(Green) Technology Adoption and Skill Reallocation

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Moving towards a *green economy*

Requires a technological transformation:
- Brown sector contracts and green expands
- Sectors transform to meet green demand

★ *Vona et al. (2018)*: Skill sorting, not (only) shortage

→ Do firms adopt the available technologies?
→ How does this interact with labour markets?
Our paper

Labour Market $\xleftarrow{\text{updating}} \xrightarrow{}$ Technology adoption

- Frictions: green tech adoption $\sim$ 35% slower - first order effect
- Workers with green skills *locked-in* brown jobs
- 2050 carbon neutrality $\Rightarrow$ labour market transitions $\uparrow \sim 10\%$
Environment: technology adoption & skills

Building on Hornstein et al. (2007) and Gautier et al. (2010):

- Firm technology + worker → homogeneous good
- Workers(technologies) with heterogeneous skills(requirements)
  - Mass 1 of workers
  - Free entry for firms
  - Skills (and requirements) uniformly distributed over unit circle
- New, greener, technologies created at constant pace
- Labour market frictions: $\lambda = \lambda_0 u^a v^{1-a}$
- Fixed amount of UI benefits, $B$
- Nash Bargaining: $\beta$ share of match surplus to worker
- Exogenous job destruction at rate $\sigma$
Skill mismatch and technology age

The productivity of a worker-technology match:

$$y(a, x) = e^{-\phi a} \left[ 1 - \frac{1}{2} \gamma x^2 \right]$$

- $\phi$: energy efficiency innovation/green demand increase
- $a$: technology age
- $x$: worker-technology skill mismatch $\sim U[0, 1/2]$
- $\gamma$: measure of specialisation
Model setup: 3 stages

Stage 1:
Invest in new technology

Stage 2:
Technology ages

Stage 3:
Technology is scrapped
**Stage 1:**
Invest in new Technology

**Stage 2:**
Technology ages

**Stage 3:**
Technology is scrapped
**Stage 1:**
Invest in new Technology

**Stage 2:**
Technology ages

**Stage 3:**
Technology is scrapped

Firm without worker

- Look for worker
  - NO MEETING: No production
  - MEETING:
    - Skill mismatch x realised
      - NO MATCH: No production
      - MATCH: Start producing with mismatch x

\[ a + 1 \]
**Stage 1:**
Invest in new Technology

**Stage 2:**
Technology ages

**Stage 3:**
Technology is scrapped

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Firm with worker and mismatch $x$

- $a \leq \bar{a}(x)$
  - Still productive
  - Keep producing

- $a > \bar{a}(x)$
  - No longer productive
  - Destroy match

Exogenous destruction
**Stage 1:**
Invest in new technology

**Stage 2:**
Technology ages

**Stage 3:**
**Technology is scrapped**

\[ a = a^* \]

All firms are without a worker

Scrap technology
Distance from the Frontier

Figure: The age distribution of matched technologies along the BGP for various search friction parameters $\lambda_0$

$\rightarrow$ Scrapping age as proxy of distance from the frontier
Skill sorting delaying green-tech adoption

Figure: The number of years a technology remains in use. $\phi = \omega(\eta + \delta)$

→ Mismatch effect: $\gamma = 0$, Search effect: $\lambda_0 \to \infty$
Decarbonisation pace and labour markets

Figure: Labour market transition rates

★ Vona (2019): climate policy driven firings reduce their political acceptability
Introduction

Baseline Model

Results

Policy

Conclusion

Carbon tax

Introduce carbon tax, \( c \): taxing older technologies to increase the pace of decarbonisation

\[
y(a, x) = e^{-\phi a} \left[ 1 - \frac{1}{2} \gamma x^2 \right] - ca
\]
Carbon tax is effective, but not specifically on sorting

Figure: Effect of a carbon tax on the scrapping age
Optimal Policy

Retraining:

- Equivalent to lowering job specialization
  → Lowers labour market transitions,
  → Increases policy acceptability

- In the absence of a carbon tax
  → Retraining subsidies for efficient policy

- In the presence of carbon tax
  → Retraining subsidies for policy acceptability

\[ a^* \]

- Sunk investment
- Search frictions
- Skill mismatch
Green Transition:

- Frictions induce first order effect on adoption delay
- Workers with green skills locked-in brown jobs
- Faster decarbonisation increases labour market transitions

Optimal policy mix: include retraining subsidies
Further Thoughts

- Skill shortage increases skills effect
- Multiplier if innovation depends on pace of adoption
- Translation to carbon footprint
- Quantitative optimal policy analysis
Thank you for your attention!

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Model Extensions

- Worker retention
- Worker retraining
- Aggregate skill shortage
- Skill biased technical change
Worker Retainment

→ Firm scraps old technology, retains worker and realises new $x$

- Some firms update w/out worker
- Retaining firm value:
  \[ V^J(\tilde{a}(x), x) = V^F_W - I > 0 \]
- Update inflow-outflow to include retaining firms

⇒ Search effect ↓
Worker Retraining

Retraining all workers: reduce mismatch by a $\zeta$ factor:

$$y(a, x) = e^{-\phi a} \left[ 1 - \frac{1}{2} \zeta \gamma x^2 \right].$$

Equivalent to a reduction of specialization, $\gamma$, by a $\zeta$ factor.
Aggregate Skill Shortage

\[ x \sim U[0, 1/2] \quad \rightarrow \quad x \sim X_{\kappa}, \quad E[X_{\kappa}] > 1/4 \]

\rightarrow\text{Distributions change accordingly.}

\Rightarrow\text{Mismatch effect} \uparrow \text{(including spatial mismatch)}

How to quantify imperfect sorting versus shortage:

- \text{Skill Shortage} = \lim_{\lambda_0 \to \infty} [Y_{\kappa} - Y_{\kappa \to 0}]

- \text{Imperfect Skill Sorting} = \lim_{\kappa \to 0} [Y_{\gamma} - Y_{\gamma \to 0}]

\rightarrow\text{Can use skills, employment, and vacancy data to estimate} \ k

\rightarrow\text{Skill biased tech change:} \ k_t \uparrow
Green skills

→ Green technologies require other technology-specific skills than predecessors\(^1\)

Are the transferable skills out there? Yes (at least partially):

- Skills gap between green and brown jobs is small\(^2\)
- 44.3% of U.S. jobs have similar tasks to green jobs\(^3\)

**Skill sorting** important, not (only) aggregate skill shortage

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\(^1\) Bremer and den Nijs (2023)
\(^2\) Vona et al. (2018)
\(^3\) Bowen et al. (2018)
Green tech requires other skills

Do your employees need to have the following skills to work with energy efficient technologies?

- No other skills than before
- Technology-specific technical skills
- General technical skills
- Basic skills
- Problem-solving
- Social skills
- Management skills

Responses:
- No
- Yes
Production function of the firm

\[ y(t, a, x) = f(x)z(t)k(t, a)^\omega \]

\[ = f(x)z_0 e^{\psi t} \left[ k_0 e^{\eta(t-a)} e^{-\delta a} \right]^\omega \]

At the balanced growth path the economy grows at a rate \( g = \psi + \omega \eta \) and a new technologies’ productivity increases at an effective rate of \( \phi = \omega(\eta + \delta) \) compared to older vintages.
Energy productivity over time (GDP / energy use)

Figure: Energy productivity in the EU, source: Eurostat
Value functions

- **Employment & Unemployment:**
  \[
  \rho V^E(a, x) = w(a, x) - \sigma \left[ V^E(a, x) - V^U \right] + V^E_a(a, x)
  \]
  - **instantaneous gain**
  - **job destruction loss**
  - **tech ageing**

  \[
  \rho V^U = B + \frac{\lambda}{u} \int_{\Omega(a^*)} [V^E(a, x) - V^U] dF(a, x)
  \]
  - **instantaneous gain**
  - **job finding gain**

- **Matched Job and Vacancy:**
  \[
  \rho V^J(a, x) = y(a, x) - w(a, x) - \sigma \left[ V^J(a, x) - V^V(a) \right] + V^J_a(a, x)
  \]
  - **instantaneous gain**
  - **job destruction loss**
  - **tech ageing**

  \[
  \rho V^V(a) = \frac{2\lambda}{\nu} \int_0^{\bar{x}(a)} \left[ V^J(a, y) - V^V(a) \right] dy + V^V_a(a)
  \]
  - **worker finding gain**
  - **tech ageing**
Distribution of technologies

- \( Y(\bar{x}) = e^{-\phi \bar{a}(x)} \left[1 - \frac{1}{2} \gamma x^2\right] = \rho V^U \)

- \( f \) & \( g \) uniform over \( x \)

**Figure:** Supports of distributions \( f \) (meetings) and \( g \) (matches)
Distributions

- $f(a, x)$: $a - x$ distribution of meeting
- $g(a, x)$: $a - x$ distribution of matches
- $\tilde{f}(a)$: share of meeting that lead to a match below $a$
- $m(a)$: vacancy/meeting age distribution
- $\tilde{g}(a)$: matches age distribution

- $f(a, x) = m(a) \cdot 2 \Rightarrow \tilde{f}(a) = f(a, x) \cdot \overline{x}(a)$
- $g(a, x) = \tilde{g}(a) \cdot \frac{1}{\overline{x}(a)}$
Inflow-outflow equations: BGP

- Inflow-outflow equation of technologies:

\[ \text{vm}(0) = \text{vm}(a) + (1 - u)\tilde{g}(a) \quad 0 < a < a^* \]

\[ \text{entering firms} \quad \text{ageing vacancies} \quad \text{ageing matches} \]

- Inflow-outflow equation for matches:

\[ \lambda \tilde{F}(a) = (1 - u)\left[ \sigma \tilde{G}(a) + \tilde{g}(a) + E(a) \right] \quad 0 < a \leq a^* \]

\[ \text{new matches} \quad \text{exogenous destruction} \quad \text{ageing matches} \quad \text{endogenous destruction} \]

\[ E(a): \text{ endogenous match destruction, } e(a) = -\frac{\tilde{g}(a)}{\tilde{x}(a)} \frac{d\tilde{x}(a)}{da}. \]
Balanced Growth Path

- Reservation match:
  \[ V^U = V^E(a, \bar{x}(a)) \iff V^J(\bar{a}(x), x) = 0 \]
  \[ \Rightarrow \rho V^U = e^{-\phi \bar{a}(x)} \left[ 1 - \frac{1}{2} \gamma x^2 \right], \quad a^* = \bar{a}(0) \]

- Firm free entry: \( V^V(0) = I \)

- Inflow-outflow of matches at \( a = a^* \):
  \[ u = 1 - \frac{\lambda \tilde{F}(a^*)}{\sigma + \tilde{g}(a^*) + E(a^*)} \]

  \( \longrightarrow \) BGP: \( \{u, v, a^*\} \), given \( V^U \) and \( \tilde{g}(a) \).
Solving for the Distributions & Surplus

- Simplyfing the inflow-outflow equations:

\[
\frac{d\tilde{g}(a)}{da} = -\left[ \frac{2\lambda \overline{x}(a)}{v} + \sigma - \frac{1}{\overline{x}(a)} \frac{d\overline{x}(a)}{da} \right] \tilde{g}(a) + \frac{2\lambda \overline{x}(a)}{1-u} m(0)
\]

→ \(\tilde{g}(a)\) as a function of \(\overline{x}(a)\)

- Surplus: \(S(a, x) := V^J(a, x) + V^E(a, x) - V^V(a) - V^U\)

\[
\Rightarrow (\rho + \sigma) S(a, x) = y(a, x) - \frac{2\lambda}{v} (1 - \beta) \int_0^{\overline{x}(a)} S(a, y) dy + S_a(a, x) - e^{-\phi a^*}
\]
Solving for $\tilde{g}(a)$ using the inflow-outflow equations

Differentiating the inflow-outflow equation and plugging in:

$$
\frac{d\tilde{g}(a)}{da} = - \left[ \frac{2\lambda \bar{x}(a)}{\nu} + \sigma - \frac{1}{\bar{x}(a)} \frac{d\bar{x}(a)}{da} \right] \tilde{g}(a) + \frac{2\lambda \bar{x}(a)}{1 - u} m(0)
$$

$$
\Rightarrow \tilde{g}(a) = \frac{2\lambda}{1 - u} m(0) \bar{x}(a) e^{-\left[ \sigma a + \frac{2\lambda}{\nu} \int_0^a \bar{x}(a) da \right]} \left[ \int_0^a e^{\sigma a + \frac{2\lambda}{\nu} \int_0^a \bar{x}(a) da} da + c \right]
$$
Numerical solution

- Solving backwards using $S(a^*, 0) = 0$

- Use and iterate until BGT is found
Iteration

- Job creation: firm free entry equation
- Job destruction: $V^U$ equation

Equilibrium: $\rho = 0.02$, $a=0.6$, $\sigma=0.1$, $\beta=0.5$, $I=2.5$, $\gamma=1.8$, $B=0.4$, $\phi=0.03$

**Figure:** Job destruction and job creation curve
Assumptions: What we do NOT do

- No absolute (only relative) worker advantage over jobs
- No directed search or on-the-job search
- No endogenous pace of innovation
- No dynamics, study BGP

Relaxed in extensions:
- No work retainment when updating technology
- No aggregate skill shortage/skill bias
## Calibration

**Table: Exogenous chosen & calibrated parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>Specialization</td>
<td>1.8</td>
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<tr>
<td>$\rho$</td>
<td>Discounting</td>
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</tr>
<tr>
<td>$\eta$</td>
<td>Capital-embodied energy efficiency</td>
<td>0.013-0.04</td>
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<tr>
<td>$\omega$</td>
<td>Capital share in production</td>
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<td>$a$</td>
<td>Cobb Douglas parameter matching function</td>
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<td>$\lambda_0$</td>
<td>Matching efficiency</td>
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<tr>
<td>$\delta$</td>
<td>Depreciation rate</td>
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<td>$\beta$</td>
<td>Wage share</td>
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<td>$\sigma$</td>
<td>Exogenous separation rate</td>
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<tr>
<td>$I$</td>
<td>Investment costs</td>
<td>2.2</td>
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<tr>
<td>$B$</td>
<td>Unemployment benefits</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\[ \phi = \omega(\eta + \delta) \]

\[ \text{IEA (2021)} \]
Calibration Targets

US data:

- **Average Technology Age** in energy intensive sector: 9 years
- Vacancy & Unemployment duration: 9 weeks & 4 months
- Unemployment rate: 5%, UI replacement rate: 30%
- Wage share of income: 70%
Average age of assets over time

- Energy-intensive
- Non-energy intensive

- Chart showing the average age of assets over time from 1950 to 2020, with the y-axis representing years and the x-axis representing years.
The calibrated BGP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>( \frac{\lambda}{v} )</th>
<th>( a^* )</th>
<th>( a_{CE}^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.02</td>
<td>11</td>
<td>15.3</td>
<td>7.6</td>
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