Labor Reallocation, Green Subsidies, and Unemployment

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Green subsidies are prevalent

- All major economies provide **green subsidies** for decarbonization. For example:
  - U.S.: The **Inflation Reduction Act** contains hundreds of billions of dollars in tax credits to green industries and technologies
  - EU: $>$€800 billion in **renewable electricity subsidies** since 2008 (European Commission, 2022) and **Green Deal Industrial Plan**
  - China: $>$\$100 billion in **renewable electricity subsidies** since 2020 (IEA, 2024)

Green subsidies, the labor market, and welfare

- The prevalence of green subsidies raises several questions

1. How do the subsidies impact the **labor market**?

   → Important to know in order to manage the transition of workers out of polluting industries

   → Few studies address this question in general equilibrium

   → No study uses a microfounded model with **search frictions**

2. How do the subsidies **compare to carbon prices** in terms of labor market outcomes and welfare?

   → Relevant to know when carbon pricing is unavailable due to, for instance, low public support (Dechezleprêtre et al., 2022; Douenne and Fabre, 2022)

3. How do the subsidies interact with the **tax system**?

   → No study examines this issue in a general equilibrium setting with involuntary unemployment

This paper: Labor market and welfare impacts of green subsidies

- Main research question: How do green (output-based) subsidies affect:
  - **Labor market** outcomes across **green, fossil, and remaining "neutral"** jobs
  - **Welfare**
- Use U.S. microdata to provide new **empirical evidence** on:
  - The **distribution** of green, fossil, and neutral jobs
  - Job-to-job **transitions**
- Develop an **empirically founded search model**
  - Compare green subsidies to carbon prices for various **financing mechanisms** and **tax systems**

Summary of findings

- Fossil workers **rarely move to green jobs** in the U.S.
  - They are more likely to start **neutral** jobs
- A green subsidy financed in a **non-distortionary** manner generates an **employment dividend** in the form of lower unemployment
  - The employment dividend makes the subsidy generate **higher welfare** relative to a carbon price for **low abatement levels**
- The **employment dividend disappears** if a green subsidy is **financed by labor taxes**
  - A subsidy then **reduces employment and welfare** relative to a carbon price

Literature (1)

1. Empirical measurements of green employment
   - **No standard definition** of a green job
   - One approach: Jobs associated with **green products** are green
     (Colmer, Lyubich and Voorheis, 2023; Curtis and Marinescu, 2023; Curtis, O'Kane and Park, 2024)
   - Alternatively: Jobs involving many **green tasks** are green
     (Vona et al., 2018; Vona, Marin and Consoli, 2019; Chen et al., 2020; Popp et al., 2021)
     - Captures jobs benefiting from the green transition, even if the product is non-green
     - For example: Engineers working on energy efficiency projects or environmental scientists conducting climate-related research

This paper: **Task-based approach** to measure the number of green jobs in the U.S.

Literature (2)

2. Employment impact of environmental regulation

   - Econometric methods (e.g., Walker, 2013; Yip, 2018; Chen et al., 2020; Popp et al., 2021)
     - But: Endogenous employment in counterfactual (unregulated) sectors due to labor reallocation (Hafstead and Williams, 2018)
   - GE analyses
     - Carbon taxes (Hafstead and Williams, 2018; Aubert and Chiroleu-Assouline, 2019; Carbone et al., 2020; Fernández Intriago, 2021; Heutel and Zhang, 2021; Hafstead, Williams and Chen, 2022; Finkelstein Shapiro and Metcalf, 2023; Castellanos and Heutel, 2024)
     - Green subsidies (Shimer, 2013; Bistline, Mehrotra and Wolfram, 2023)

This paper: **GE analysis of green subsidies** in a microfounded model with **search frictions**

Literature (3)

3. Interaction of environmental regulation and the tax system
   - Full employment (Bovenberg and de Mooij, 1994; Bovenberg and van der Ploeg, 1994; Goulder, 1995; Parry, 1995; Bovenberg and Goulder, 1996; Fullerton, 1997; Parry, 1998; Fullerton and Metcalf, 2001; Bento and Jacobsen, 2007; Carbone and Smith, 2008; Kaplow, 2012; Goulder, Hafstead and Williams, 2016; Barrage, 2019)
   - With unemployment (Carraro, Galeotti and Gallo, 1996; Bovenberg, 1997; Bovenberg and van der Ploeg, 1998a,b; Koskela and Schöb, 1999; Wagner, 2005; Hafstead and Williams, 2018)
     - But: Focus on carbon taxes

This paper: Employment impact of green subsidies with **involuntary unemployment** and **preexisting distortions**

Literature (4)

4. Search literature

   - Search models and climate policy (Hafstead and Williams, 2018; Aubert and Chiroleu-Assouline, 2019; Fernández Intriago, 2021; Hafstead, Williams and Chen, 2022; Finkelstein Shapiro and Metcalf, 2023)
   - Matching function $\rightarrow$ Determines the number of hires
     - Most studies use a matching function with one job type
     - Hafstead and Williams (2018) develop a matching function characterized by matching within and across job types
     - Key parameter: ξ $\rightarrow$ Controls the degree of friction associated with matching between firms and workers of different types

This paper: **Estimate** ξ using the search model and account for an empirically relevant **neutral job type**

Outline

1. Empirical analysis
2. Model
3. Calibration
4. Employment and welfare impacts
5. Conclusion

Occupation data

- **Panel data on occupations** from the Survey of Income and Program Participation (SIPP)
  - SIPP: Representative survey of the U.S. population by the U.S. Census Bureau
  - Survey participants are asked each year about their monthly occupation
  - Two panels: 2013-2016 and 2017-2020 (8 years in total)
    - 42,323 and 30,441 people in the respective panels

Harmonizing the occupation codes

- Next step: **Classify** the occupations as “green”, “fossil”, or “neutral”

Classifying "green" jobs

- Define green jobs using a **task-based approach** (Vona et al., 2018)
  - Rooted in the labor economics literature (Autor, Levy and Murnane, 2003; Acemoglu and Autor, 2011; Autor, 2013)
  - Conceptualizes a job as a **collection of tasks**
  - Green job = Job involving many green tasks
  - Intuition: Jobs in which workers devote a lot of time to environmental activities are green
- Advantage: Captures jobs benefiting from the green transition, irrespective of the product
- **Green job := Job with $\geq$ 50% of green tasks**, weighted by task importance

⏩ Sensitivity: Green task share

Task data

- Occupation-level task data from the U.S. Occupational Information Network (O*NET)
  - Main source of occupational information in the U.S.
  - Funded by the U.S. Department of Labor
- For 974 occupations (8-digit O*NET-SOC level):
  - **Task descriptions** (based on employee surveys, occupational experts, desk research)
  - **Task importance scores** (based on employee surveys and occupational experts)
  - **Task classification as green or non-green**

Green task classification of O*NET

- By reviewing the literature, O*NET identifies occupations expected to either experience task changes or be created from green economy activities and technologies
- For each of these occupations, O*NET conducts desk research to identify all **tasks created from green economy** activities and technologies

  $\rightarrow$ **Green tasks**

⏩ Green economy definition ⏩ Green job list ⏩ Task aggregation procedure

Examples of O*NET jobs with a weighted green task share $\geq$ 50%

O*NET code	Title	Total tasks	Green tasks	Weighted green task share (%)
17-2081.00	Environmental Engineers	28	28	100
19-2041.01	Climate Change Analysts	14	14	100
19-2041.02	Environmental Restoration Planners	22	22	100
19-2041.03	Industrial Ecologists	38	38	100
47-2231.00	Solar Photovoltaic Installers	26	26	100
47-4099.02	Solar Thermal Installers and Technicians	21	21	100
49-9081.00	Wind Turbine Service Technicians	13	13	100
49-9099.01	Geothermal Technicians	24	24	100

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Green task examples of “47-2231.00 - Solar Photovoltaic Installers"

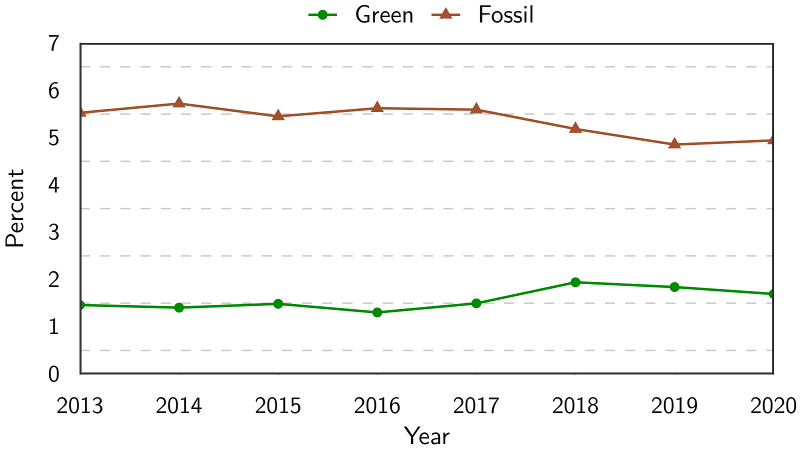
- “**Install photovoltaic (PV) systems** in accordance with codes and standards, using drawings, schematics, and instructions."
- ‘Perform routine photovoltaic (PV) **system maintenance** on modules, arrays, batteries, power conditioning equipment, safety systems, structural systems, weather sealing, or balance of systems equipment."
- “Visually **inspect and test** photovoltaic (PV) modules or systems."

Classifying "fossil" jobs

- No fossil task data - define fossil jobs as jobs disproportionately found in dirty industries
- Procedure:
  1. Identify the 5% most **emissions-intensive industries** in SIPP
     - Emissions data: EPA
     - Industry-level employment data: BLS
  2. **Fossil job** $:=$ Job ≥ 8 times more likely to be found in one of these dirty industries
- Fossil workers $\rightarrow$ Workers at risk of being harmed by environmental regulation because of their industry

Fossil jobs · Overlapping jobs · Dirty industries · Crosswalking industries · Sensitivity

Green jobs have increased slightly, but most jobs are neutral

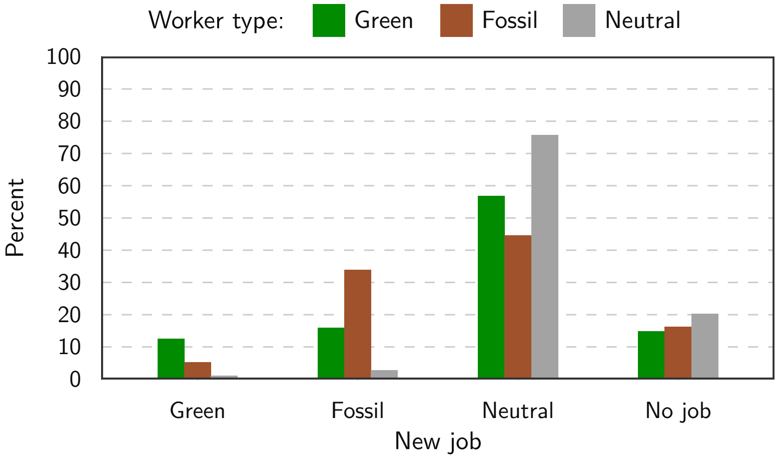


⏩ Only core tasks ⏩ No green jobs in dirty industries ⏩ Only fossil jobs in dirty industries

⏩ Fossil job ≥10 times more likely in dirty industry ⏩ Neutral jobs in dirty industries are fossil

⏩ Fossil job ≥6 times more likely in dirty industry ⏩ Overlapping jobs are fossil ⏩ Dirty industry := Top 1% of emissions-intensity

Fossil workers are more likely to start a neutral job than a green job



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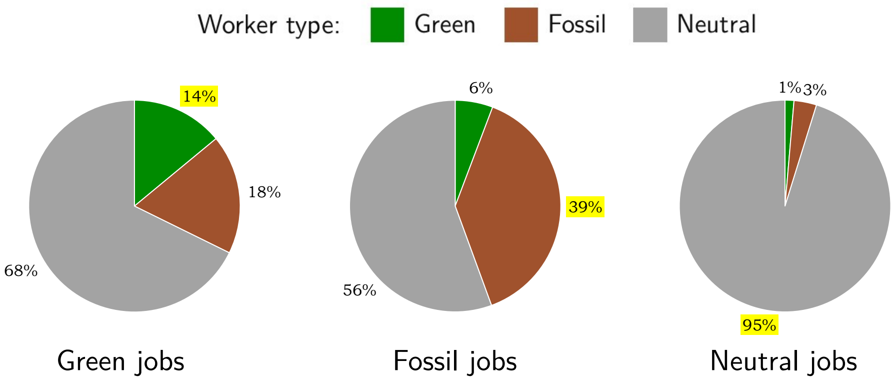
Distribution of workers starting each job



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Model overview

- Search model that builds on Shimer (2010) and Hafstead and Williams (2018)
- Month $t \in \{0, 1, 2, ...\}$ (suppressed henceforth for legibility)
- Firm $j \in \{\mathtt{g}, \mathtt{f}, \mathtt{z}\}$, where $\mathtt{g}$ = green, $\mathtt{f}$ = fossil, $\mathtt{z}$ = neutral
- Worker $i \in \{\mathtt{g}, \mathtt{f}, \mathtt{z}\}$ (a worker is defined by their most recent workplace)
- There are n_i **employed workers** and u_i **unemployed workers** of type i

Firms: Recruitment & production

- Firm j hires n_j workers and assigns v_j to **recruitment** and $n_j - v_j = l_j$ to **production**
  - **Recruitment** allows the firm to hire more workers. Costly because of:
    1. Search frictions
    2. Preexisting payroll taxes
  - **Production** generates **output**
    $$y_j = \zeta l_j h_j,$$
    where ζ is labor productivity and h_j is hours worked
- **Fossil firms generate ϵ emissions** per unit of output. Total emissions are
$$e = \epsilon y_{\mathtt{f}}$$

Prices and climate policy

- Firms sell their goods at price p_j to consumers
- They receive net price p_j^y:

$$p_j^y = \begin{cases} p_j - \tau^E \epsilon & \text{for } j = \texttt{f}, \\ p_j + s & \text{for } j = \texttt{g}, \\ p_j & \text{for } j = \texttt{z}, \end{cases}$$

where s is a subsidy and τ^E is an emissions price

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Firm's problem

- Let $\overline{v}_j$ be the **recruiter ratio** (Shimer, 2010; Hafstead and Williams, 2018):

$$\overline{v}_j = \frac{v_j}{n_j}$$

- Firm's problem: Choose the $\overline{v}_j$, conditional on the stock of employed workers n_j, that maximizes the firm's value over time

- The Bellman equation is

$$J(n_j) = \max_{\overline{v}_j} \left[p_j^y \zeta h_j n_j (1 - \overline{v}_j) - (1 + \tau^P) n_j h_j w_j + \mathbb{E}\left[p^a J(n_j') \right] \right],$$

where J is a value function, τ^P is a payroll tax, w_j is the wage, p^a is the price of an Arrow security, and n_j' is employment in the next period that is defined by a standard law of motion

Law of motion

Firm value maximization and envelope condition

- Firm value maximization requires the marginal value of a production worker to equal the marginal value of a recruiter ⏩ Algebra

- Differentiating the Bellman equation with respect to the number of workers n_j gives the envelope condition

$$J_{n_j} = p_j^y \zeta h_j - (1+\tau^P) h_j w_j + (1-\pi)\mathbb{E}\Big[p^a J'_{n_j}\Big],$$

where J_{n_j} is the value today of hiring a worker, π is the quit rate, and

$$p_j^y = \begin{cases} p_j - \tau^E \epsilon & \text{for } j = f, \\ p_j + s & \text{for } j = g, \\ p_j & \text{for } j = z \end{cases}$$

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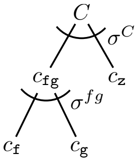
Workers

- Nested consumption to reflect different substitution possibilities across goods:



- Workers get utility from consumption C and disutility from work:

$$U(C, h_i) = \log\left(C\right) - \psi \frac{\chi}{1+\chi} h_i^{\frac{1+\chi}{\chi}},$$

  where ψ represents disutility of work and χ is the Frisch elasticity of labor supply

- Standard assumption: A **representative household** provides workers with full insurance (Merz, 1995)
  - Simplifies the household's problem
  - Captures the aggregate welfare impact, but not the incidence across workers

Household's problem

- Household's problem: Choose the **consumption** and **next period's assets** a' that maximize lifetime utility s.t. a budget constraint and standard laws of motion for employed and unemployed workers

- The Bellman equation is

$$V\left(a, n_{\mathcal{J}}, u_{\mathcal{J}}\right) = \max_{C,a'} \left[\sum_{j \in \mathcal{J}} n_j U\left(C, h_j\right) + \sum_{i \in \mathcal{J}} u_i U\left(C, 0\right) + \beta \mathbb{E}\left[V\left(a', n'_{\mathcal{J}}, u'_{\mathcal{J}}\right)\right] \right]$$

BC and laws of motion

Utility maximization, envelope conditions, and Euler equation

- Utility maximization requires:

$$\text{MB of consumption} = \text{MC of consumption},$$
$$\text{PV of one future asset unit} = \text{Cost of this unit}$$

- Differentiating the Bellman equation w.r.t. the control variables $\rightarrow$ Envelope conditions

- Combining the equilibrium condition for consumption with the envelope condition for next period's assets $\rightarrow$ Euler equation

Algebra

Government and market clearing

- The government collects revenue from a labor income tax τ^L, payroll tax τ^P and emissions price, and returns it as transfers T, unemployment benefits, and subsidy payments:

$$\left(\tau^L + \tau^P\right) \sum_j n_j w_j h_j + \tau^E e = T + \sum_i u_i p^C b_i + s y_{\mathrm{g}},$$

  where b_i is unemployment benefits per worker, valued at p^C

- The market clearing conditions are complementary to prices p_j:

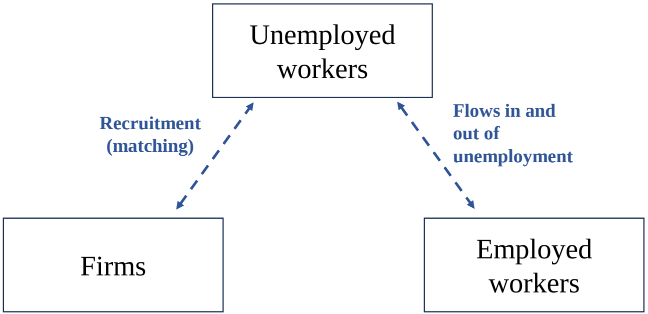
$$y_j \geq c_j \quad \perp \quad p_j \quad \forall j$$

Labor market overview

- Unemployed workers and firms interact through an **endogenous matching process**, whereby firms recruit workers
- **Search frictions** (Mortensen and Pissarides, 1994) prevent them from matching at zero cost
- Nash bargaining upon matching

⏩ Nash bargaining ⏩ Labor market tightnesss

Labor market



Matching

$$m_{ij} = \mu_j \upsilon_j h_j u_i \left[\xi_j \underbrace{\left(\sum_k \upsilon_k h_k \right)}_{\substack{\text{Total}\\ \text{recruitment}\\ \text{effort}}}^{-\gamma} \underbrace{\overline{u}}_{\substack{\text{Total}\\ \text{unem.}}}^{\gamma-1} + (1-\xi_j) \underbrace{(\upsilon_j h_j)}_{\substack{\text{Firm } j\text{'s}\\ \text{recruitment}\\ \text{effort}}}^{-\gamma} \underbrace{u_i}_{\substack{\text{Unem.}\\ \text{of } i}}^{\gamma-1} \delta_{ij} \right]$$

m_{ij} = Number of **matches** between firm j and workers of type i

μ_j = Matching efficiency

υ_j = Number of recruiters

h_j = Hours

γ = Elasticity of matching wrt. unemployment

δ_{ij} = Kronecker delta equal to 1 if $i = j$ and 0 otherwise

k = Alias for j

$\xi_j \in [0,1]$ = **Friction associated with cross-type matching**

Cross-type matching

$$m_{ij} = \mu_j \upsilon_j h_j u_i \left[\xi_j \left(\sum_k \upsilon_k h_k \right)^{-\gamma} \overline{u}^{\gamma-1} + (1-\xi_j) (\upsilon_j h_j)^{-\gamma} u_i^{\gamma-1} \delta_{ij} \right]$$

- $\xi_j = 0 \rightarrow$ Firm j can only recruit workers of type j (no cross-type matching)

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- $\xi_j = 0 \rightarrow$ Firm j can only recruit workers of type j (no cross-type matching)

- $\xi_j = 1 \rightarrow$ Workers i and $j \neq i$ are equally likely to match with firm j (matching does not depend on a worker's type)

Cross-type matching

$$m_{ij} = \mu_j \upsilon_j h_j u_i \left[\xi_j \left(\sum_k \upsilon_k h_k \right)^{-\gamma} \quad \overline{u} \quad ^{\gamma-1} + (1-\xi_j) \ (\upsilon_j h_j) \ ^{-\gamma} \quad u_i \quad ^{\gamma-1} \delta_{ij} \right]$$

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- $\xi_j = 1 \rightarrow$ Workers i and $j \neq i$ are equally likely to match with firm j (matching does not depend on a worker's type)
- $\xi_j \in (0,1) \rightarrow$ The share of cross-type matches for firm j is, all else constant, proportional to ξ_j

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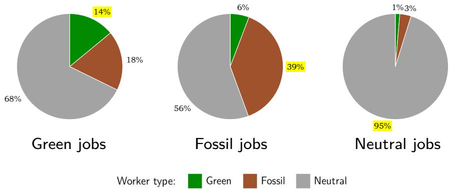
Solving for ξ_j

- Let ω_j be the **share of matches for firm j with workers of type j**
- From the empirical analysis,

$$\omega_j = \begin{cases} 0.14 & \text{for } j = \texttt{g}, \\ 0.39 & \text{for } j = \texttt{f}, \\ 0.95 & \text{for } j = \texttt{z} \end{cases}$$



- Solving for ξ_j to match moments in the initial equilibrium gives

$$\xi_j = \begin{cases} 0.87 & \text{for } j = \texttt{g}, \\ 0.58 & \text{for } j = \texttt{f}, \\ 1^* & \text{for } j = \texttt{z} \end{cases}$$

Algebra

*Capped at 1

Remaining calibration

(a) Direct calibration

Parameter description	Symbol	Value	Source
Quit rate	π	0.037	BLS data
Bargaining power of employer	η	0.5	Literature
Matching elasticity	γ	0.5	Literature
Discount factor	β	0.997	World Bank data
Frisch elasticity of labor supply	χ	1	Literature
Elasticity in top consumption nest	σ^C	0.5	Literature
Elasticity in bottom consumption nest	σ^{fg}	0.75	Set relative to σ^C
Labor income tax	τ^L	0.29	OECD data
Payroll tax	τ^P	0.15	OECD data

(b) Calibration using the benchmark

Parameter description	Symbol	Value
Cross-type matching friction for firm $j \in \{\texttt{f},\texttt{g},\texttt{z}\}$	ξ_j	0.58, 0.87, 1
Matching efficiency for firm $j \in \{\texttt{f},\texttt{g},\texttt{z}\}$	μ_j	4.19, 3.87, 3.84
Labor productivity	ζ	3.20
Disutility of work	ψ	5.93
CES share of good $r \in \{\texttt{f},\texttt{g},\texttt{z},\texttt{fg}\}$	ϱ_r	0.73, 0.27, 0.93, 0.07
Unemployment benefits for worker $i \in \{\texttt{f},\texttt{g},\texttt{z}\}$	b_i	0.25, 0.27, 0.28
Emissions factor	ϵ	0.00741

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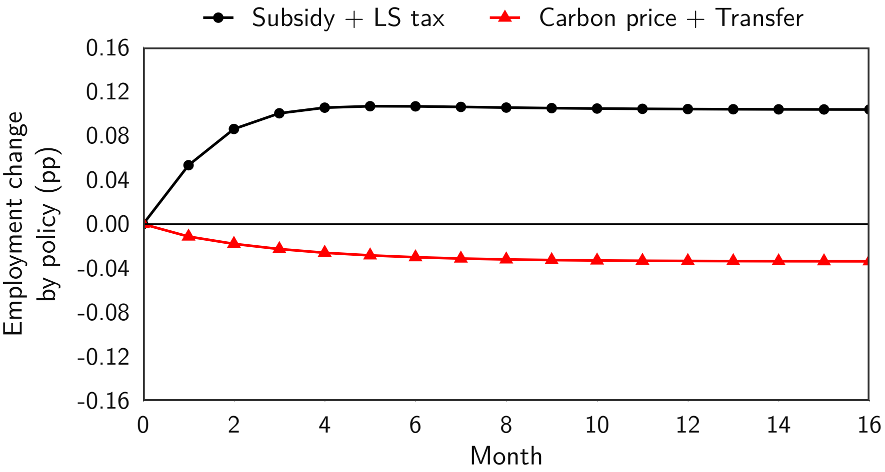
Policies

1. A subsidy on green firms' output
   - Subsidy expenditure = \$781 billion over 10 years (estimated IRA tax credits in the main scenario of Bistline, Mehrotra and Wolfram, 2023)
2. A price on fossil firms' emissions
   - Same abatement level as the subsidy

- Compare outcomes to a business as usual benchmark

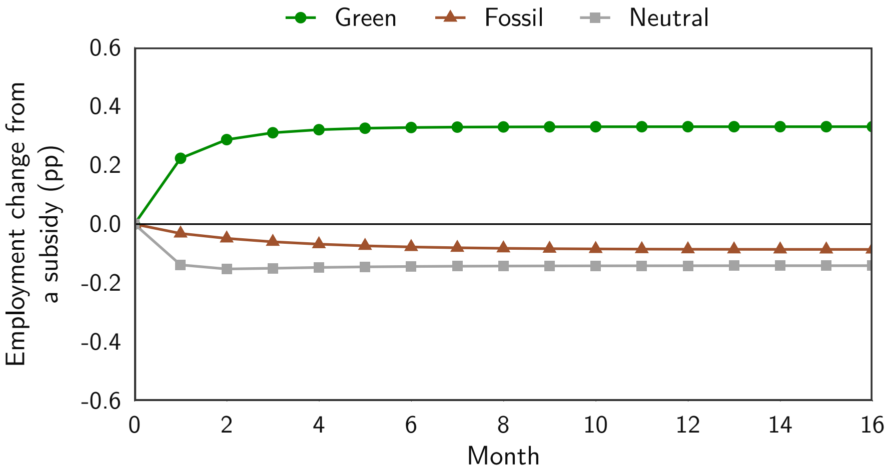
Non-Distortionary Financing & Recycling Mechanisms

A green subsidy increases employment relative to a carbon price...



▸▸ Sensitivity ▸▸ Subsidy rate

... because the subsidy generates large green job gains



Sensitivity

The subsidy has three effects

1. **Substitution effect**: A subsidy shifts demand to green goods by making them relatively cheaper

Table 1. Changes in % wrt. benchmark

	Price	Output	Recruitment	Match value in $t = 0$
Green	0	19.8	19.5	97.1
Fossil	30.1	-1.7	-1.9	8.6
Neutral	30.1	0.0	-0.2	17.0

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The subsidy has three effects

1. **Substitution effect**: A subsidy shifts demand to green goods by making them relatively cheaper

2. **Match value effect**: A subsidy **increases the value of a match** for green firms
   $\rightarrow$ A green worker generates $p_g + s > p_g$ per unit of output

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Green	0	19.8	19.5	97.1
Fossil	30.1	-1.7	-1.9	8.6
Neutral	30.1	0.0	-0.2	17.0

The subsidy has three effects

1. **Substitution effect**: A subsidy shifts demand to green goods by making them relatively cheaper

2. **Match value effect**: A subsidy **increases the value of a match** for green firms
   $\rightarrow$ A green worker generates $p_{\mathrm{g}} + s > p_{\mathrm{g}}$ per unit of output

3. **Income effect**: Lump sum taxes reduce household income
   $\rightarrow$ BUT: **Recruitment is not distorted**

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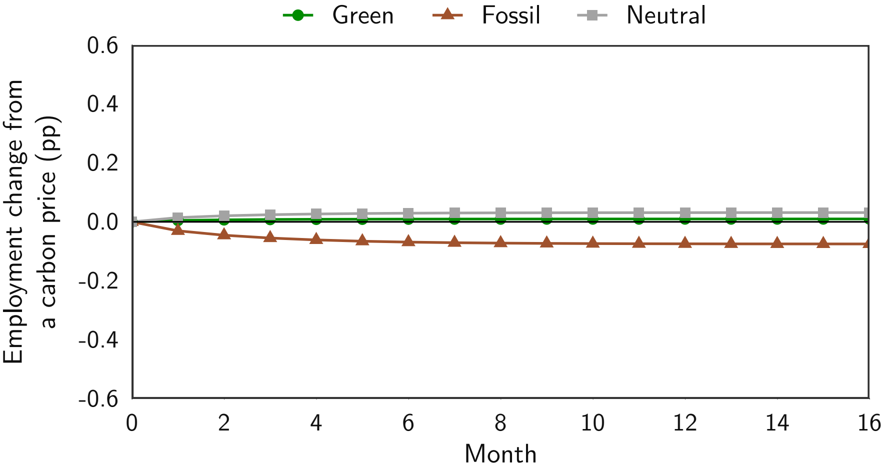
   $\rightarrow$ BUT: **Recruitment is not distorted**

$\Longrightarrow$ Effects 2 and 3 counteract search frictions and preexisting taxes for green firms without adding distortions

$\Longrightarrow$ Net result: Large green job gains and higher overall employment

Numbers

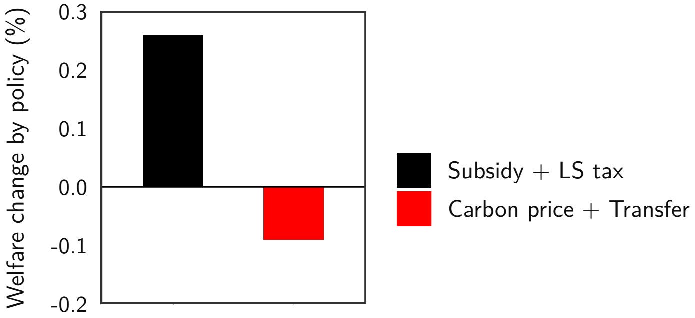
A carbon price generates small green employment gains



Match value

Welfare

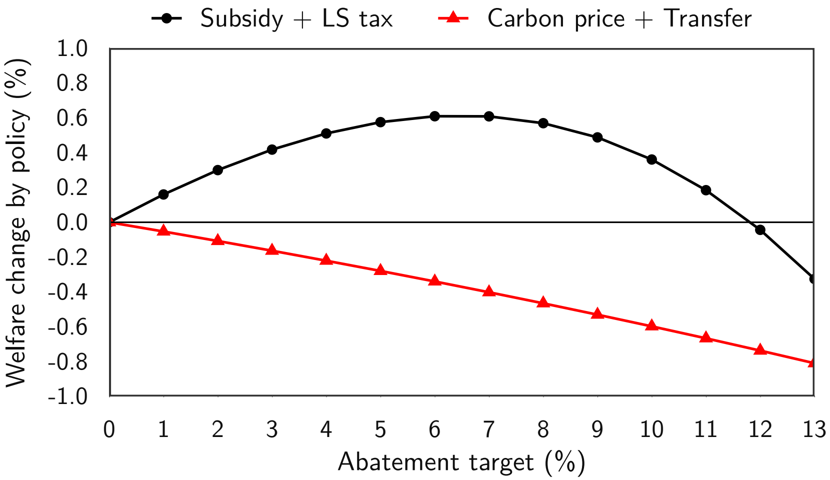
- The employment gains from a subsidy translate into higher welfare (measured by the equivalent variation) relative to a carbon price



Welfare calculations

Sensitivity

The welfare gains disappear at high abatement levels



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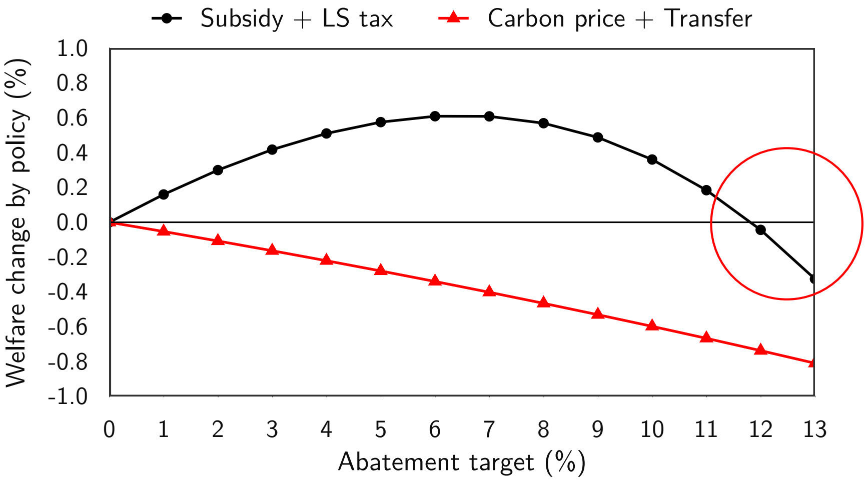
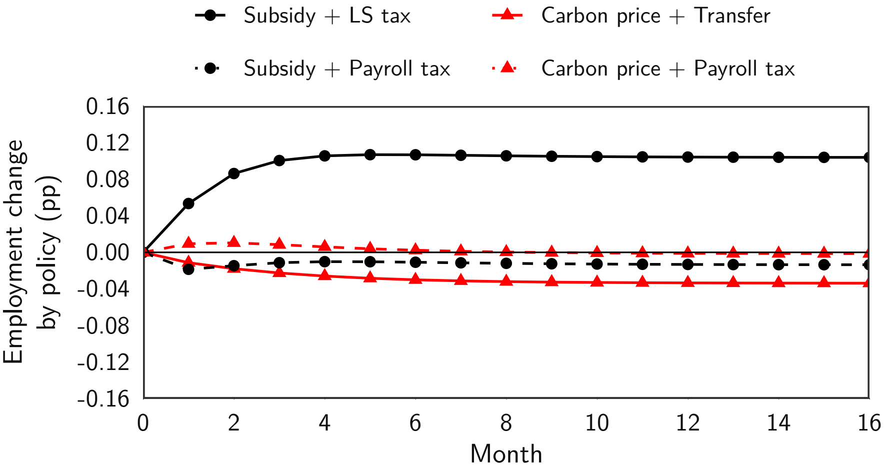
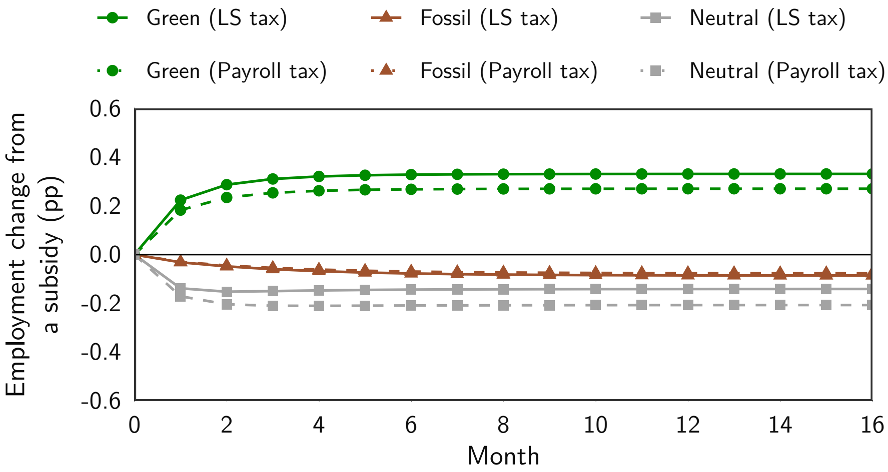


Switching to Distortionary Financing & Recycling Mechanisms

A subsidy no longer generates job gains if financed by distortionary payroll taxes

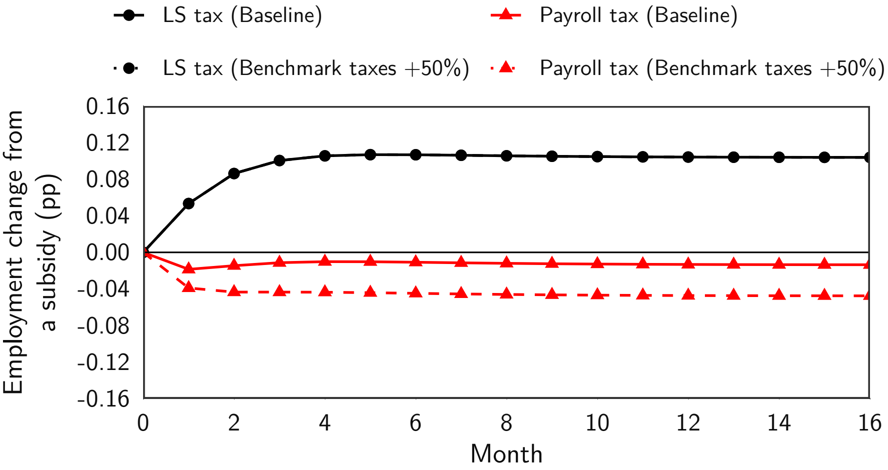


Payroll taxes increase the cost of hiring, reducing green job gains



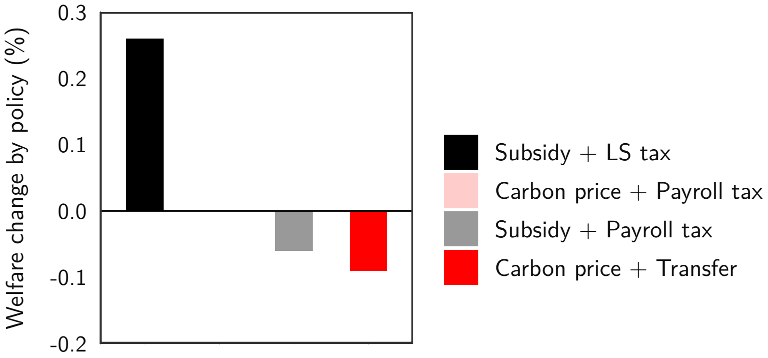
▸▸ Carbon price

Payroll taxes are even costlier when preexisting distortions are high



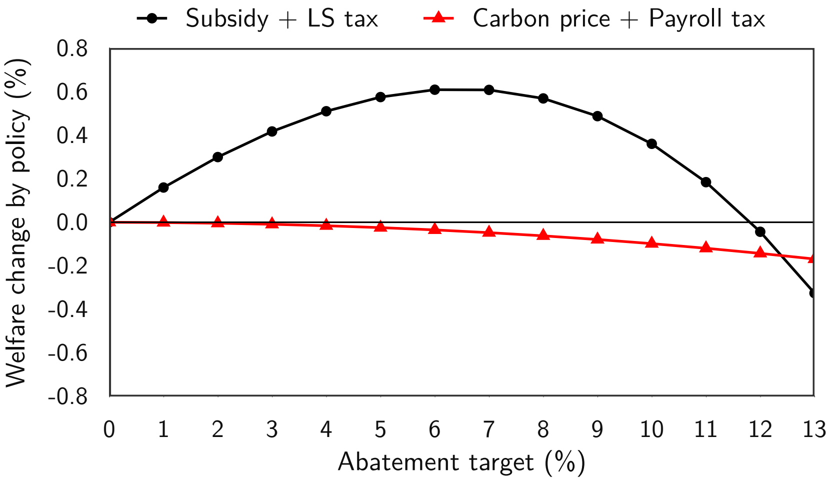
Welfare comparison

- Highest welfare from a green subsidy financed in a non-distortionary manner
- With payroll taxes, the welfare loss is smaller from a carbon price (-0.00%) compared to a green subsidy (-0.06%)

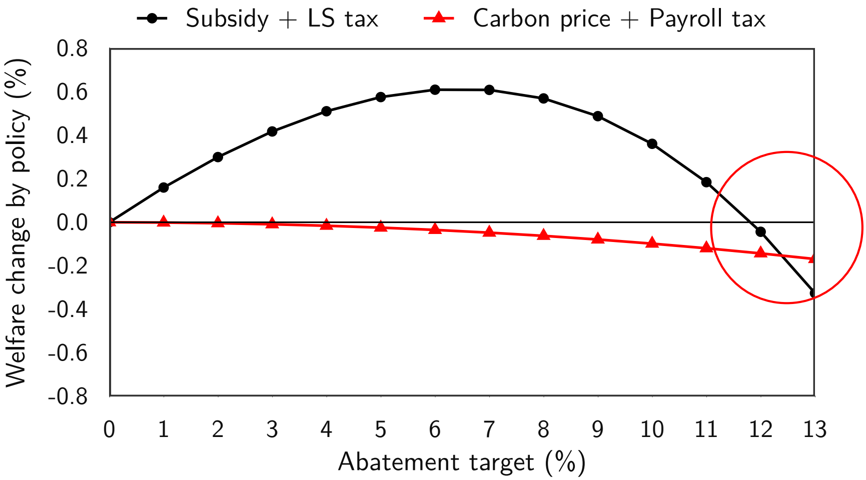


Sensitivity

A green subsidy is less cost-efficient than a carbon price at high abatement levels



A green subsidy is less cost-efficient than a carbon price at high abatement levels



Outline

1. Empirical analysis
2. Model
3. Calibration
4. Employment and welfare impacts
5. Conclusion

Conclusion

- Fossil workers rarely transition to green jobs in the U.S.
  - They are instead more likely to start neutral jobs
- The financing mechanism is an important determinant of a green subsidy's performance
  - Non-distortionary mechanism: A subsidy increases employment and, for low abatement levels, increases welfare vs. a carbon price
  - Distortionary mechanism: A subsidy reduces employment and welfare vs. a carbon price

Thank you!

Crosswalking the Census Occupation codes to SOC

- The 2013-2016 and 2017-2020 SIPP panels use Census Occupation codes (versions 2010 and 2018 respectively)

  $\rightarrow$ Map to the 2010 Standard Occupational Classification (SOC) system using crosswalks from the U.S. Census Bureau

- 42 out of 518 occupations in the 2017-2020 panel have a one-to-many mapping that would give respondents multiple jobs
  - To achieve a one-to-one mapping, I choose the modal SOC code in the 2013-2016 panel

Main text

“Green economy” definition used by O*NET

“The green economy encompasses the economic activity related to reducing the use of fossil fuels, decreasing pollution and greenhouse gas emissions, increasing the efficiency of energy usage, recycling materials, and developing and adopting renewable sources of energy." (Dierdorff et al., 2009, p. 3)

Main text

Green jobs

O*NET code	Title	Total tasks	Green tasks	Weighted green task share
11-1011.03	Chief Sustainability Officers	18	18	1
11-3051.02	Geothermal Production Managers	17	17	1
11-3051.03	Biofuels Production Managers	14	14	1
11-3051.04	Biomass Power Plant Managers	18	18	1
11-3051.06	Hydroelectric Production Managers	19	19	1
11-9041.01	Biofuels/Biodiesel Technology and Product Development Managers	19	19	1
11-9121.02	Water Resource Specialists	21	21	1
11-9199.09	Wind Energy Operations Managers	16	16	1
11-9199.10	Wind Energy Project Managers	15	15	1
11-9199.11	Brownfield Redevelopment Specialists and Site Managers	22	22	1
13-1199.01	Energy Auditors	21	21	1
13-1199.05	Sustainability Specialists	14	14	1
17-2081.00	Environmental Engineers	28	28	1
17-2081.01	Water/Wastewater Engineers	27	27	1
17-2141.01	Fuel Cell Engineers	26	26	1
17-2199.03	Energy Engineers	21	21	1
17-2199.10	Wind Energy Engineers	16	16	1
17-2199.11	Solar Energy Systems Engineers	13	13	1
17-3025.00	Environmental Engineering Technicians	26	26	1
19-1013.00	Soil and Plant Scientists	27	17	0.62
19-1031.01	Soil and Water Conservationists	33	33	1
19-2041.01	Climate Change Analysts	14	14	1
19-2041.02	Environmental Restoration Planners	22	22	1
19-2041.03	Industrial Ecologists	38	38	1

Main text

Green jobs (continued)

O*NET code	Title	Total tasks	Green tasks	Weighted green task share
19-3011.01	Environmental Economists	19	19	1
19-4091.00	Environmental Science and Protection Technicians, Including Health	26	26	1
41-3099.01	Energy Brokers	16	16	1
41-4011.07	Solar Sales Representatives and Assessors	13	13	1
47-1011.03	Solar Energy Installation Managers	15	15	1
47-2231.00	Solar Photovoltaic Installers	26	26	1
47-4041.00	Hazardous Materials Removal Workers	21	21	1
47-4099.02	Solar Thermal Installers and Technicians	21	21	1
47-4099.03	Weatherization Installers and Technicians	18	18	1
49-9081.00	Wind Turbine Service Technicians	13	13	1
49-9099.01	Geothermal Technicians	24	24	1
51-8099.01	Biofuels Processing Technicians	19	19	1
51-8099.03	Biomass Plant Technicians	16	16	1
51-8099.04	Hydroelectric Plant Technicians	21	21	1
51-9199.01	Recycling and Reclamation Workers	18	18	1
53-1021.01	Recycling Coordinators	23	23	1
53-7081.00	Refuse and Recyclable Material Collectors	16	16	1

Main text

Green jobs (SOC)

SOC code	Title	Weighted green task share
17-2081	Environmental Engineers	1
17-2141	Mechanical Engineers	0.53†
19-2040	Environmental Scientists and Geoscientists	0.57
41-3099	Sales Representatives, Services, All Other	1
47-2231	Solar Photovoltaic Installers	1
47-4041	Hazardous Materials Removal Workers	1
47-4090	Miscellaneous Construction and Related Workers	0.67
49-9081	Wind Turbine Service Technicians	1
49-909X	Other installation, maintenance, and repair workers	0.5
51-9199	Production Workers, All Other	1†
53-7081	Refuse and Recyclable Material Collectors	1

Note: † Jobs that were identified as both green and fossil.

Green job description

Fossil job description

Task aggregation procedure

- I aggregate the tasks from an 8-digit to a 6-digit occupational level
- 297 out of 974 occupations in O*NET share a 6-digit parent group
  - To account for potential weight differences across occupations in the same parent group (based on Vona, Marin and Consoli, 2019):
    1. If an occupation corresponding to the parent group (i.e., ending in ".00") has few green tasks, set the parent group's green task share to zero
    2. Otherwise, average the green task shares across the occupations in the parent group

⏩ Main text

Task aggregation examples

O*NET-SOC code	O*NET-SOC title	Total tasks	Green tasks	Method
11-1011.00	Chief Executives	31	0	Zero
11-1011.03	Chief Sustainability Officers	18	18	
11-2011.00	Advertising and Promotions Managers	26	0	Zero
11-2011.01	Green Marketers	16	16	
11-3051.00	Industrial Production Managers	14	0	Zero
11-3051.01	Quality Control Systems Managers	27	0	
11-3051.02	Geothermal Production Managers	17	17	
11-3051.03	Biofuels Production Managers	14	14	
11-3051.04	Biomass Power Plant Managers	18	18	
11-3051.05	Methane/Landfill Gas Collection System Operators	21	21	
11-3051.06	Hydroelectric Production Managers	19	19	
11-3071.01	Transportation Managers	28	6	Mean
11-3071.02	Storage and Distribution Managers	31	7	
11-3071.03	Logistics Managers	30	9	

Main text

Fossil jobs

SOC code	Title
11-3051	Industrial Production Managers
11-9041	Architectural and Engineering Managers
17-2041	Chemical Engineers
17-2110	Industrial Engineers, Including Health and Safety
17-2121	Marine Engineers and Naval Architects
17-2131	Materials Engineers
17-2171	Petroleum Engineers
17-3020	Engineering Technicians, Except Drafters
19-2030	Chemists and Materials Scientists
19-4011	Agricultural and Food Science Technicians
19-4031	Chemical Technicians
43-5061	Production, Planning, and Expediting Clerks
47-5010	Derrick, Rotary Drill, and Service Unit Operators, Oil, Gas, and Mining
47-5021	Earth Drillers, Except Oil and Gas
47-5040	Mining Machine Operators
47-50XX	Other Extraction Workers
49-2091	Avionics Technicians
49-9010	Control and Valve Installers and Repairers
49-9043	Maintenance Workers, Machinery
49-9044	Millwrights
49-904X	Industrial and Refractory Machinery Mechanics
49-9096	Riggers
49-9098	Helpers–Installation, Maintenance, and Repair Workers
51-1011	First-Line Supervisors of Production and Operating Workers
51-2011	Aircraft Structure, Surfaces, Rigging, and Systems Assemblers
51-2031	Engine and Other Machine Assemblers

Main text

Fossil jobs (continued)

SOC code	Title
51-2041	Structural Metal Fabricators and Fitters
51-2090	Miscellaneous Assemblers and Fabricators
51-3020	Butchers and Other Meat, Poultry, and Fish Processing Workers
51-3091	Food and Tobacco Roasting, Baking, and Drying Machine Operators and Tenders
51-3093	Food Cooking Machine Operators and Tenders
51-3099	Food Processing Workers, All Other
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic
51-4022	Forging Machine Setters, Operators, and Tenders, Metal and Plastic
51-4031	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic
51-4033	Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic
51-4050	Metal Furnace Operators, Tenders, Pourers, and Casters
51-4070	Molders and Molding Machine Setters, Operators, and Tenders, Metal and Plastic
51-4111	Tool and Die Makers
51-4199	Metal Workers and Plastic Workers, All Other
51-6063	Textile Knitting and Weaving Machine Setters, Operators, and Tenders
51-6064	Textile Winding, Twisting, and Drawing Out Machine Setters, Operators, and Tenders
51-7041	Sawing Machine Setters, Operators, and Tenders, Wood
51-7042	Woodworking Machine Setters, Operators, and Tenders, Except Sawing
51-8031	Water and Wastewater Treatment Plant and System Operators
51-8090	Miscellaneous Plant and System Operators
51-9010	Chemical Processing Machine Setters, Operators, and Tenders
51-9020	Crushing, Grinding, Polishing, Mixing, and Blending Workers
51-9041	Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders

Main text

Fossil jobs (continued)

SOC code	Title
51-9051	Furnace, Kiln, Oven, Drier, and Kettle Operators and Tenders
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers
51-9111	Packaging and Filling Machine Operators and Tenders
51-9191	Adhesive Bonding Machine Operators and Tenders
51-9195	Molders, Shapers, and Casters, Except Metal and Plastic
51-9196	Paper Goods Machine Setters, Operators, and Tenders
51-9197	Tire Builders
51-9198	Helpers–Production Workers
53-5011	Sailors and Marine Oilers
53-6031	Automotive and Watercraft Service Attendants
53-7021	Crane and Tower Operators
53-7051	Industrial Truck and Tractor Operators
53-7070	Pumping Station Operators
53-7199	Material Moving Workers, All Other

Main text

Dirty industries

Census code	Census title
0370	Oil and gas extraction
0380	Coal mining
0390	Metal ore mining
0470	Nonmetallic mineral mining and quarrying
0480	Not specified type of mining
0490	Support activities for mining
0570	Electric power generation, transmission and distribution
0580	Natural gas distribution
0590	Electric and gas, and other combinations
0670	Water, steam, air-conditioning, and irrigation systems
0680	Sewage treatment facilities
0690	Not specified utilities
1070	Animal food, grain and oilseed milling
1080	Sugar and confectionery products
1090	Fruit and vegetable preserving and specialty food manufacturing
1170	Dairy product manufacturing
1180	Animal slaughtering and processing
1280	Seafood and other miscellaneous foods, n.e.c.
1290	Not specified food industries
1370	Beverage manufacturing
1390	Tobacco manufacturing
1480	Fabric mills, except knitting mills
1490	Textile and fabric finishing and fabric coating mills
1570	Carpet and rug mills
1870	Pulp, paper, and paperboard mills

Main text

Dirty industries (continued)

Census code	Census title
2070	Petroleum refining
2090	Miscellaneous petroleum and coal products
2170	Resin, synthetic rubber, and fibers and filaments manufacturing
2180	Agricultural chemical manufacturing
2190	Pharmaceutical and medicine manufacturing
2270	Paint, coating, and adhesive manufacturing
2280	Soap, cleaning compound, and cosmetics manufacturing
2290	Industrial and miscellaneous chemicals
2380	Tire manufacturing
2390	Rubber products, except tires, manufacturing
2470	Pottery, ceramics, and plumbing fixture manufacturing
2480	Clay building material and refractories manufacturing
2490	Glass and glass product manufacturing
2570	Cement, concrete, lime, and gypsum product manufacturing
2590	Miscellaneous nonmetallic mineral product manufacturing
2670	Iron and steel mills and steel product manufacturing
2680	Aluminum production and processing
2690	Nonferrous metal (except aluminum) production and processing
2770	Foundries
2990	Not specified metal industries
3180	Engine, turbine, and power transmission equipment manufacturing
3390	Electronic component and product manufacturing, n.e.c.
3490	Electric lighting and electrical equipment manufacturing, and other electrical component manufacturing, n.e.c.

Main text

Dirty industries (continued)

Census code	Census title
3570	Motor vehicles and motor vehicle equipment manufacturing
3580	Aircraft and parts manufacturing
3590	Aerospace products and parts manufacturing
3670	Railroad rolling stock manufacturing
3770	Sawmills and wood preservation
3780	Veneer, plywood, and engineered wood products
3990	Not specified manufacturing industries
4490	Petroleum and petroleum products merchant wholesalers
5090	Gasoline stations
5680	Fuel dealers
6270	Pipeline transportation

Main text

Crosswalking from NAICS to the Census Industry system

- Map the dirty industry classification from NAICS to SIPP's Census Industry system using crosswalks from the U.S. Census Bureau
- Two challenges:
  1. Multiple industries sometimes map to the same Census code
     $\rightarrow$ Problematic when only some of the industries are dirty, since the Census code is then only partly dirty
  2. Some dirty industries lack a mapping to a Census code
     $\rightarrow$ They instead indirectly map through parent groups (on a 2-digit or 3-digit level) or subcategories (on a 5-digit or 6-digit level)

Main text

Challenge #1: Multiple industries mapping to the same Census code

NAICS code	NAICS title	Dirty NAICS?	Census code	Census title	Call Census code dirty?
3344	Semiconductor and Other Electronic and Component Manufacturing	Yes	3390	Electronic component and product manufacturing, n.e.c.	Yes
3346	Manufacturing and Reproducing Magnetic and Optical Media	No			
3351	Electric Lighting Equipment Manufacturing	No	3490	Electric lighting and electrical equipment manufacturing, and other electrical component manufacturing, n.e.c.	Yes
3353	Electrical Equipment Manufacturing	No			
3359	Other Electrical Equipment and Component Manufacturing	Yes			
3361	Motor Vehicle Manufacturing	Yes	3570	Motor vehicles and motor vehicle equipment manufacturing	Yes
3362	Motor Vehicle Body and Trailer Manufacturing	No			
3363	Motor Vehicle Parts Manufacturing	No			
5611	Office Administrative Services	No	7780	Other administrative and other support services	No†
5612	Facilities Support Services	Yes			
5619	Other Support Services	No			
6112	Junior Colleges	No	7870	Colleges, universities, and professional schools, including junior colleges	No†
6113	Colleges, Universities, and Professional Schools	Yes			

Note: † I do not call this Census code dirty as it is typically not thought of as an industry most vulnerable to decarbonization.

Main text

Challenge #2a: 2-digit and 3-digit NAICS codes in the crosswalk with some dirty 4-digit industries

NAICS code in crosswalk	Share of 4-digit NAICS codes that are dirty	Census code	Census title	Call Census code dirty?
Part of 311	8/9	1290	Not specified food industries	Yes
Part of 331 and 332	5/14	2990	Not specified metal industries	Yes
Part of 31-33	41/86	3990	Not specified manufacturing industries	Yes
488	1/6	6290	Services incidental to transportation	No†
562	2/3	7790	Waste management and remediation services	No‡

Note: † I do not call this Census code dirty since only one out of six NAICS codes are dirty.
‡ I do not call this Census code dirty as it is typically not thought of as an industry most vulnerable to decarbonization.

Main text

Challenge #2b: Dirty NAICS codes with subcodes mapping to a Census code

Dirty NAICS code	Dirty NAICS title	NAICS code in crosswalk	NAICS title in crosswalk	Census code	Census title	Call Census code dirty?
2213	Water, Sewage and Other Systems	22131 22133 22132	Water Supply and Irrigation Systems Steam and Air-Conditioning Supply Sewage Treatment Facilities	0670 0680	Water, Steam, Air-conditioning, and Irrigation systems Sewage Treatment Facilities	Yes Yes
3132	Fabric Mills	31321 31322 31323	Broadwoven Fabric Mills Narrow Fabric Mills and Schiffli Machine Embroidery Nonwoven Fabric Mills	1480	Fabric mills, except knitting mills	Yes†
3132	Fabric Mills	31324 3151	Knit Fabric Mills Apparel Knitting Mills	1670	Knitting Fabric Mills, and Apparel Knitting Mills	No†
3141	Textile Furnishings Mills	31411	Carpet and Rug Mills	1570	Carpet and Rug Mills	Yes‡
3141	Textile Furnishings Mills	31412 3149	Curtain and Linen Mills Other Textile Product Mills	1590	Textile Product Mills, Except Carpet and Rug	No‡
3241	Petroleum and Coal Products Manufacturing	32411	Petroleum Refineries	2070	Petroleum refining	Yes*
3241	Petroleum and Coal Products Manufacturing	32412 32419	Asphalt Paving, Roofing, and Saturated Materials Manufacturing Miscellaneous petroleum and coal products	2090	Miscellaneous petroleum and coal products	Yes*

Note: † I call Census "1480" dirty as it maps to most subcodes of dirty NAICS "3132". I call Census "1670" non-dirty as NAICS "3151" is not dirty.
‡ NAICS "3149" is not dirty and I thus call Census "1590" non-dirty. NAICS "3141" is dirty. I attribute the dirty part of it to subcode "31411" and thus call Census "1570" dirty.
* The parent 4-digit NAICS is "3241 - Petroleum and Coal Products Manufacturing". I consider this NAICS code as well as its subcodes dirty. I therefore call Census "2070" and "2090" dirty.

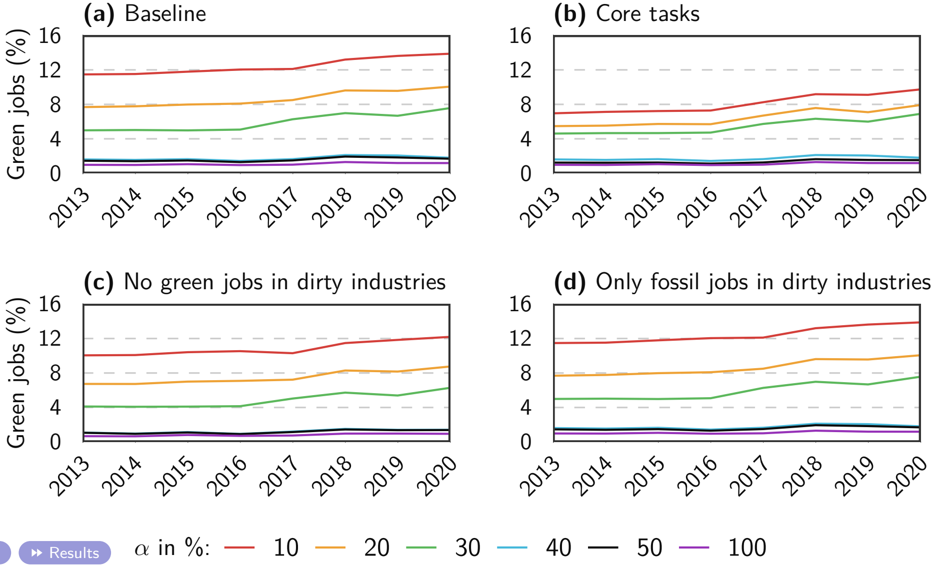
Main text

Challenge #2b: Dirty NAICS codes with subcodes mapping to a Census code (continued)

Dirty NAICS code	Dirty NAICS title	NAICS code in crosswalk	NAICS title in crosswalk	Census code	Census title	Call Census code dirty?
3262	Rubber Product Manufacturing	32621	Tire Manufacturing	2380	Tire Manufacturing	Yes
		32622	Rubber and Plastics Hoses and Belting Manufacturing	2390	Rubber Products, Except Tires, Manufacturing	Yes
		32629	Other Rubber Product Manufacturing			
3271	Clay Product and Refractory Manufacturing	32711	Pottery, Ceramics, and Plumbing Fixture Manufacturing	2470	Pottery, Ceramics, and Plumbing Fixture Manufacturing	Yes
		327120	Clay Building Material and Refractories Manufacturing	2480	Clay Building Material and Refractories Manufacturing	Yes
3364	Aerospace Product and Parts Manufacturing	336411	Aircraft Manufacturing	3580	Aircraft and parts manufacturing	Yes
		336412	Aircraft Engine and Engine Parts Manufacturing			
		336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing			
		336414	Guided Missile and Space Vehicle Manufacturing	3590	Aerospace products and parts manufacturing	Yes
		336415	Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing			
		336419	Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing			

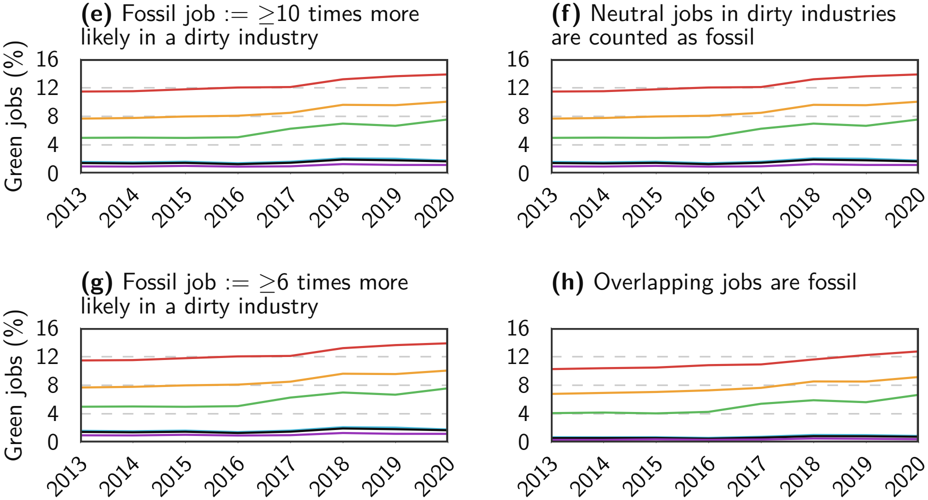
⏩ Main text

Green job share by sensitivity test (panels) and α (lines)



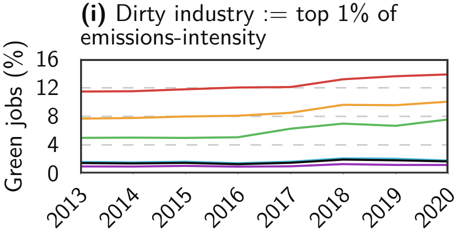
Data Results

Green job share by sensitivity test (panels) and α (lines)



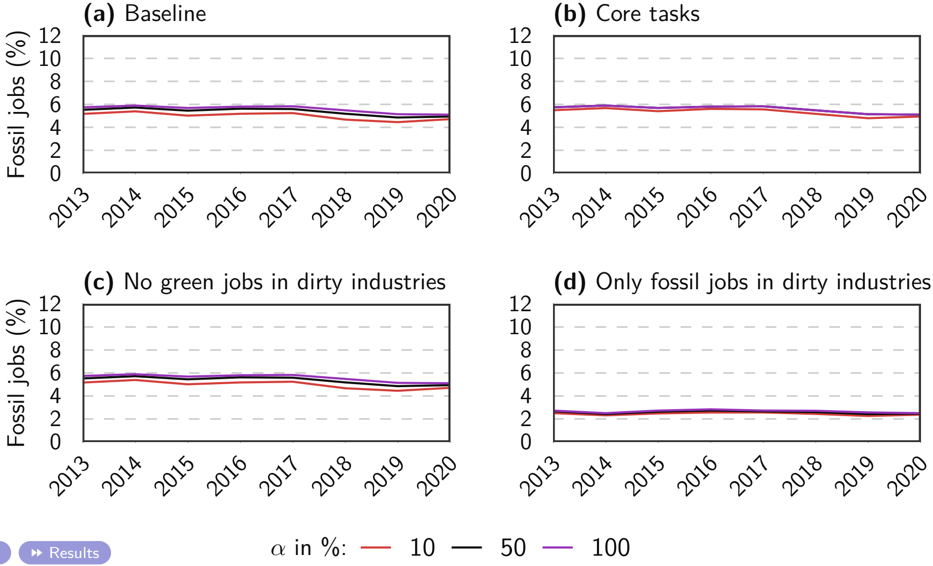
▸▸ Data ▸▸ Results α in %: 10 20 30 40 50 100

Green job share by sensitivity test (panels) and α (lines)



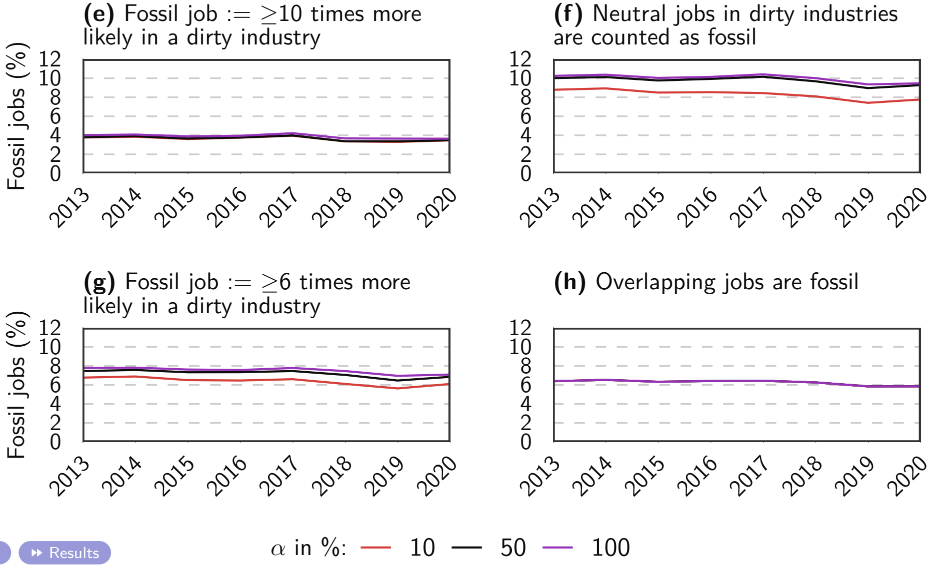
Data Results α in %: 10 20 30 40 50 100

Fossil job share by sensitivity test (panels) and α (lines)



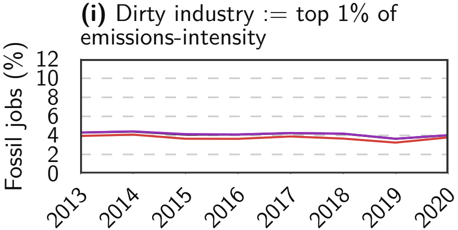
Data Results

Fossil job share by sensitivity test (panels) and α (lines)



Data
Results

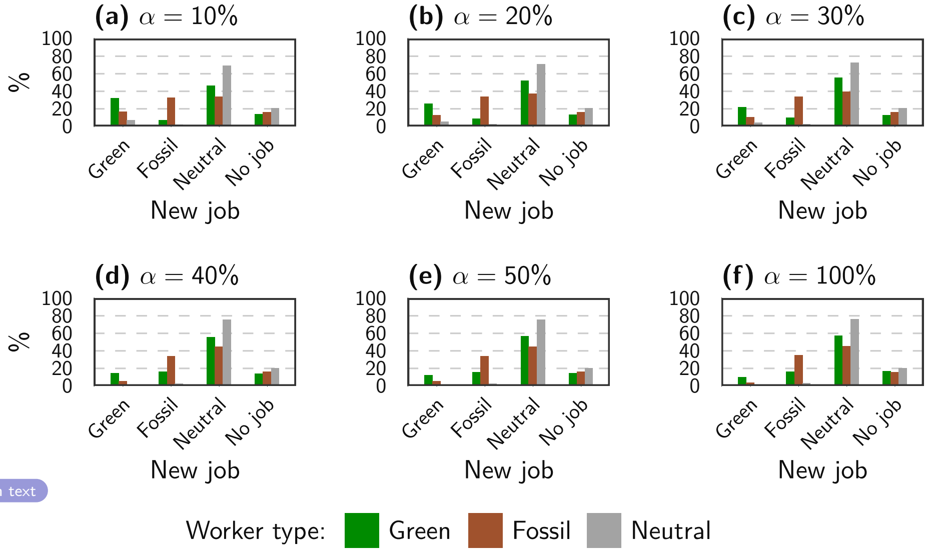
Fossil job share by sensitivity test (panels) and α (lines)



α in %: 10 50 100

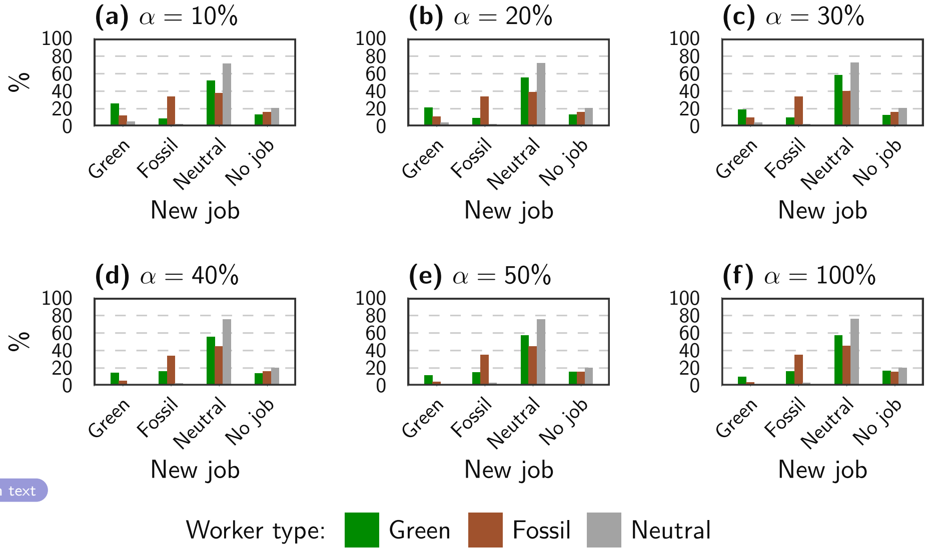
Data Results

Job-finding probability by α, job, and worker



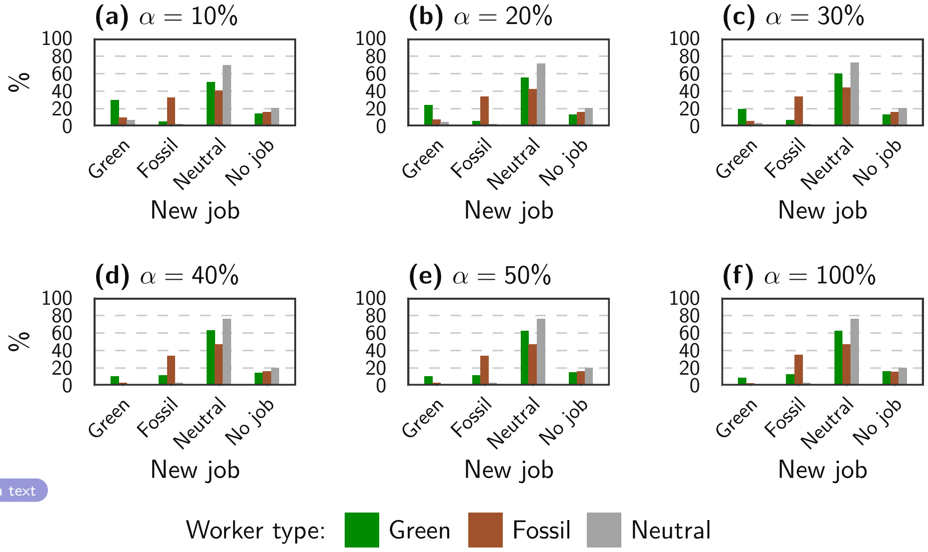
Main text

Job-finding probability by α, job, and worker (only core tasks)



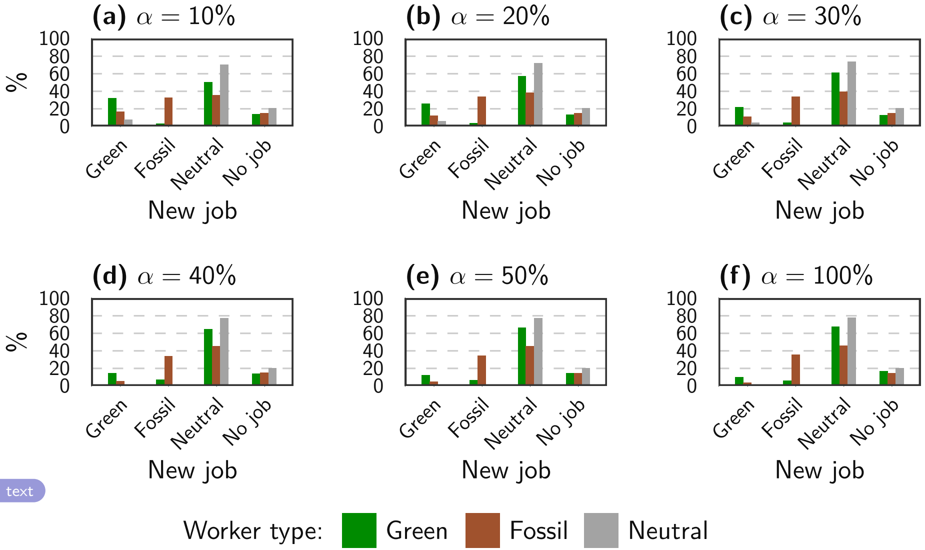
Main text

Job-finding probability by α, job, and worker (no green jobs in dirty industries)



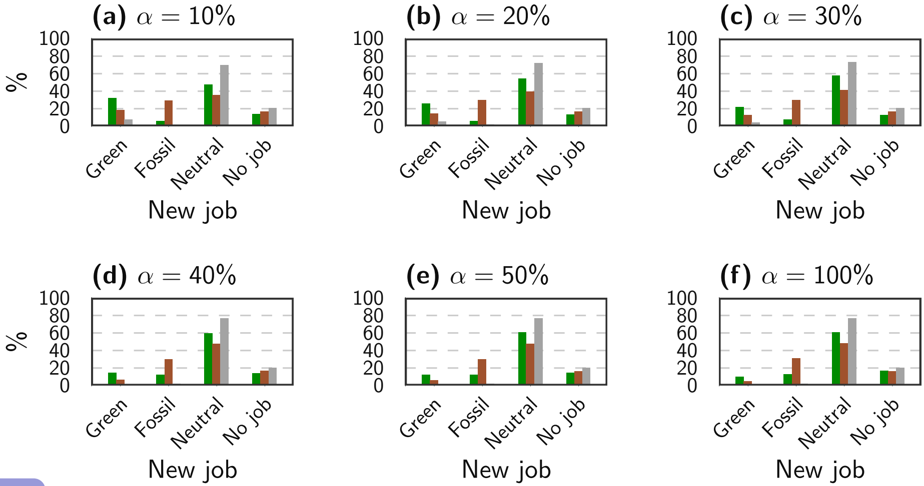
Main text

Job-finding probability by α, job, and worker (only fossil jobs in dirty industries)



Main text

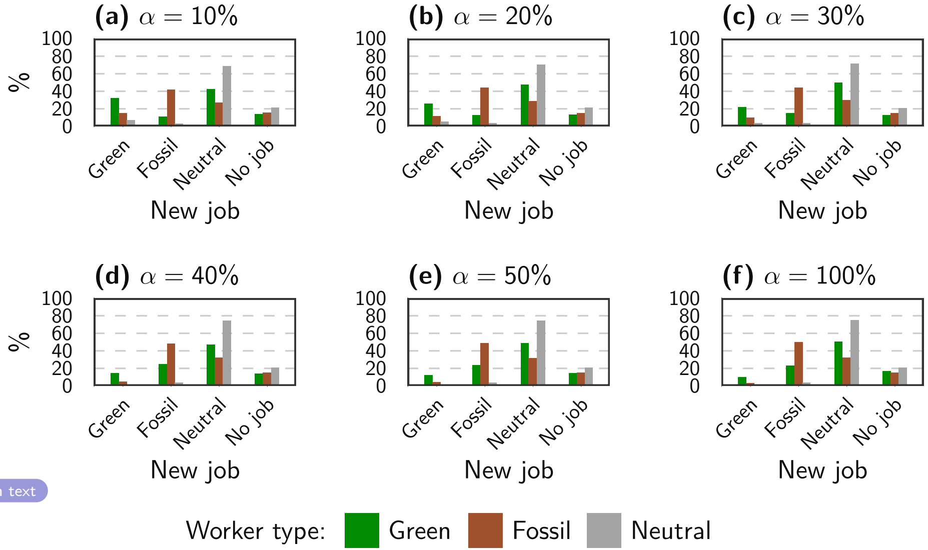
Job-finding probability by α, job, and worker (fossil job ≥10 times in dirty industries)



Worker type: Green Fossil Neutral

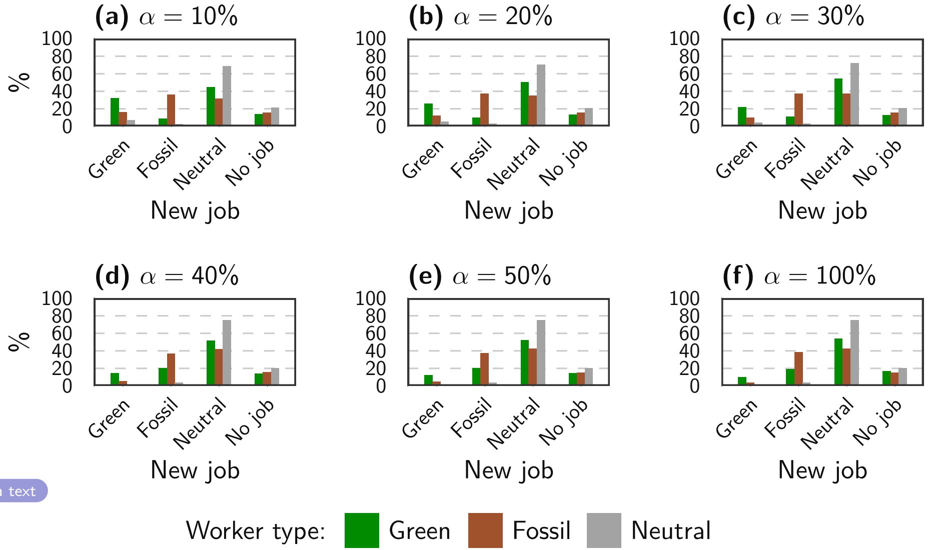
Main text

Job-finding probability by α, job, and worker (no neutral jobs in dirty industries)



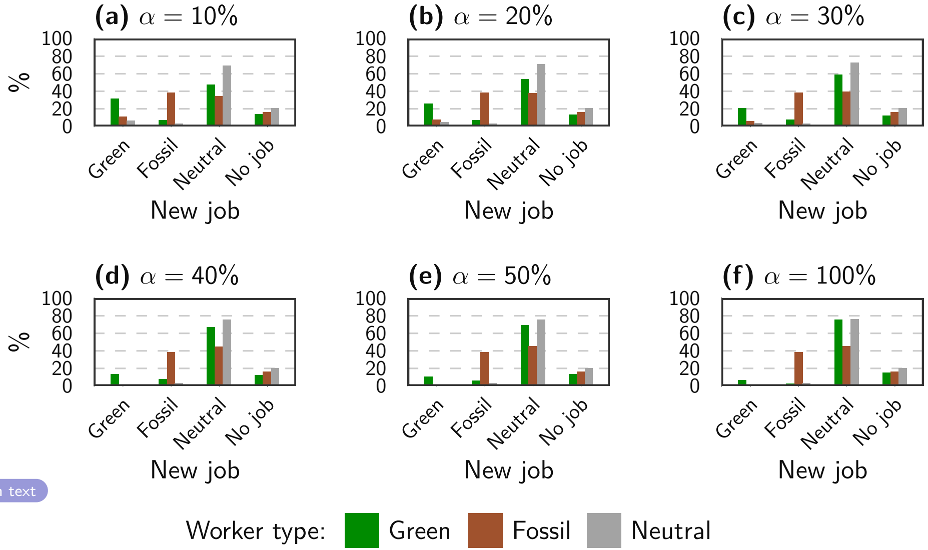
Main text

Job-finding probability by α, job, and worker (fossil job ≥6 times in dirty industries)



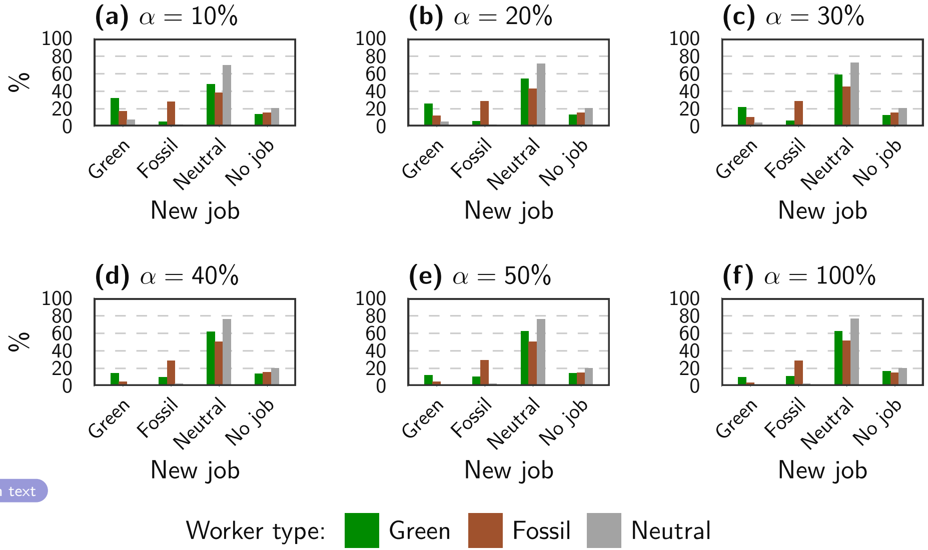
Main text

Job-finding probability by α, job, and worker (overlapping jobs are fossil)



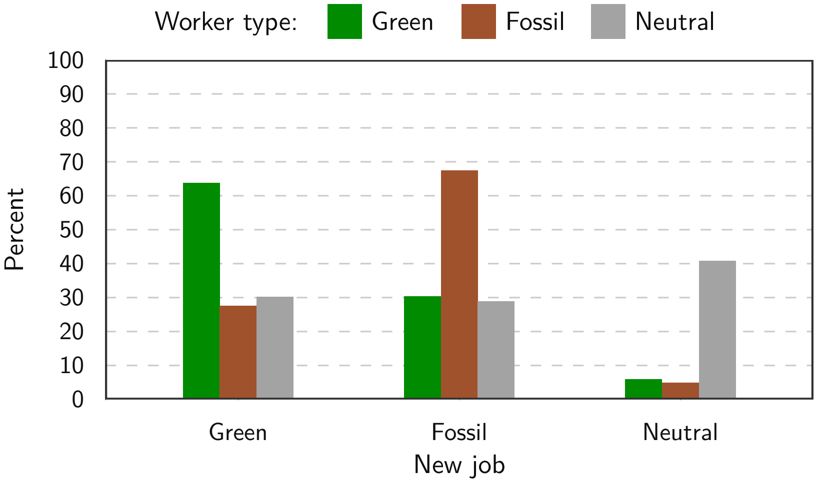
Main text

Job-finding probability by α, job, and worker (1% emissions-intensity cutoff)



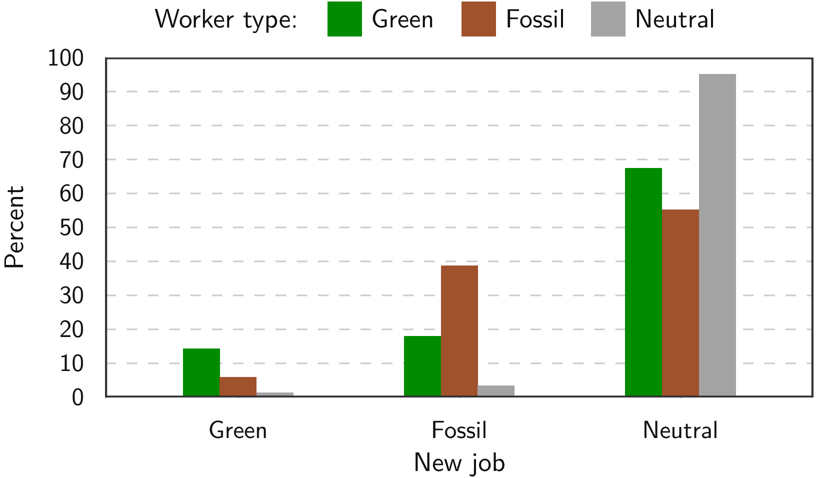
▸▸ Main text

Job finding probabilities with standardized employment sizes



Main text Non-standardized employment shares

Job finding probabilities without standardizing employment sizes



Main text

Firm's problem (with law of motion for employment)

- Firm's problem: Choose the $\overline{v}_j$, conditional on the stock of employed workers n_j, that maximizes the firm's value over time
- The Bellman equation is

$$J(n_j) = \max_{\overline{v}_j} \left[p_j^y \zeta h_j n_j (1 - \overline{v}_j) - (1 + \tau^P) n_j h_j w_j + \mathbb{E}\left[p^a J(n_j') \right] \right],$$

where

$$n_j' = n_j - \pi n_j + q_j \overline{v}_j h_j n_j,$$

with π being an exogenous quit rate and $q_j = \sum_i m_{ij} / v_j h_j$ the number of matches per recruitment effort

Main text

Firm FOC

The FOC with respect to $\overline{v}_j$ gives

$$p_j^y \zeta = q_j \mathbb{E}\Big[p^a J'_{n_j}\Big],$$

where $J'_{n_j} := \partial J(n'_j)/\partial n_j$ is the value in the next period of employing a worker today

Main text

Household's problem

The Bellman equation is

$$V\left(a, n_{\mathcal{J}}, u_{\mathcal{J}}\right) = \max_{C,a'} \left[\sum_j n_j U\left(C, h_j\right) + \sum_i u_i U\left(C, 0\right) + \beta \mathbb{E}\left[V\left(a', n'_{\mathcal{J}}, u'_{\mathcal{J}}\right)\right]\right],$$

subject to

$$p^C C + p^a a' \leq \sum_j (1 - \tau^L) n_j w_j h_j + \sum_i u_i p^C b_i + a + p^C T,$$

$$n'_j = n_j - \pi n_j + \sum_i \phi_{ij} u_i \qquad \forall j,$$

$$u'_i = \pi n_i + u_i(1 - \sum_j \phi_{ij}) \qquad \forall i,$$

where $\phi_{ij} = m_{ij}/u_i$ is the probability of worker i matching with firm j

Main text

HH FOCs, envelope conditions, and Euler equation

- The FOCs with respect to consumption and next period assets are

$$\frac{1}{C} = \lambda p^C,$$
$$\beta \mathbb{E}\left[V'_{a'}\right] = \lambda p^a, \tag{1}$$

where λ is the Lagrange multiplier for the budget constraint

- Differentiating the Bellman equation gives the envelope conditions

$$V'_{a'} = \lambda', \tag{2}$$
$$V_{n_j} = U(C, h_j) + \lambda(1 - \tau^L) w_j h_j + \beta\left((1-\pi)\mathbb{E}\left[V'_{n_j}\right] + \pi\mathbb{E}\left[V'_{u_j}\right]\right) \qquad \forall j,$$
$$V_{u_i} = U(C, 0) + \lambda p^C b_i + \beta\left(\mathbb{E}\left[V'_{u_i}\right] + \sum_j \phi_{ij}\left(\mathbb{E}\left[V'_{n_j}\right] - \mathbb{E}\left[V'_{u_i}\right]\right)\right) \qquad \forall i$$

- Combining (1) and (2) gives the Euler equation $p^a = \beta \frac{\lambda'}{\lambda}$

Main text

Nash bargaining

- A worker and firm divide the match surplus $J_{n_j} + V_{n_j} - V_{u_j}$ according to Nash bargaining:

$$\max_{w_j, h_j} J_{n_j}^{\eta} \left[V_{n_j} - V_{u_j} \right]^{1-\eta} \quad \forall j$$

- Solving gives the following respective equilibrium conditions for hours and wages:

$$(1+\tau^P)\psi h_j^{\frac{1}{\chi}} = (1-\tau^L)\lambda p_j^y \zeta \quad \forall j,$$

$$(1-\tau^L)h_j w_j = (1-\eta)\left[\frac{1-\tau^L}{1+\tau^P} p_j^y \zeta h_j\right]$$

$$+\eta\left[\frac{\psi\chi h_j^{1+\frac{1}{\chi}}}{\lambda(1+\chi)} + \overline{p} b_j + \beta \frac{\sum_i \phi_{ji}\left(V'_{n_i} - V'_{u_j}\right)}{\lambda}\right] \quad \forall j$$

Main text

Recruiting productivity, job finding probability, labor market tightness

$$q_j = \mu_j \left[\xi_j \theta^{-\gamma} + (1-\xi_j)\theta_{jj}^{-\gamma} \right]$$
$$\phi_{ij} = \mu_j \left[\xi_j \theta_j \theta^{-\gamma} + (1-\xi_j)\theta_{ij}^{1-\gamma}\delta_{ij} \right]$$

q_j = Recruiting productivity ($\sum_i m_{ij}/(\upsilon_j h_j)$)

ϕ_{ij} = Job finding probability ($\sum_i m_{ij}/u_i$)

θ_{ij} = Ratio of recruitment effort by firm j to unemployed workers of type i ($\upsilon_j h_j/u_i$)

θ_j = Ratio of recruitment effort by firm j to all unemployed workers ($\upsilon_j h_j/\overline{u}$)

$\overline{\theta}$ = Ratio of total recruitment effort to all unemployed workers ($\sum_j \upsilon_j h_j/\overline{u}$)

Main text

Solving for ξ_j

- Let ω_j be the **share of matches for firm j with workers of type j**

$$\omega_j = \begin{cases} 0.14 & \text{for } j = \mathtt{g}, \\ 0.39 & \text{for } j = \mathtt{f}, \\ 0.95 & \text{for } j = \mathtt{z} \end{cases}$$

- ω_j is linked to cross-type matching friction ξ_j by

$$\omega_j = \frac{m_{jj}}{\sum_i m_{ij}}, \tag{3}$$

where

$$m_{ij} = \mu_j \upsilon_j h_j u_i \left[\xi_j \left(\sum_k \upsilon_k h_k \right)^{-\gamma} \overline{u}^{\gamma-1} + (1-\xi_j)(\upsilon_j h_j)^{-\gamma} u_i^{\gamma-1} \delta_{ij} \right] \tag{4}$$

- Solving for ξ_j to match initial equilibrium moments using (3), (4), and ω_j gives

$$\xi_j = \begin{cases} 0.87 & \text{for } j = \mathtt{g}, \\ 0.58 & \text{for } j = \mathtt{f}, \\ 1^* & \text{for } j = \mathtt{z} \end{cases}$$

*Capped at 1

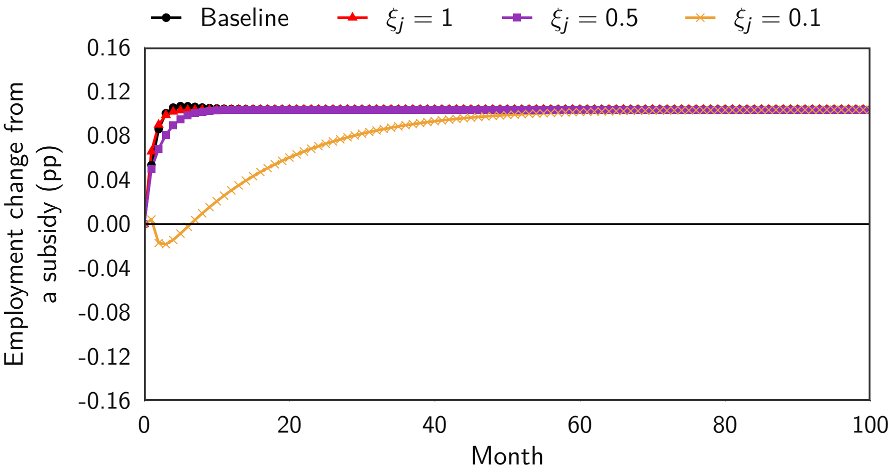
Main text

Employment change by policy instrument and parameter (in pp vs. BaU)

	Subsidy + LS tax	Subsidy + Payroll tax	Carbon price + Transfer	Carbon price + Payroll tax
Baseline	0.104	-0.014	-0.034	-0.001
q_j up by 50%	0.155	-0.025	-0.050	-0.002
q_j down by 50%	0.048	-0.005	-0.016	-0.001
$\eta = 0.7$	0.226	-0.050	-0.072	-0.003
$\eta = 0.3$	0.041	-0.004	-0.014	-0.001
$\gamma = 0.75$	0.052	-0.006	-0.017	-0.001
$\gamma = 0.25$	0.155	-0.024	-0.050	-0.003
$\chi = 2$	0.078	-0.009	-0.024	-0.001
$\chi = 0.5$	0.121	-0.019	-0.041	-0.002
$\sigma^{fg} = 1.5$	0.026	-0.002	-0.025	-0.001
$\sigma^{fg} = 0.6$	0.253	-0.047	-0.036	-0.002
$\sigma^{C} = 0.6$	0.166	-0.030	-0.030	-0.001
$\sigma^{C} = 0.4$	0.075	-0.008	-0.038	-0.002
Flat nesting	0.689	-0.193	-0.026	-0.001
13% abatement	0.840	-1.252	-0.301	-0.046
$\xi_j = 1$	0.104	-0.014	-0.033	-0.001
$\xi_j = 0.5$	0.104	-0.014	-0.033	-0.001
$\xi_j = 0.1$	0.104	-0.014	-0.033	-0.001

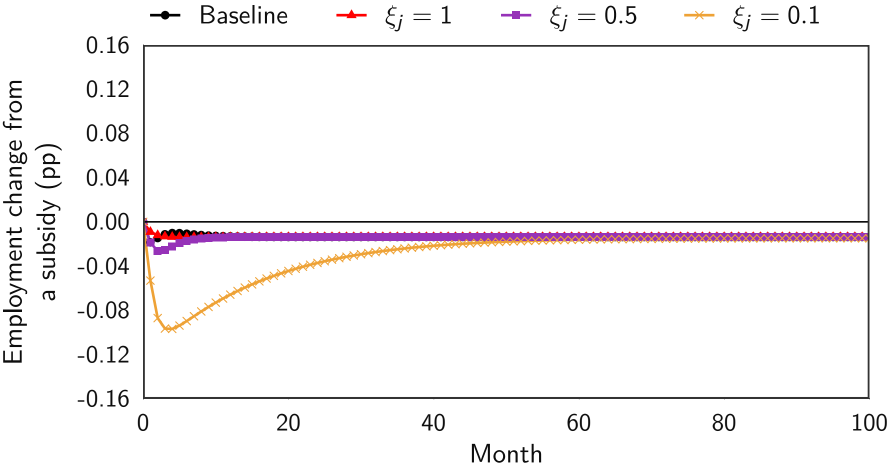
Main text ξ_j sensitivity (lump sum taxes) ξ_j sensitivity (payroll taxes)

Employment change from a green subsidy with lump sum taxes for various ξ_j



▸▸ Main text

Employment change from a green subsidy with payroll taxes for various ξ_j



Main text

Outcomes from a green subsidy by financing mechanism

	% change in recruitment effort		% change in hours		Subsidy rate	
	LS	Payroll	LS	Payroll	LS	Payroll
Baseline	1.74	-0.48	0.198	-0.014	0.30	0.25
q_j up by 50%	2.76	-0.69	0.175	-0.015	0.31	0.24
q_j down by 50%	0.66	-0.32	0.223	-0.014	0.30	0.25
$\eta = 0.7$	4.19	-1.17	0.148	-0.017	0.31	0.24
$\eta = 0.3$	0.51	-0.30	0.224	-0.014	0.29	0.25
$\gamma = 0.75$	2.65	-0.55	0.223	-0.014	0.30	0.25
$\gamma = 0.25$	0.84	-0.38	0.173	-0.014	0.31	0.24
$\chi = 2$	1.23	-0.39	0.293	-0.020	0.31	0.25
$\chi = 0.5$	2.09	-0.59	0.121	-0.010	0.29	0.25
$\sigma^{fg} = 1.5$	0.43	-0.10	0.047	-0.002	0.06	0.06
$\sigma^{fg} = 0.6$	4.21	-1.36	0.551	-0.050	1.01	0.57
$\sigma^{C} = 0.6$	2.71	-0.95	0.339	-0.031	0.53	0.37
$\sigma^{C} = 0.4$	1.29	-0.28	0.139	-0.008	0.21	0.18
Flat nesting	9.72	-4.80	2.355	-0.194	4.67	1.08
13% abatement	12.03	-21.93	3.298	-0.934	8.16	3.55
$\xi_j = 1$	1.74	-0.48	0.198	-0.014	0.30	0.25
$\xi_j = 0.5$	1.74	-0.48	0.198	-0.014	0.30	0.25
$\xi_j = 0.1$	1.74	-0.48	0.198	-0.014	0.30	0.25

Main text

Effects of a green subsidy with lump sum taxes by firm/worker type and sensitivity test

	Benchmark unemployment benefits			Benchmark flow value of unemployment				Benchmark fundamental surplus ratio				Employment change (pp)		
	g	f	z	g	f	z	mean	g	f	z	mean	g	f	z
Baseline	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.33	-0.09	-0.14
q_j up by 50%	0.29	0.28	0.29	0.62	0.61	0.62	0.62	0.06	0.08	0.05	0.05	0.34	-0.09	-0.10
q_j down by 50%	0.21	0.17	0.23	0.54	0.50	0.56	0.56	0.18	0.24	0.16	0.16	0.32	-0.09	-0.19
$\eta = 0.7$	0.30	0.29	0.31	0.63	0.62	0.63	0.63	0.04	0.05	0.04	0.04	0.35	-0.08	-0.04
$\eta = 0.3$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.32	-0.09	-0.18
$\gamma = 0.75$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.32	-0.09	-0.18
$\gamma = 0.25$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.34	-0.09	-0.10
$\chi = 2$	0.16	0.14	0.17	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.34	-0.09	-0.17
$\chi = 0.5$	0.38	0.36	0.39	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.32	-0.08	-0.12
$\sigma^{fg} = 1.5$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.14	-0.08	-0.03
$\sigma^{fg} = 0.6$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.82	-0.10	-0.47
$\sigma^{C} = 0.6$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.59	-0.09	-0.33
$\sigma^{C} = 0.4$	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	0.22	-0.08	-0.07
Flat nesting	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	4.29	-0.18	-3.42
13% abatement	0.27	0.25	0.28	0.60	0.58	0.61	0.61	0.09	0.12	0.08	0.08	5.82	-0.73	-4.26
$\xi_j = 1$	0.28	0.28	0.28	0.61	0.61	0.61	0.61	0.08	0.08	0.08	0.08	0.33	-0.09	-0.14
$\xi_j = 0.5$	0.28	0.28	0.28	0.61	0.61	0.61	0.61	0.08	0.08	0.08	0.08	0.33	-0.09	-0.14
$\xi_j = 0.1$	0.28	0.28	0.28	0.61	0.61	0.61	0.61	0.08	0.08	0.08	0.08	0.33	-0.09	-0.14

Main text

Changes from a green subsidy with lump sum taxes by firm (in % vs. BaU)

Firm	Time period	Gross price p_j	Output y_j	Recruiters υ_j	Recruiting productivity q_j	Recruitment $\upsilon_j q_j h_j$	Match value J_{n_j}
Green	$t = 0$	0	-4.3	345.0	-8.6	356.7	97
	SS	0	19.8	21.6	-1.9	19.5	33
Fossil	$t = 0$	15.1	-13.9	-20.9	3.5	-18.6	9
	SS	30.1	-1.7	-0.2	-1.9	-1.9	33
Neutral	$t = 0$	15.9	-13.4	-2.5	-1.9	-4.3	17
	SS	30.1	0.0	1.5	-1.9	-0.2	33

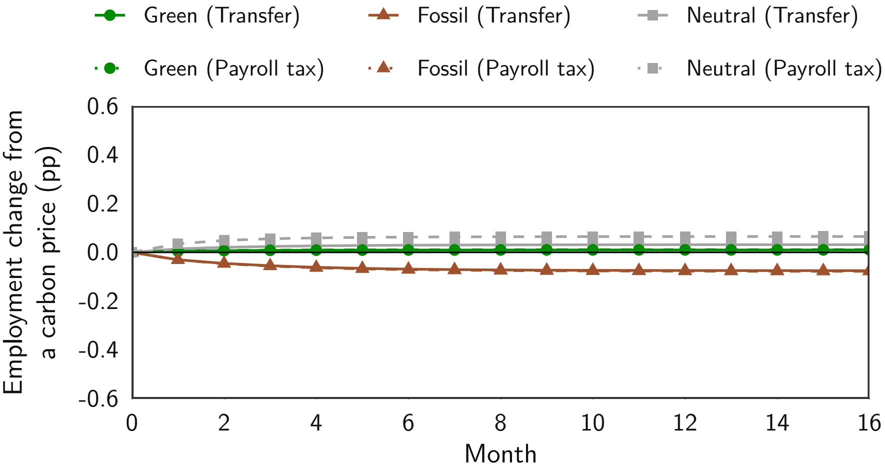
Main text

Changes from a carbon price with transfer recycling by firm (in % vs. BaU)

Firm	Time period	Gross price p_j	Output y_j	Recruiters υ_j	Recruiting productivity q_j	Recruitment $\upsilon_j q_j h_j$	Match value J_{n_j}
Green	$t=0$	0	0.3	7.4	0.0	7.6	1
	SS	0	0.5	0.0	0.6	0.6	-1
Fossil	$t=0$	1.7	-0.9	-21.0	5.2	-17.8	-9
	SS	3.0	-1.7	-2.2	0.6	-1.6	-1
Neutral	$t=0$	-0.2	0.1	0.0	0.5	0.4	-1
	SS	0.0	0.0	-0.5	0.6	0.0	-1

Main text

Employment change from a carbon price by job type and recycling mechanism



⏩ Main text

Measuring welfare

- Welfare corresponds to the discounted lifetime utility of the representative household
- The household's utility in a given period is

$$\log(C) - \sum_j n_j \frac{\psi\chi}{1+\chi} h_j^{1+\frac{1}{\chi}}$$

- Measure welfare changes using the equivalent variation
- Fix n_j and h_j at their benchmark levels (in line with Hafstead and Williams, 2018) since workers do not control them
  $\rightarrow$ Welfare changes stem solely from changes in consumption

Main text Welfare by distortion level Welfare with leisure

Welfare change by policy instrument and parameter (in % vs. BaU)

	Subsidy + LS tax	Subsidy + Payroll tax	Carbon price + Transfer	Carbon price + Payroll tax
Baseline	0.257	-0.058	-0.090	-0.003
q_j up by 50%	0.287	-0.070	-0.098	-0.004
q_j down by 50%	0.226	-0.049	-0.081	-0.003
$\eta = 0.7$	0.323	-0.095	-0.108	-0.005
$\eta = 0.3$	0.223	-0.048	-0.081	-0.003
$\gamma = 0.75$	0.225	-0.050	-0.081	-0.002
$\gamma = 0.25$	0.289	-0.069	-0.099	-0.005
$\chi = 2$	0.325	-0.059	-0.105	-0.003
$\chi = 0.5$	0.199	-0.059	-0.077	-0.003
$\sigma^{fg} = 1.5$	0.067	-0.008	-0.066	-0.002
$\sigma^{fg} = 0.6$	0.541	-0.201	-0.097	-0.003
$\sigma^{C} = 0.6$	0.382	-0.127	-0.080	-0.003
$\sigma^{C} = 0.4$	0.192	-0.032	-0.102	-0.004
Flat nesting	0.220	-0.787	-0.069	-0.003
13% abatement	-0.325	-3.897	-0.809	-0.169
$\xi_j = 1$	0.257	-0.058	-0.090	-0.002
$\xi_j = 0.5$	0.257	-0.058	-0.090	-0.002
$\xi_j = 0.1$	0.256	-0.062	-0.090	-0.003

Main text (non-distortionary mechanisms)   Main text (all mechanisms)

Welfare change by policy instrument and distortion level (in % vs. BaU)

Initial distortion level	Subsidy + LS tax	Subsidy + Payroll tax	Carbon price + Transfer	Carbon price + Payroll tax
Baseline	0.26	-0.06	-0.09	-0.00
50% higher τ^L, τ^P	0.26	-0.15	-0.09	-0.01

▸▸ Welfare calculations

Welfare change when accounting for leisure by policy and distortion level (in % vs. BaU)

Initial distortion level	Subsidy + LS tax	Subsidy + Payroll tax	Carbon price + Transfer	Carbon price + Payroll tax
Baseline	0.10	-0.04	-0.04	-0.00
50% higher τ^L, τ^P	0.14	-0.11	-0.06	-0.01

Welfare calculations

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