(Green) Technology Adoption and Skill Reallocation

Sacha den Nijs [†] Stefanos Tyros [†]

[†]Vrije Universiteit Amsterdam & Tinbergen Institute

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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

$$\text{Labour Market} \overset{\text{updating}}{\longleftrightarrow} \text{Technology adoption}$$

- 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 $\rightarrow$ 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: β share of match surplus to worker
- Exogenous job destruction at rate σ

Green Skills Assumptions

Skill mismatch and technology age

The productivity of a worker-technology match:

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

- ϕ: energy efficiency innovation/green demand increase
- a: technology age
- x: worker-technology skill mismatch $\sim U[0, 1/2]$
- γ: measure of specialisation

Full Production Function | Energy Efficiency

Model setup: 3 stages

Stage 1: Invest in new technology

Stage 2: Technology ages

Stage 3: Technology is scrapped

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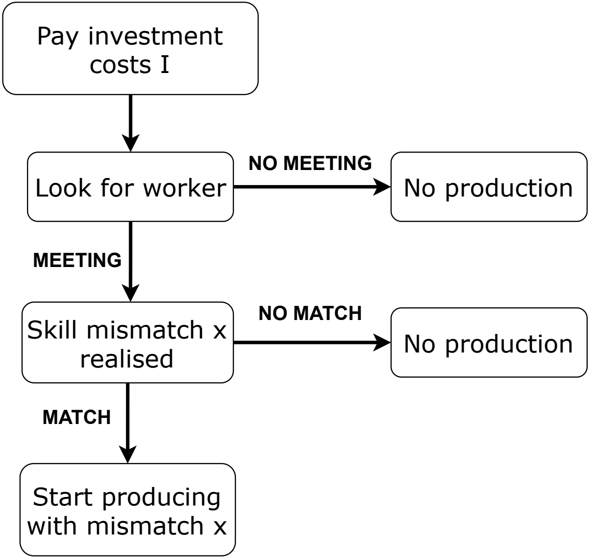
Invest in new Technology

Stage 2:
Technology ages

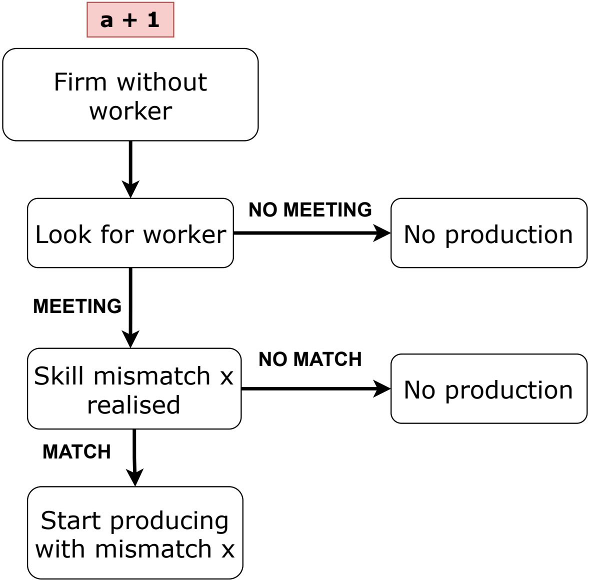
Stage 3:
Technology is scrapped



Stage 1:
Invest in new Technology

Stage 2:
Technology ages

Stage 3:
Technology is scrapped



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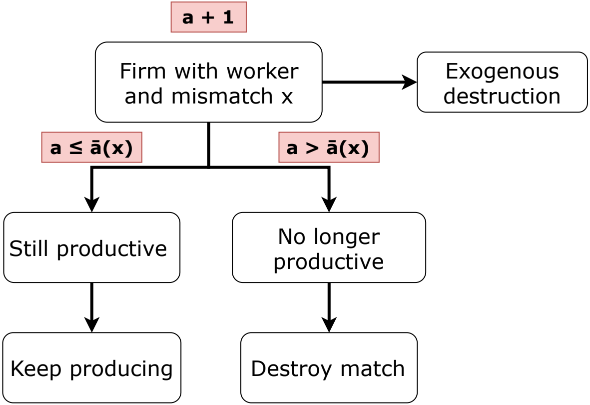

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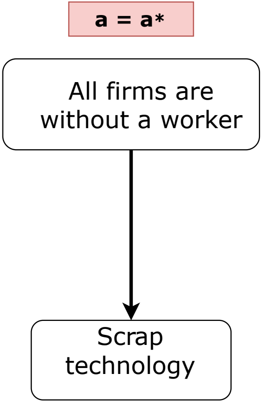


Value Functions Inflow-Outflow

Distance from the Frontier

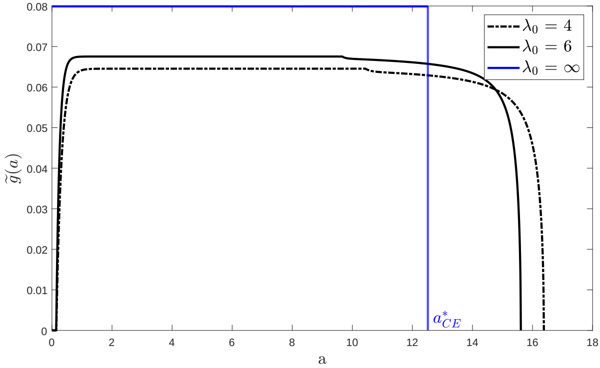


Figure: The age distribution of matched technologies along the BGP for various search friction parameters λ_0

$\rightarrow$ Scrapping age as proxy of distance from the froniter

Calibration

Skill sorting delaying green-tech adoption

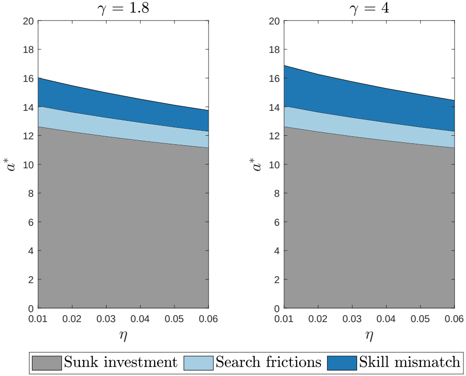


Figure: The number of years a technology remains in use. $\phi = \omega(\eta + \delta)$

$\rightarrow$ Mismatch effect: $\gamma = 0$, Search effect: $\lambda_0 \rightarrow \infty$

Decarbonisation pace and labour markets

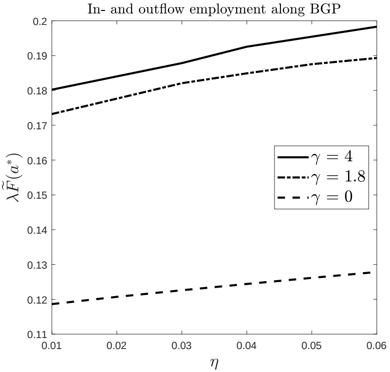


Figure: Labour market transition rates

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

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

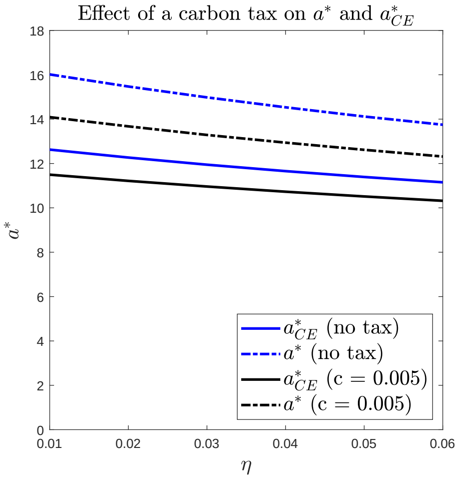
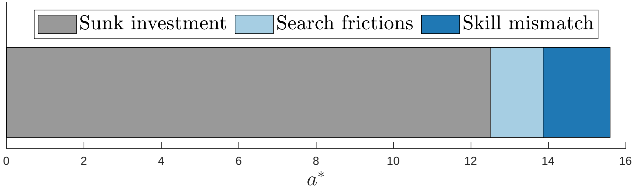


Figure: Effect of a carbon tax on the scrapping age

Optimal Policy

Retraining:

- Equivalent to lowering job specialization
  $\rightarrow$ Lowers labour market transitions, Retraining
  $\rightarrow$ Increases policy acceptability
- In the absence of a carbon tax
  $\rightarrow$ Retraining subsidies for efficient policy
- In the presence of carbon tax
  $\rightarrow$ Retraining subsidies for policy acceptability



Conclusion

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!

Stefanos Tyros - stefanos.tyros@vu.nl

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Model Extensions

- Worker retainment
- Worker retraining
- Aggregate skill shortage
- Skill biased technical change

Return

Worker Retainment

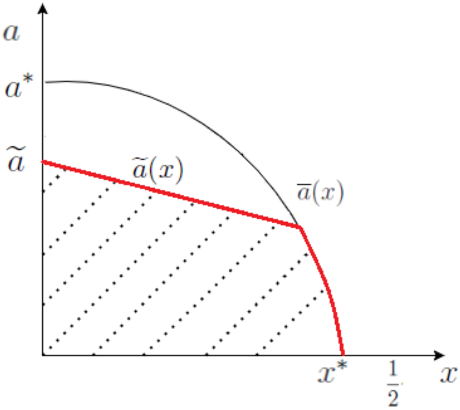
→ Firm scraps old technology, retains worker and realises new x

- Some firms update w/out worker
- Retaining firm value:

$$V^J(\widetilde{a}(x), x) = V_W^F - I > 0$$

- Update inflow-outflow to include retaining firms

⇒ Search effect ↓



Worker Retraining

Retraining all workers: reduce mismatch by a ζ factor:

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

Equivalent to a reduction of specialization, γ, by a ζ factor. Return

Aggregate Skill Shortage

★ $x \sim U[0, 1/2] \quad \longrightarrow \quad x \sim X_\kappa, \quad E[X_\kappa] > 1/4$

$\rightarrow$ Distributions change accordingly.

$\Rightarrow$ Mismatch effect $\uparrow$ (including spatial mismatch)

How to quantify imperfect sorting versus shortage:

- Skill Shortage $= \lim_{\lambda_0 \to \infty} [Y_\kappa - Y_{\kappa \to 0}]$
- Imperfect Skill Sorting $= \lim_{\kappa \to 0} [Y_\gamma - Y_{\gamma \to 0}]$

$\rightarrow$ Can use skills, employment, and vacancy data to estimate κ

$\rightarrow$ Skill biased tech change: $\kappa_t \uparrow$

Green skills

→ Green technologies require other technology-specific skills than predecessors[1]

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

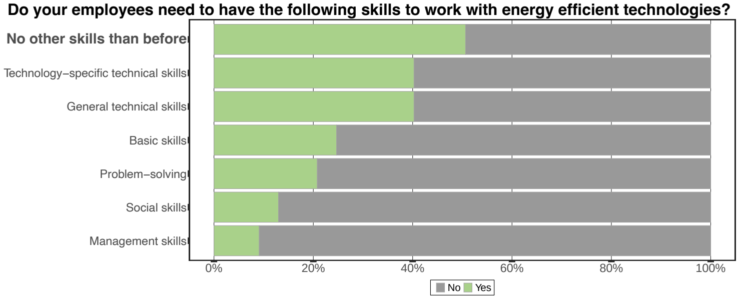
- Skills gap between green and brown jobs is small[2]
- 44.3% of U.S. jobs have similar tasks to green jobs[3]

Skill sorting important, not (only) aggregate skill shortage

Return

[1] Bremer and den Nijs (2023)
[2] Vona et al. (2018)
[3] Bowen et al. (2018)

Green tech requires other skills



Production function of the firm

$$\begin{aligned} y(t,a,x) &= f(x)z(t)k(t,a)^{\omega} \\ &= f(x)z_0 e^{\psi t}\left[k_0 e^{\eta(t-a)} e^{-\delta a}\right]^{\omega} \end{aligned}$$

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.

Return

Energy productivity over time (GDP / energy use)

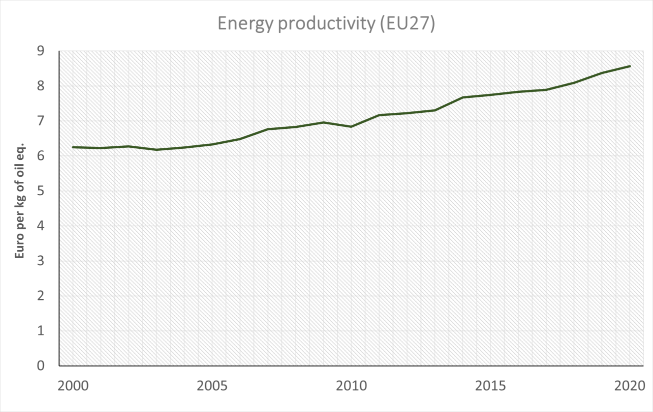


Figure: Energy productivity in the EU, source: Eurostat

Return

Value functions

- Employment & Unemployment:

$$\rho V^E(a,x) = \underbrace{w(a,x)}_{\text{instantaneous gain}} - \sigma \underbrace{\left[V^E(a,x) - V^U\right]}_{\text{job destruction loss}} + \underbrace{V^E_a(a,x)}_{\text{tech ageing}}$$

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

- Matched Job and Vacancy:

$$\rho V^J(a,x) = \underbrace{y(a,x) - w(a,x)}_{\text{instantaneous gain}} - \sigma \underbrace{\left[V^J(a,x) - V^V(a)\right]}_{\text{job destruction loss}} + \underbrace{V^J_a(a,x)}_{\text{tech ageing}}$$

$$\rho V^V(a) = \underbrace{\frac{2\lambda}{v}\int_0^{\overline{x}(a)} \left[V^J(a,y) - V^V(a)\right] dy}_{\text{worker finding gain}} + \underbrace{V^V_a(a)}_{\text{tech ageing}}$$

Return

Distribution of technologies

- $Y(\overline{x}) = e^{-\phi \overline{a}(x)} \left[1 - \frac{1}{2}\gamma x^2\right] = \rho V^U$
- f & g uniform over x Distributions

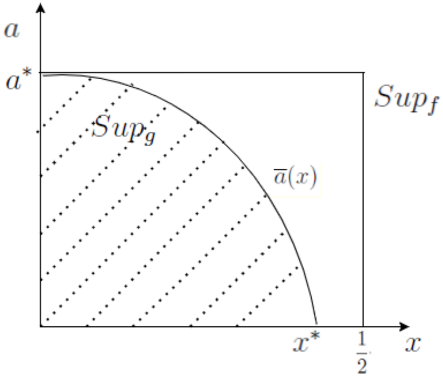


Figure: Supports of distributions f (meetings) and g (matches)

Return

Distributions

Return

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

- $f(a,x)=m(a)\cdot 2 \Rightarrow \widetilde{f}(a)=f(a,x)\cdot\overline{x}(a)$

- $g(a,x)=\widetilde{g}(a)\cdot\frac{1}{\overline{x}(a)}$

Inflow-outflow equations: BGP

- Inflow-ouflow equation of **technologies**:

$$\underbrace{vm(0)}_{\text{entering firms}} = \underbrace{vm(a)}_{\text{ageing vacancies}} + \underbrace{(1-u)\widetilde{g}(a)}_{\text{ageing matches}} \quad 0 < a < a^*$$

- Inflow-outflow equation for **matches**:

$$\underbrace{\lambda \widetilde{F}(a)}_{\text{new matches}} = (1-u)\Big[\underbrace{\sigma \widetilde{G}(a)}_{\text{exogenous destruction}} + \underbrace{\widetilde{g}(a)}_{\text{ageing matches}} + \underbrace{E(a)}_{\text{endogenous destruction}} \Big] \quad 0 < a \leq a^*$$

E(a): endogenous match destruction, $e(a) = -\frac{\widetilde{g}(a)}{\overline{x}(a)} \frac{d\overline{x}(a)}{da}$.

Balanced Growth Path

Return

- Reservation match:

$$V^U = V^E(a, \overline{x}(a)) \quad \Leftrightarrow \quad V^J(\overline{a}(x), x) = 0$$

$$\Rightarrow \rho V^U = e^{-\phi \overline{a}(x)} \left[1 - \tfrac{1}{2}\gamma x^2\right], \quad a^* = \overline{a}(0)$$

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

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

$\longrightarrow$ BGP: $\{u, v, a^*\}$, given V^U and $\widetilde{g}(a)$.

Solving for the Distributions & Surplus

- Simplyfing the inflow-outflow equations:

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

$\rightarrow \widetilde{g}(a)$ as a function of $\overline{x}(a)$ Solving for $\widetilde{g}$

- 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:

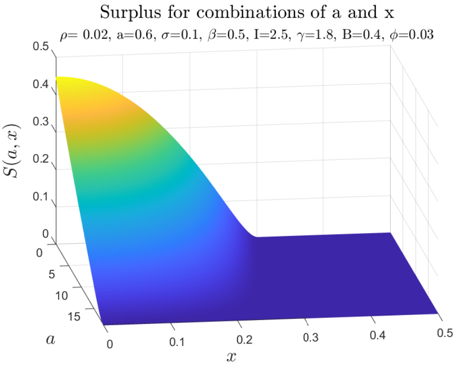
$$\frac{d\tilde{g}(a)}{da} = -\left[\frac{2\lambda\overline{x}(a)}{v} + \sigma - \frac{1}{\overline{x}(a)}\frac{d\overline{x}(a)}{da}\right]\tilde{g}(a) + \frac{2\lambda\overline{x}(a)}{1-u}m(0)$$

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

Return

Numerical solution

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



- Use and iterate until BGT is found Iteration

Iteration

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

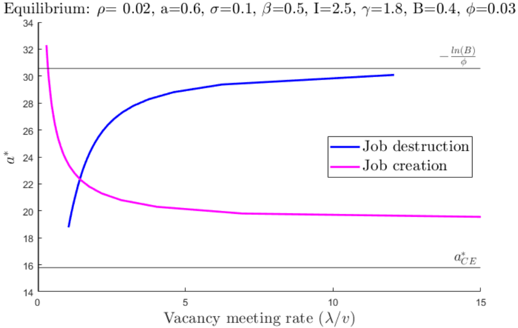


Figure: Job destruction and job creation curve

Return

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

Return Extensions

Calibration

Table: Exogenous chosen & calibrated parameters

Parameter	Description	Value
γ	Specialization	1.8
ρ	Discounting	0.02
η	Capital-embodied energy efficiency	0.013-0.04[4]
ω	Capital share in production	0.3
a	Cobb Douglas parameter matching function	0.5
λ_0	Matching efficiency	6
δ	Depreciation rate	0.13
β	Wage share	0.7
σ	Exogenous separation rate	0.05
I	Investment costs	2.2
B	Unemployment benefits	0.1

▷ $\phi = \omega(\eta + \delta)$

Return | Numerical Solution | Targets | Balanced Growth Path

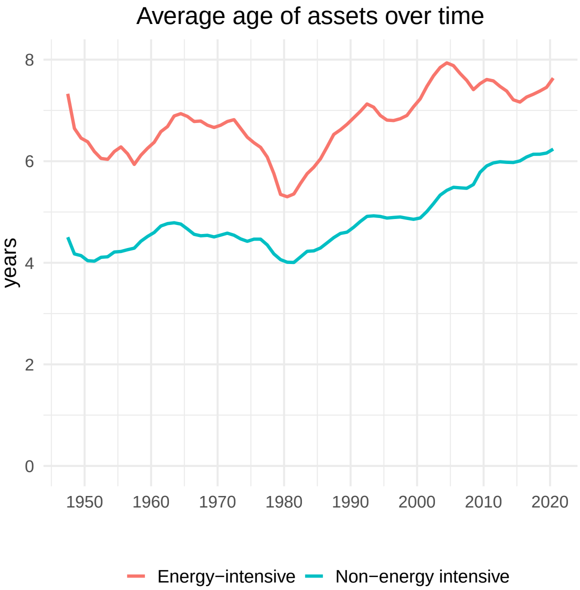
[4] IEA (2021)

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%

Return


Average age of assets over time
years
8
6
4
2
0
1950
1960
1970
1980
1990
2000
2010
2020
Energy−intensive
Non−energy intensive

Return

The calibrated BGP

Table: Resulting BGP from calibration

u	v	$\frac{\lambda}{v}$	a^*	a^*_{CE}
0.05	0.02	11	15.3	7.6

Return