_0^A) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c_t^A)}{u'(c_0^A)} \left( \Delta^* t + \Sigma^A, t \right) dt$$

How automated workers value flows

where $\Delta^* t$ is aggregate term and $\Sigma^A, t + \Sigma^N, t = 0$ are distributional terms.

No borrowing constraints $\rightarrow \frac{u'(c_t^N)}{u'(c_0^N)} = \frac{u'(c_t^A)}{u'(c_0^A)} \rightarrow \text{Efficiency}$ (only distributional terms)
Consider a perturbation $\delta \alpha$ starting from the laissez-faire. Welfare change

$$
\frac{\delta U}{\delta \alpha} = \eta^N u'(c^N_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^N_t)}{u'(c^N_0)} \times (\Delta^*_t + \Sigma^{N,*}_t)\,dt
$$

$$
+ \eta^A u'(c^A_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^A_t)}{u'(c^A_0)} \times (\Delta^*_t + \Sigma^{A,*}_t)\,dt
$$

where $\Delta^*_t$ is aggregate term and $\Sigma^{A,*}_t + \Sigma^{N,*}_t = 0$ are distributional terms.

No borrowing constraints $\rightarrow \frac{u'(c^N_t)}{u'(c^N_0)} = \frac{u'(c^A_t)}{u'(c^A_0)} \rightarrow \text{Efficiency}$ (only distributional terms)

Still rationale for redistribution since $u'(c^N_t) < u'(c^A_t)$, e.g., utilitarian weights.
Consider a perturbation $\delta \alpha$ starting from the laissez-faire. Welfare change

$$\frac{\delta U}{\delta \alpha} = \eta^N u' (c^N_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^N_t)}{u'(c^N_0)} \times \left( \Delta^*_t + \Sigma^N_\ast \right) dt$$

$$+ \eta^A u' (c^A_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^A_t)}{u'(c^A_0)} \times \left( \Delta^*_t + \Sigma^A_\ast \right) dt$$

where $\Delta^*_t$ is aggregate term and $\Sigma^A_\ast + \Sigma^N_\ast = 0$ are distributional terms.

Borrowing constraints $\frac{u'(c^N_t)}{u'(c^N_0)} > \frac{u'(c^A_t)}{u'(c^A_0)} \rightarrow$ Inefficiency
Consider a perturbation $\delta \alpha$ starting from the laissez-faire. Welfare change

$$\frac{\delta U}{\delta \alpha} = \eta^N u'(c^N_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^N_t)}{u'(c^N_0)} \times (\Delta^*_t + \Sigma_{t,*}^N) \, dt$$

$$+ \eta^A u'(c^A_0) \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^A_t)}{u'(c^A_0)} \times (\Delta^*_t + \Sigma_{t,*}^A) \, dt$$

where $\Delta^*_t$ is aggregate term and $\Sigma_{t,*}^A + \Sigma_{t,*}^N = 0$ are distributional terms.

Borrowing constraints $\rightarrow \frac{u'(c^N_t)}{u'(c^N_0)} > \frac{u'(c^A_t)}{u'(c^A_0)} \rightarrow$ Inefficiency

There is a conflict between how the firm and displaced workers value the effects of automation over time. This creates room for Pareto improvements.
**Constrained Inefficiency (for any Pareto weights)**

**Proposition.** (Constrained inefficiency)

Generically, there exists \( \{\delta \alpha, \delta T\} \) such that \( \delta U^A > 0 \) and \( \delta U^N = 0 \). This requires \( \delta \alpha < 0 \).
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\begin{align*}
\delta \alpha \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^A_t)}{u'(c^A_0)} \left( \Delta^*_t + \Sigma^*_t, A \right) dt \\
\delta \alpha \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^N_t)}{u'(c^N_0)} \left( \Delta^*_t + \Sigma^*_t, N \right) dt
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\begin{align*}
\text{(automated)} & \quad \delta \alpha \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^A_t)}{u'(c^A_0)} \left( \Delta_t^* + \Sigma_t^{*,A} \right) dt > 0 \\
\text{(non-automated / firm)} & \quad \delta \alpha \times \int_0^{+\infty} \exp(-\rho t) \frac{u'(c^N_t)}{u'(c^N_0)} \left( \Delta_t^* + \Sigma_t^{*,N} \right) dt < 0
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\begin{align*}
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1. The output gains from automation \( \Delta_t^* \) **build up** over time

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3. Set \( \delta \alpha < 0 \), and \( \delta T < 0 \) to compensate non-auto. workers (akin to future transfer)
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(automated) \( \delta U^A > 0 \)

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Taxing automation increases aggregate consumption and redistributes early on during the transition, precisely when displaced workers value it more.
Optimal Policy Intervention

Optimal intervention depends on how the government values efficiency vs. equity.
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- No pref. for equity: The government uses efficiency weights \( \{ \eta^{h,\text{effic}} \} \)
  
  Gov’t does not distort an efficient allocation to improve equity (think ”inverse marginal utility weights”)

Proposition.
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\[
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\]

- **Back-loaded**

  \(<\exp\left(-\int_0^t r_s ds\right) \text{ for } h=A\)
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**Proposition.** (Taxing automation on efficiency grounds)

A government using efficiency weights \{\eta^{\text{h,effic}}\} finds it optimal to tax automation.

- **Pref. for equity**: Government taxes even more with utilitarian weights
Tax capital → might improve insurance or prevent capital overaccumulation

(Aiyagari, 1995; Conesa et al., 2009; Dávila et al., 2021)
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  1. Does not rely on uninsured income risk

  2. Slow down automation only while workers reallocate and are borrowing constrained. No tax in the long-run.
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- To clarify 2., add important features over long horizons: gradual automation + OLG

\[
\begin{align*}
d\alpha_t &= (x_t - \delta \alpha_t) \, dt; \\
\text{Law of motion} \\
Y_t &= G^* (\mu_t; \alpha_t) - q_t x_t \\
\text{Output net of investment cost}
\end{align*}
\]
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To clarify 2., add important features over long horizons: gradual automation + OLG

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

\( d\alpha_t \) is the Law of motion, \( Y_t \) is the output net of investment cost

Workers have identical MRS and MU in the long-run \(\alpha_t^{LF} / \alpha_t^{FB} \to 1 \text{ as } t \to +\infty\)

No efficiency nor equity rationale for intervention
Firm

Production – Acemoglu-Restrepo

\[ y_t^A = A^A (\alpha + \mu^A)^{1-\eta} \quad \text{and} \quad y_t^N = A^N (\mu^N)^{1-\eta} \]

\[ Y = \left[ \phi \left( y_t^A \right)^{\frac{\nu-1}{\nu}} + (1 - \phi) \left( y_t^N \right)^{\frac{\nu-1}{\nu}} \right]^{\frac{1}{\nu-1}} \]

Investment – Guerreiro et al

Law of motion: \( d\alpha_t = (x_t - \delta \alpha_t) \, dt; \alpha_0 = 0 \)

Cost p/unit: \( q_t = q_{\text{fin}} + \exp(-\psi t) \left( q_{\text{init}} - q_{\text{fin}} \right) \)
## Quantitative Model

### Firm

**Production – Acemoglu-Restrepo**

\[
y_t^A = A^A \left( \alpha + \mu^A \right)^{1-\eta} \quad \text{and} \quad y_t^N = A^N \left( \mu^N \right)^{1-\eta}
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### 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**

\[
\gamma_t^{labor} (x) = \xi \exp (Z) \, W_t^h
\]

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

\[
\xi_t = (1-\theta) \xi_{t-} \quad \text{if move; Replacement rate } b
\]

\[
\gamma_t^{\text{net}} (x) = \mathcal{T} \left( \gamma_t^{\text{labor}} (x) + \exp (Z) \, \Pi_t^{\text{div}} \right)
\]
Calibration

- Initial stationary eq (no automation) = year 1980. A occupations = Routine-intensive
- Mix of external (15 param.) and internal (8 param.) calibration

**Table 1: Internal Calibration**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Calibration</th>
<th>Target / Source</th>
</tr>
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<tbody>
<tr>
<td>$\rho$</td>
<td>Discount rate</td>
<td>0.04</td>
<td>2% real interest rate</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Mobility hazard</td>
<td>0.364</td>
<td>Gross mobility 1980 (10%)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Fréchet parameter</td>
<td>0.036</td>
<td>Elasticity of labor supply (1)</td>
</tr>
<tr>
<td>$A_A, A_N$</td>
<td>Productivities</td>
<td>0.719, 1.710</td>
<td>$Y_0 = 1$, symm. wages</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Share of automated occupations</td>
<td>0.537</td>
<td>Routine empl. share 1980 (55%)</td>
</tr>
<tr>
<td>$q^{\text{fin}}$</td>
<td>Final cost of autom.</td>
<td>5.621</td>
<td>Log wage gap (0.45) in Cortes et al (2016)</td>
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<tr>
<td>$\psi$</td>
<td>Cost convergence rate</td>
<td>0.054</td>
<td>Half-life of wage gap (15 yrs) in Cortes et al (2016)</td>
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Half-life of automation: 15 years at LF v. 20 years at SB
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<th>Less liquidity</th>
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<tr>
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<td>0.93%</td>
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Note: ‘Less liquidity’ and ‘Less reallocation’ denote alternative calibrations where we target a ratio of liquidity to GDP of 0.35 (instead of 0.5) and a separation rate of 7.2% (instead of 10%), respectively. ‘More complements’ denotes an alternative calibration where the elasticity of substitution across occupations is 0.76 (instead of 0.9).
Welfare Gains From Slowing Down Automation

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Wage supplements: In PDV, second best is as if the govt gave $19,126 to the avg. automated worker, and would tax $4,622 from the avg. non-automated worker.
Two novel results in economies where automation displaces workers, and these workers face reallocation and borrowing frictions.
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1. Automation is inefficient when frictions are sufficiently severe
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   Raises agg. consumption and redistributes early on, precisely when displaced workers value it more

Quantitatively: important welfare gains from slowing down automation
Active labor market interventions might not be available (Heckman et al., Card et al.)

Gov't now internalizes indirect effect of automation due to reallocation $T' (\alpha) > 0$

$$T' (\alpha) \times \frac{1}{2} \lambda \exp (-\lambda T) \times \int_{T(\alpha)}^{+\infty} \exp (-\rho t) \left\{ \eta^N u' (c^N_t) - \eta^A u' (c^A_t) \right\} \times (\Delta_t + \Sigma^N_t) \, dt$$

Can reinforce or dampen incentives to tax automation, depending on Pareto weights.

Utilitarian $\rightarrow$ tax less. Efficiency weights $\rightarrow$ tax more.