The Distributional Impacts of Decarbonization Policies

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Abstract

We develop a quantitative framework to study the distributional consequences of decarbonization policies across regions, sectors, and worker demographics. The starting point is the observation that regions and sectors differ sharply in their exposure to carbon policy and energy prices. Our model features: (a) a fossil-fuel production sector supplying inputs to energy producers and final goods to households; (b) fossil-fuel and renewable energy producers; (c) multiple sectors that combine labor, capital, and energy with heterogeneous substitution patterns; (d) imperfectly mobile workers across sectors and regions; and (e) costly trade across locations.

After calibrating the model to several sources of U.S. data, we study two counterfactuals: (i) a once-and-for-all carbon tax levied on fossil-fuel output, and (ii) an exogenous expansion of renewable-energy capital across all U.S. locations. We also outline several extensions to be completed over the next 6–8 months: (1) endogenizing the accumulation of energy-related and sector-specific capital; (2) incorporating observable worker heterogeneity (skills and age) that shapes labor mobility responses; and (3) allowing for imperfect transmission of energy across locations, leading to region-specific energy prices and potentially amplifying inequality.

Our framework provides a rich structure for evaluating how different climate policies affect workers, producers, and the spatial distribution of economic activity.

1 Introduction

Carbon taxes and cap-and-trade increase the cost of using fossil fuels in production, with the potential to disproportionately affect regions, industries, and workers most exposed to fossil-fuel and electricity prices. These policies place especially heavy burdens on older workers and those with lower levels of education, who face higher mobility frictions and have fewer opportunities to transition out of their initial jobs.

Green-energy development and subsidies, by contrast, shift resources toward renewables, benefiting regions and industries better positioned to adopt or produce clean technologies. Renewable technologies may either accelerate the decline of traditional energy sectors—if their expansion depresses electricity prices—or have more limited effects if they do not.

In both cases, timing is central: losses from carbon pricing or green-energy expansion are immediate and concentrated, while emissions reductions unfold more gradually. The heterogeneity in impacts across regions, sectors, and workers is therefore key for the political sustainability of decarbonization efforts and underscores the need for transition-smoothing policies that can broaden their support.

Given how central distributional consequences are for the successful and durable implementation of climate policies, it is striking how little systematic work exists on this topic. We also lack an authoritative quantitative general-equilibrium framework that captures distributional effects across space, sectors, demographics, and factors of production, with a clear focus on the adjustment process. To fill this gap, we build a structural model incorporating these features and use it to answer four main questions. First, which groups bear the largest burden of a carbon tax? Second, how quickly should we expect economies to adjust to carbon pricing or the adoption of renewable technologies? Third, how should revenues from carbon taxes be redistributed? Fourth, how do the impacts of carbon taxes and renewable-energy subsidies interact when the two policies are implemented together?

Our framework consists of a dynamic spatial general-equilibrium model of the United States with 50 states and 33 economic sectors. In the model, electricity is produced using two types of capital: renewable-based capital and fossil-fuel-based capital. The productivity of renewable capital varies across the country, depending on exposure to sunlight, wind, and hydro resources, with marginal cost assumed to be zero (as in Arkolakis and Walsh, 2023). Fossil-fuel-based capital, by contrast, requires fossil fuel inputs and exhibits decreasing returns to scale, generating increasing and convex local supply curves for energy. Goods (including fuel itself) and services are produced using labor, capital, and electricity. States

and sectors are connected via costly trade, imperfect mobility of workers across states and sectors, electricity transmission, and the government transfers which may accompany energy policy. Capital is currently assumed to be sector-specific and spatially immobile—but we are working on an extension allowing for endogenous capital accumulation across sectors and regions, but also across renewables and traditional fossil-fuel based energy production.

We calibrate the model to U.S. data on value added, expenditures, and wage payments from the Bureau of Economic Analysis (BEA); data on energy capital stocks and production from the Energy Information Administration (EIA); regional trade flows from the Commodity Flow Survey (CFS); and labor allocations and worker transitions from the American Community Survey (ACS) and Current Population Survey (CPS).

To illustrate the appeal and usefulness of our framework, we first present two counterfactual exercises and then describe the extensions we are implementing to enrich it. Our first exercise is a permanent and unanticipated 20% tax on fossil fuels, with revenues rebated to workers in a lump-sum fashion. Along the transition path, the impact on aggregate output is under 0.01%, but this masks large disparities in the incidence of the shock. The fossil-fuel sector contracts by 11%, generating substantial spatial heterogeneity in the tax's incidence. States that are intensive in fossil-fuel production—such as Texas—experience a protracted 40-year population decline that results in a 1% long-run population loss. This migration response is accompanied by sizable dispersion in real wage effects across locations. Interestingly, rebating tax revenues to workers more than offsets the tax's impact on labor earnings: 99.5% of workers experience a welfare gain, not counting the carbon-mitigation benefits of the tax. By contrast, capital owners lose from the policy, with a 0.6% decline in their income.

Our second exercise represents a positive shock to renewable generation technology: we exogenously increase the effective stock of renewable generation capital by 25% uniformly across space. Strikingly, fossil-fuel usage—and the associated emissions—declines by less than 0.1%, a far smaller effect than under the carbon tax. The reason is that the resulting 0.3% gain in real income largely offsets substitution away from fossil-fuel generation. Real wages also rise meaningfully—by more than 0.2% on average—though this does not account for the costs of discovering or deploying the new technology. The policy has a negligible effect on fuel prices, with the consequence that no particular sector or region is targeted or disproportionately affected, in sharp contrast to the carbon-tax experiment.

We are pursuing several extensions of our basic framework, each adding an important dimension that links decarbonization policies to their distributional consequences. First,

we are introducing endogenous capital accumulation for both renewable and fossil-based technologies, enabling us to study the dynamics and effectiveness of green-energy subsidies. Second, incorporating worker demographics—such as education and age—will allow a richer characterization of distributional effects across regions, industries, and worker types, speaking directly to policymakers' concerns. We are also adding input–output linkages to capture realistic supply-chain relationships and interdependencies, which are known to spread and amplify the effects of localized shocks (Caliendo and Parro, 2015, e.g.,). Finally, we will incorporate transmission frictions across locations, allowing decarbonization policies to produce heterogeneous impacts on electricity prices and, in turn, further distributional consequences. Because we already have sketches for each of these extensions, we are confident that we will have a complete draft of the paper within six months, well before the conference.

While it is a strong lesson of modern trade economics that sectoral heterogeneity in exposure to shocks can translate to large spatial and worker heterogeneity in policy impacts, the literature that considers rich spatial equilibrium in the impacts of energy transition policies remains thin.[1] Schlattmann (2024), Morehouse (2022), and Arkolakis and Walsh (2023) are recent examples, but none feature the labor market dynamics and worker heterogeneity that are our focus.

We also bring to the energy transition literature explicit structural treatments of some potential negative consequences of adaptation through reallocation, which must be balanced against the positive. It is a common theme in the spatial macroeconomic and trade literatures that worker mobility facilitates adaptation, reducing negative welfare impacts and spatial heterogeneity in welfare impacts. Bilal and Rossi-Hansberg (2025) and Conte, Desmet and Rossi-Hansberg (2025) make this point strongly in the cases of climate impacts and carbon taxes, respectively. However, increased worker mobility may also come—as in our analysis—at the cost, in more exposed locations, of accelerated population declines, economic downturns, and spatial reallocation in the value of preexisting fixed factors (as in Sun (2025)). These trade-offs, between inequality in policy impacts across competing margins, sharply motivate our analysis of policy design and the allocation of budget-balancing taxes and transfers.

The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 describes the data. Section 4 details the calibration procedure. Section 5 reports

[1] See, for instance, Artuç, Chaudhuri and McLaren (2010), Autor, Dorn and Hanson (2013), Dix-Carneiro (2014), Dix-Carneiro and Kovak (2017), Dix-Carneiro and Kovak (2019), Traiberman (2019), and Caliendo, Dvorkin and Parro (2019).

our current results. Finally, section 6 outlines the extensions we plan to implement before the conference.

2 Model

2.1 Environment

We consider an environment with multiple locations, $\ell \in \mathcal{L} \equiv \{1, \ldots, |\mathcal{L}|\}$, and multiple sectors, $j \in \{1, \ldots, J\} \cup E \cup F$. We reserve the notation E for the energy / electricity sector and F for the fossil-fuel sector, which will play a central role in our analysis. Time is discrete, and periods are indexed by $t = 1, \ldots, T$. There is a mass $\overline{L}$ of hand-to-mouth workers who choose where to live and work in each period. In addition to workers, each location contains local capitalists who own the capital stock used in each sector j as well as in energy production. Specifically, there are two types of energy producers: those using renewable energy capital—such as solar panels and wind turbines—denoted K_ℓ^R, and those using fossil fuel-based capital—such as coal power plants—denoted K_ℓ^F. All capitalists are assumed to be immobile and unable to undertake new investments at present—Section 6 discusses the extensions we are developing, including forward-looking capitalists who can invest in capital. The government may impose sector-j-specific output taxes, including on fuel production, and rebate the resulting revenues to workers through lump-sum transfers.

2.2 Technology

2.2.1 Local Final Goods Producers

Final goods in location ℓ are assembled using sector-specific composite goods $Q_{\ell,j,t}$, according to a Cobb-Douglas production function:

$$Q_{\ell,t} = \prod_{j \in J \cup E \cup F} Q_{\ell,j,t}^{\mu_j}, \tag{1}$$

where, by abuse of notation, we write J for the full set $\{1, ..., J\}$, and μ_j are expenditure weights that are constant across locations and sum to one. The sector-specific composite goods $Q_{\ell,j,t}$ are constructed as Armington aggregates over sector-j intermediate goods

sourced from all possible origins ℓ':

$$Q_{\ell,j,t} = \left(\sum_{\ell'=1}^{L} q_{\ell',\ell,j,t}^{\frac{\rho_j - 1}{\rho_j}} \right)^{\frac{\rho_j}{\rho_j - 1}}, \tag{2}$$

where $q_{\ell',\ell,j,t}$ denotes the quantity of sector-j goods sourced by location ℓ from origin ℓ', and ρ_j is the sector-specific elasticity of substitution. However, we consider energy (E) and fuel (F) as homogeneous goods.

2.2.2 Intermediate Local Goods and Fossil Fuel Producers

Intermediate goods in sector $j \in J$ and location ℓ are produced using electricity E, labor L, and capital K, according to:

$$y_{\ell,j,t} = z_{\ell,j} \left(\left(\beta_j^E\right)^{\frac{1}{\sigma_j}} E_{\ell,j,t}^{\frac{\sigma_j - 1}{\sigma_j}} + \left(1 - \beta_j^E\right)^{\frac{1}{\sigma_j}} \left(L_{\ell,j,t}^{\beta_j^L} K_{\ell,j,t}^{1-\beta_j^L} \right)^{\frac{\sigma_j - 1}{\sigma_j}} \right)^{\frac{\sigma_j}{\sigma_j - 1}}, \tag{3}$$

where $z_{\ell,j}$ denotes total factor productivity (TFP) in sector j and location ℓ; σ_j is the elasticity of substitution between electricity and the labor-capital bundle; β_j^E is a sector-specific weight on energy; and β_j^L is the labor share in the labor-capital bundle.

Note that when $\sigma_j = 1$, the production function reduces to Cobb-Douglas, while $\sigma_j \to 0$ corresponds to a Leontief production function. The production function for the fuel sector ($j = F$) follows the same functional form as (3).

2.2.3 Local Energy Production

In modeling local energy producers, we largely follow Arkolakis and Walsh (2023). Total electricity output in location ℓ is given by the sum of electricity produced from renewable capital (R) and fossil-fuel-based capital (F):

$$y_{\ell,t}^E = y_{\ell,t}^{E,R} + y_{\ell,t}^{E,F},$$

where the superscript indicates the energy source.

Renewable energy is produced at zero marginal cost but is subject to a capacity constraint:

$$y_{\ell,t}^{E,R} \leq \theta_{\ell,t}^R K_{\ell,t}^R, \tag{4}$$

where $K^R_{\ell,t}$ denotes the installed nameplate capacity of renewable capital in location ℓ, and $\theta^R_{\ell,t}$ is the productivity of renewable capital in that location. The same installed capacity can generate different amounts of electricity across locations, depending on local conditions such as solar exposure and wind intensity. Because renewable electricity has zero marginal cost, it is always utilized first.

Electricity generated from fossil fuels is produced according to:

$$y^{E,F}_{\ell,t} = z_{\ell,E} \left(K^F_{\ell,t}\right)^{\alpha} F^{1-\alpha}_{\ell,t}, \tag{5}$$

where $K^F_{\ell,t}$ denotes the installed fossil-fuel-based capital, $F_{\ell,t}$ is the quantity of fuel used and $z_{\ell,E}$ is a productivity shifter. Since fossil-fuel-based capital is assumed to be fixed at present, this production function exhibits decreasing returns to scale in fuel. The only variable input in the production of fossil-based electricity is fuel, and the demand for fuel in location $\ell \in \mathcal{L}$ is given by:

$$F^D_{\ell,t} = \begin{cases} 0 & \text{if } y^E_{\ell,t} \leq \theta^R_{\ell,t} K^R_{\ell,t} \\ \left(K^F_{\ell,t}\right)^{-\frac{\alpha}{1-\alpha}} \left(\frac{y^E_{\ell,t} - \theta^R_{\ell,t} K^R_{\ell,t}}{z_{\ell,E}}\right)^{\frac{1}{1-\alpha}} & \text{if } y^E_{\ell,t} > \theta^R_{\ell,t} K^R_{\ell,t}. \end{cases} \tag{6}$$

2.3 Labor Supply

Workers employed in region ℓ and sector j at time t receive a wage $w_{\ell,j,t}$, as well as a tax rebate b_t that is uniform across sectors and locations. Workers may also choose not to work, in which case we say they have state u and they earn no labor income (so that $w_{\ell,u,t} = 0$). All workers are hand-to-mouth and therefore spend their entire labor income and transfers on the final good in each period.

As in Artuç, Chaudhuri and McLaren (2010), at the end of each period, workers must decide on their location and sector for the next period. If a worker chooses to switch sectors, $j \to n$, migrate, $\ell \to k$, or both, they incur a deterministic switching cost $C_{\ell,j,k,n}$. In addition, in each period, workers receive an idiosyncratic shock to their switching costs, denoted $\varepsilon_{k,n,t}$. For notational convenience, we omit individual-specific subscripts, but these idiosyncratic shocks are independently and identically distributed across workers, time, sectors, and locations. They follow a Gumbel distribution, with variance governed by the scale parameter ν. The dynamic problem of a worker initially placed in location ℓ and sector j

(including $j = u$) at time t is given by:

$$\widetilde{\mathcal{V}}_{\ell,j,t}\left(w_{\ell,j,t}, P_{\ell,t}, b_t, \boldsymbol{\varepsilon}_t\right) = \frac{w_{\ell,j,t} + b_t}{P_{\ell,t}} + \eta_{\ell,j} + \max_{k\in\mathcal{L}, n\in J\cup F\cup u} \left\{ \nu\varepsilon_{k,n,t} - C_{\ell,j,k,n} + \beta E_t\left[\widetilde{\mathcal{V}}_{k,n,t+1}\left(w_{k,n,t+1}, P_{\ell,t+1}, b_{t+1}, \boldsymbol{\varepsilon}_{t+1}\right)\right] \right\}, \tag{7}$$

where $P_{\ell,t}$ is the location-specific price of the final good, $\eta_{\ell,j}$ is a time-invariant, non-pecuniary value of being in location ℓ and sector j, and E_t is the expectation operator over future wages, prices, transfers, and idiosyncratic shocks, conditional on information available at time t.

It is convenient to integrate across individuals in order to define the expected value function—henceforth referred to simply as the value function—as well as the associated transition rates. In particular, integrating equation (7) over the idiosyncratic shocks $\boldsymbol{\varepsilon}_t$ yields:

$$\mathcal{V}_{\ell,j,t}(w_{\ell,j,t}, P_{\ell,t}, b_t) = \frac{w_{\ell,j,t} + b_t}{P_{\ell,t}} + \eta_{\ell,j} + \nu \log\left(\sum_{k\in\mathcal{L}, n\in J\cup F\cup u} \exp\left(\frac{-C_{\ell,j,k,n} + \beta E_t\left[\mathcal{V}_{k,n,t+1}(w_{k,n,t+1}, P_{\ell,t+1}, b_{t+1})\right]}{\nu}\right)\right) \tag{8}$$

where the expectation operator E_t now refers only to expectations over the future path of wages, prices and transfers. Aggregating workers' decisions at the end of period t, we obtain that transitions rates between t and $t+1$ take the convenient logit form:

$$m_{\ell,j,k,n,t} = \frac{\exp\left(\frac{-C_{\ell,j,k,n} + \beta E_t \mathcal{V}_{k,n,t+1}}{\nu}\right)}{\sum_{k',n'} \exp\left(\frac{-C_{\ell,j,k',n'} + \beta E_t \mathcal{V}_{k',n',t+1}}{\nu}\right)}, \tag{9}$$

with the arguments of $\mathcal{V}_{k,n,t+1}$ omitted for concision, and where $\ell, k \in \mathcal{L}$, and $j, n \in J \cup F \cup u$. These transition rates imply the following law of motion for labor supply:

$$L^S_{k,n,t+1} = \sum_{\ell\in\boldsymbol{L}, j\in J\cup F\cup u} m_{\ell,j,k,n,t} L^S_{\ell,j,t},$$

where $L^S_{\ell,j,t}$ is the supply of labor to region ℓ, sector $j \in J \cup F \cup u$ at time t.

Local (sector- or energy-specific) capitalists do not make any decisions; they simply con-

sume the final good each period using their capital income. As mentioned, we are currently working on relaxing this assumption to allow capitalists to be forward looking and to trade off consumption and investment.

2.4 Demand and Prices

2.4.1 Energy Markets

We assume that fossil-fuels are homogeneous across locations of production and are perfectly tradable. This implies a single price of fossil fuels, denoted $p_{F,t}$, which is common across all locations and sectors.

Given equations (4), (5) and (6), the total cost of generating $y_{\ell,t}^E$ units of electricity in location ℓ is given by:

$$C\left(y_{\ell,t}^E\right) = \begin{cases} 0 & \text{if } y_{\ell,t}^E \leq \theta_{\ell,t}^R K_{\ell,t}^R \\ p_{F,t}\left(K_{\ell,t}^F\right)^{-\frac{\alpha}{1-\alpha}} \left(\frac{y_{\ell,t}^E - \theta_{\ell,t}^R K_{\ell,t}^R}{z_{\ell,E}}\right)^{\frac{1}{1-\alpha}} & \text{if } y_{\ell,t}^E > \theta_{\ell,t}^R K_{\ell,t}^R \end{cases}. \tag{10}$$

We also assume that electricity is a homogeneous good, freely tradable across space, and therefore has a unique price across all locations and sectors, denoted by $p_{E,t}$. It is priced at marginal cost, so that for all $\ell \in \mathcal{L}$:

$$p_{\ell E,t} = C'\left(y_{\ell,t}^E\right) = p_{E,t},$$

with the marginal cost function given by:

$$C'\left(y_{\ell,t}^E\right) = \begin{cases} 0 & \text{if } y_{\ell,t}^E \leq \theta_{\ell,t}^R K_{\ell,t}^R \\ \frac{1}{1-\alpha}\frac{p_{F,t}}{z_{\ell,E}}\left(K_{\ell,t}^F\right)^{-\frac{\alpha}{1-\alpha}} \left(\frac{y_{\ell,t}^E - \theta_{\ell,t}^R K_{\ell,t}^R}{z_{\ell,E}}\right)^{\frac{\alpha}{1-\alpha}} & \text{if } y_{\ell,t}^E > \theta_{\ell,t}^R K_{\ell,t}^R \end{cases}. \tag{11}$$

Electricity generation $y_{\ell,t}^E$ leads to renewable capital and fossil-fuel-based capital incomes according to:

$$\begin{aligned} \Pi_{\ell,t}^R &= p_{E,t} y_{\ell,t}^{E,R}, \\ \Pi_{\ell,t}^F &= p_{E,t} y_{\ell,t}^{E,F} - C\left(y_{\ell,t}^E\right) = \alpha p_{E,t} y_{\ell,t}^{E,F} \quad \text{if } y_{\ell,t}^E > \theta_{\ell,t}^R K_{\ell,t}^R. \end{aligned}$$

2.4.2 Final Goods

Let $I_{\ell,t}$ denote total income in location ℓ, given by the sum of wage income, tax rebates, and capital income:

$$I_{\ell,t} = \sum_{j \in J \cup F} (w_{\ell,j,t} + b_t) L_{\ell,j,t} + b_t L_{\ell,u,t} + \sum_{j \in J \cup F} r_{\ell,j,t} K_{\ell,j,t} + \Pi^R_{\ell,t} + \Pi^F_{\ell,t},$$

where $r_{\ell,j,t}$ is the rental price of capital in location ℓ, sector j, at time t, $L_{\ell,u,t}$ is the number of unemployed workers in region ℓ at time t, and $\Pi^R_{\ell,t}$ and $\Pi^F_{\ell,t}$ are profits from renewable and fossil energy producers, respectively.

Let $P_{\ell,t}$ be the price of the final good in location ℓ, which is given by:

$$P_{\ell,t} = \prod_{j \in J \cup E \cup F} \left(\frac{P_{\ell,j,t}}{\mu_j} \right)^{\mu_j},$$

where $P_{\ell,j,t}$ are location- and sector-specific prices. This implies the following demand for sector-specific composite goods:

$$P_{\ell,j,t} Q_{\ell,j,t} = \mu_j I_{\ell,t}.$$

2.4.3 Intermediate Goods

Intermediate goods in sectors $j \in J$ (excluding fuel) are subject to iceberg trade costs $\tau_{\ell,\ell',j} \geq 1$ when shipped from location ℓ to location ℓ', with $\tau_{\ell,\ell,j} = 1$ for all ℓ and $j \in J$. Markets are otherwise competitive, so the after-tax price of an intermediate good j produced in location ℓ equals its marginal cost:

$$(1 - \chi_{j,t}) p_{\ell,j,t} = \frac{1}{z_{\ell,j}} \times \left(\beta^E_j p_{E,t}^{1-\sigma_j} + (1 - \beta^E_j) c_{KL,\ell,j,t}^{1-\sigma_j} \right)^{\frac{1}{1-\sigma_j}},$$

where

$$c_{KL,\ell,j,t}(w_{\ell,j,t}, r_{\ell,j,t}) = \left(\frac{w_{\ell,j,t}}{\beta^L_j} \right)^{\beta^L_j} \left(\frac{r_{\ell,j,t}}{1 - \beta^L_j} \right)^{1-\beta^L_j},$$

and $\chi_{j,t}$ is the tax rate on sector j output.

The price of an intermediate good j produced in location ℓ and sold in location ℓ' is given by:

$$p_{\ell,\ell',j,t} = p_{\ell,j,t} \tau_{\ell,\ell',j}.$$

Given the Armington structure and assumptions on pricing, the price of the composite

good $j \in J$ in location $\ell \in \mathcal{L}$ is given by:

$$P_{\ell,j,t} = \left(\sum_{k \in \mathcal{L}} \left(p_{k,j,t} \tau_{k,\ell,j} \right)^{1-\rho_j} \right)^{\frac{1}{1-\rho_j}} .$$

Demand for intermediate goods sourced from location ℓ' to location ℓ is then:

$$q_{\ell',\ell,j,t} = \frac{\mu_j I_{\ell,t}}{P_{\ell,j,t}^{1-\rho_j}} \left(p_{\ell',j,t} \tau_{\ell',\ell,j} \right)^{-\rho_j} . \tag{12}$$

The unit cost function in sector j is given by:

$$c_j(w_{\ell,j,t}, r_{\ell,j,t}, p_{E,t}) = \frac{1}{z_{\ell,j,t}} \left(\beta_j^E p_{E,t}^{1-\sigma_j} + (1-\beta_j^E) \, c_{KL,j}(w_{\ell,j,t}, r_{\ell,j,t})^{1-\sigma_j} \right)^{\frac{1}{1-\sigma_j}} .$$

From this, one can compute the factor demand functions for all $\ell \in \mathcal{L}$ and for all $j \in J$:

$$L_{\ell,j,t}^D = y_{\ell,j,t} \times \frac{(1-\beta_j^E) \, c_{KL,j}(w_{\ell,j,t}, r_{\ell,j,t})^{1-\sigma_j}}{c_j(w_{\ell,j,t}, r_{\ell,j,t}, p_{E,t})^{-\sigma_j}} \times \frac{\beta_j^L}{w_{\ell,j,t}}, \tag{13}$$

$$K_{\ell,j,t}^D = y_{\ell,j,t} \times \frac{(1-\beta_j^E) \, c_{KL,j}(w_{\ell,j,t}, r_{\ell,j,t})^{1-\sigma_j}}{c_j(w_{\ell,j,t}, r_{\ell,j,t}, p_{E,t})^{-\sigma_j}} \times \frac{1-\beta_j^L}{r_{\ell,j,t}}, \tag{14}$$

$$E_{\ell,j,t}^D = y_{\ell,j,t} \times \beta_j^E \frac{p_{E,t}^{-\sigma_j}}{c_j(w_{\ell,j,t}, r_{\ell,j,t}, p_{E,t})^{-\sigma_j}}. \tag{15}$$

2.4.4 Fuel

As previously noted, fuel is homogeneous and costlessly traded, so its price is constant across locations:

$$p_{\ell F,t} \equiv p_{F,t} \quad \forall \ell.$$

The market for fuels is perfectly competitive, implying that for all ℓ:

$$(1-\chi_{F,t}) p_{F,t} = \frac{1}{z_{\ell,F}} \left(\beta_F^E \, p_{E,t}^{1-\sigma_F} + (1-\beta_F^E) c_{KL} \left(w_{\ell,F,t}, r_{\ell,F,t} \right)^{1-\sigma_F} \right)^{\frac{1}{1-\sigma_F}} ,$$

where $\chi_{F,t}$ is the output tax on fuel. Zero profits in fuel production pin down $r_{\ell,F,t}$ as a function of $p_{F,t}$, $p_{E,t}$ and wages $w_{\ell,F,t}$:

$$r_{\ell,F,t} = \left[\frac{\left(\beta_F^L\right)^{\beta_F^L} \left(1-\beta_F^L\right)^{1-\beta_F^L}}{w_{\ell,F,t}^{\beta_F^L}} \left(\frac{\left((1-\chi_F)\, p_{F,t} z_{\ell,F}\right)^{1-\sigma_F} - \beta_F^E\, p_E^{1-\sigma_F}}{1-\beta_F^E} \right)^{\frac{1}{1-\sigma_F}} \right]^{\frac{1}{1-\beta_F^L}} \tag{16}$$

Leading to labor demand in fuel in location $\ell \in \mathcal{L}$ given by $L_{\ell,F,t}^D$:

$$L_{\ell,F,t}^D = \frac{\beta_F^L}{1-\beta_F^L} \left(\frac{r_{\ell,F,t}}{w_{\ell,F},t} \right) \times K_{\ell,F}, \tag{17}$$

where $K_{\ell,F}$ is the (fixed) stock of fuel-specific capital in location ℓ. The demand for electricity (in production) is then obtained as:

$$E_{\ell,F,t}^D = \frac{\beta_F^E}{1-\beta_F^E} \left(\frac{\beta_F^L}{1-\beta_F^L} \right)^{\beta^L} \left(\frac{c_{F,KL}\left(w_{\ell,F,t}, r_{\ell,F,t}\right)}{p_{E,t}} \right)^{\sigma_F} \left(\frac{r_{\ell,F,t}}{w_{\ell,F,t}} \right)^{\beta_F^L} K_{\ell,F}^S, \tag{18}$$

where $c_{F,KL}$ is the unit cost of the labor-capital bundle:

$$c_{F,KL}\left(w_{\ell,F}, r_{\ell,F}\right) = \left(\frac{w_{\ell,F}}{\beta_F^L} \right)^{\beta_F^L} \left(\frac{r_{\ell,F}}{1-\beta_F^L} \right)^{1-\beta_F^L} \tag{19}$$

Finally, aggregate demand for fuel across all locations is given by:

$$\sum_{\ell} \left(\frac{\mu_F I_{\ell,t}}{p_{F,t}} + F_{\ell,t}^D \right),$$

where $F_{\ell,t}^D$ denotes the quantity of fuel used in electricity generation in location ℓ given by equation (6).

2.5 Taxes and Rebates

In our baseline, we always assume that taxes are rebated lump-sum to consumers:

$$b_t = \frac{\sum_{\ell \in \mathcal{L}} \sum_{j \in J \cup F} \chi_j p_{\ell,j,t} y_{\ell,j,t}}{\sum_{\ell \in \mathcal{L}} \sum_{j \in J \cup F \cup u} L_{\ell,j,t}^S}. \tag{20}$$

2.6 Equilibrium

A steady-state equilibrium in this economy is a set of wages $\{w_{\ell,j}\}_{\ell \in \mathcal{L},\, j \in J \cup F}$; rental rates $\{r_{\ell,j}\}_{\ell \in \mathcal{L},\, j \in J \cup F}$; prices $\{p_{\ell,j}\}_{\ell \in \mathcal{L},\, j \in J}$, p_F, and p_E; labor allocations $\{L_{\ell,j}\}_{\ell \in \mathcal{L},\, j \in J \cup F}$; capital

allocations $\{K_{\ell,j}\}_{\ell\in\mathcal{L},\, j\in J\cup F}$; production and shipments $\{q_{\ell',\ell,j}\}_{\ell,\ell'\in\mathcal{L},\, j\in J}$, $\{y_{\ell,F}\}_{\ell\in\mathcal{L}}$, $\{y_\ell^{E,R}\}_{\ell\in\mathcal{L}}$, and $\{y_\ell^{E,F}\}_{\ell\in\mathcal{L}}$; and a transfer b such that:

1. Given wages, prices, and transfers, workers solve the Bellman equation (8), which implies transition rates given by equation (9).

2. Labor supply $\left\{L_{k,n}^S\right\}$ across locations k and sectors n is constant and satisfies:

$$L_{k,n}^S = \sum_{\ell\in\mathcal{L}} \sum_{j\in J\cup F\cup u} m_{\ell,j,k,n}\, L_{\ell,j}^S.$$

3. The supply of capital $\left\{K_{\ell,j}^S\right\}$ across locations ℓ and sectors j is constant.

4. Aggregate income in region $\ell \in \mathcal{L}$ is given by:

$$I_\ell = \sum_{j\in J\cup F} (w_{\ell,j} + b)L_{\ell,j} + bL_{\ell,u} + \sum_{j\in J\cup F} r_{\ell,j}K_{\ell,j} + \Pi_\ell^R + \Pi_\ell^F,$$

   where the tax rebate b is given by:

$$b = \frac{\sum_{\ell\in\mathcal{L}} \sum_{j\in J\cup F} \chi_j p_{\ell,j} y_{\ell,j}}{\sum_{\ell\in\mathcal{L}} \sum_{j\in J\cup F\cup u} L_{\ell,j}^S}.$$

5. Shipments $\{q_{\ell',\ell,j}\}$ and factor demands $L_{\ell,j}^D$, $K_{\ell,j}^D$, and $E_{\ell,j}^D$ solve equations (12), (13), (14), and (15), respectively.

6. Labor and electricity demands in fuel solve equations (16), (17), (18), and (19).

7. Electricity production $\left\{y_\ell^E\right\}$ is such that marginal costs equal electricity prices, as in equation (11).

8. Markets clear:

   - **Labor markets** clear at the (ℓ, j) level (for all ℓ and $j \in J \cup F$):

$$L_{\ell,j}^D = L_{\ell,j}^S$$

   - **Capital markets** clear at the (ℓ, j) level (for all ℓ and $j \in J \cup F$):

$$K_{\ell,j}^D = K_{\ell,j}^S$$

- **National electricity market** clears:

$$\sum_{\ell \in \mathcal{L}} \sum_{j \in J \cup F} E^D_{\ell,j} + \frac{\mu_E \sum_\ell I_\ell}{p_E} = \sum_{\ell \in \mathcal{L}} y^E_\ell$$

- **National fuel market** clears:

$$\sum_{\ell \in \mathcal{L}} \left(\frac{\mu_F I_\ell}{p_F} + F^D_\ell \right) = \sum_{\ell \in \mathcal{L}} y_{\ell,F}$$

- **Goods markets** clear for all $\ell \in \mathcal{L}$ and all $j \in J$:

$$\sum_{\ell' \in \mathcal{L}} q_{\ell,\ell',j}\, \tau_{\ell,\ell',j} = y_{\ell,j}$$

3 Data

Locations and Sectors

We use the 50 U.S. states as our geographic units, merging the District of Columbia with Maryland. Sectors are defined according to the 2022 North American Industry Classification System (NAICS); a complete list is provided in Table 1. The reference year is 2017, and whenever possible, we use five-year averages—pooling data from 2015 to 2019—to improve precision.

Production, Final Expenditure Shares and Trade

State- and sector-specific value added comes from the Bureau of Economic Analysis (BEA) National Accounts.

Producer sector-specific energy and labor expenditures come from the BEA Use Table. We use these data to calibrate the energy (β^E_j) and labor (β^L_j) cost shares in the production functions. For the final-good production function, we rely on value-added shares for non-energy sectors (μ_j for $j \in J \cup F$) and on household expenditure on the energy sector (μ_E), expressed as a share of total value added. These variables are also taken from the 2017 BEA Use Table.

Sector-specific trade flows across states come from the Commodity Flow Survey (CFS). We use these data to infer trade costs $\tau_{\ell,k,j}$ for $\ell, k \in \mathcal{L}$ and $j \in J$. The CFS is released

Sector	NAICS 2022	NAICS Description
1	211, 324	Oil and gas extraction, Petroleum and Coal Products Manufacturing
2	11	Crop Production, Animal Production, Aquaculture, Forestry, Fishing
3	212–213	Mining
4	23	Construction
5	311–312	Food, Beverage, and Tobacco Product Manufacturing
6	313–316	Textile mills, apparel, leather, allied products
7	321	Wood product manufacturing
8	322	Paper manufacturing
9	323	Printing and related support activities
10	325	Chemical manufacturing
11	326	Plastics and rubber products manufacturing
12	327	Nonmetallic mineral product manufacturing
13	331	Primary metal manufacturing
14	332	Fabricated metal product manufacturing
15	333	Machinery manufacturing
16	334	Computer and electronic product manufacturing
17	335	Electrical equipment, appliance, and component manufacturing
18	336	Motor vehicles, bodies and trailers, and parts manufacturing
19	337	Furniture and related product manufacturing
20	339	Miscellaneous manufacturing
21	42	Wholesale trade
22	44–45	Retail trade
23	48–49	Transportation and warehousing
24	51	Information
25	52	Finance and insurance
26	53	Real estate and rental and leasing
27	54–55	Professional, Scientific, and Technical Services, Management of companies
28	56	Administrative and support and waste management and remediation services
29	61	Educational services
30	62	Health care and social assistance
31	71	Arts, entertainment, and recreation
32	72	Accommodation and food services
33	81	Other services (except government and government enterprises)

Table 1: Sectors definition by 2022 North American Industry Classification System (NAICS)

every five years; to increase precision, we average data from the 2012 and 2017 waves and treat the resulting values as 2017 levels.

Energy Production

Renewable and fossil capacities and energy generation come from the Energy Information Administration (EIA). Renewable sources include solar, wind, geothermal, hydroelectric, and nuclear; non-renewables include coal, natural gas, petroleum, and biomass. Nameplate capacities by energy type and location, which map directly into K_ℓ^R and K_ℓ^F, are taken from Form EIA-860. Net generation by energy type and location, which maps into $y_\ell^{E,R}$ and $y_\ell^{E,F}$, comes from EIA-923. All variables are collected for the year 2017.

Labor Market Data

We use the American Community Survey (ACS) to construct data on labor allocations across states and sectors. Our sample includes individuals aged 20–60, excluding students, Social Security recipients, armed-forces personnel, and individuals who resided abroad in the previous year. All ACS variables are averaged over 2015–2019 to improve precision.

We also use the ACS to obtain worker flows from origin states to state-sector destinations. To complement these flows, we incorporate sector-to-sector transitions from the Current Population Survey (CPS), applying the same sample restrictions and computing analogous 2015-2019 averages. Combining these two sources, we impute the full matrix of transitions across all state-sector pairs, as described in our calibration section. These flows discipline the labor-supply parameters, including mobility costs and sector-specific amenities.

4 Calibration

Our calibration imposes a series of parameter values that are standard in the literature. The elasticity of subsitution in production σ_j is set to 1 (in which case the production functions take a Cobb Douglas form) or σ_j is set to 0 (in which case the production functions take a Leontief form). The Armington elasticity ρ_j is imposed to be equal to 5, a value standard in the international trade literature. In our baseline calibration, we set output taxes χ_j to 0. We follow Arkolakis and Walsh (2023) and set the expenditure share on fuel in energy production α to 0.7. The intertemporal discount factor is set to the standard value of 0.95. These parameters are displayed in Table 2.

Table 2: Parameters Calibrated Externally

Parameter	Description	Value	Source
σ_j	Elasticity of substitution in production	0 or 1	–
ρ_j	Armington elasticity	5	Standard
χ_j	Output taxes	0	–
α	Expenditure share on fuel in electricity production	0.7	Arkolakis and Walsh (2023)
β	Intertemporal discount factor	0.95	Standard

We calibrate the following set of parameters internally:

a) Production function coefficients and capital stocks: $\left\{\beta_j^L\right\}_{j\in J}$, $\left\{\beta_j^E\right\}_{j\in J}$, and $\left\{K_{\ell,j}^S\right\}_{\ell\in\mathcal{L},j\in J}$.

b) Productivities: $\{z_{\ell,j}\}_{\ell\in\mathcal{L},j\in J}$.

c) Fuel-based energy productivities: $\{z_{\ell,E}\}_{\ell\in\mathcal{L}}$.

d) Renewable Capital Productivities: $\left\{\theta_\ell^R\right\}_{\ell\in\mathcal{L}}$.

e) Final goods coefficients: $\{\mu_j\}_{j\in J\cup E}$.

f) Trade costs: $\{\tau_{\ell,k,j}\}_{\ell,k\in\mathcal{L},j\in J}$.

g) Labor Supply parameters: ν, $\{C_{\ell,j,n,k}\}_{\ell,n\in\mathcal{L},j,k\in J\cup u}$ and $\{\eta_{\ell,j}\}_{\ell\in\mathcal{L},j\in J\cup u}$.

In the remainder of this section we go briefly go through each set of parameters, with more details provided in Appendix A. For internal calibration we assume that the economy is initially in steady state

a) Production Function Coefficients and Capital Stocks

Production function coefficients are calibrated in the standard way using labor shares. However, there are discrepancies between the ACS and the BEA, and we make an assumption about wages in order to ensure that value-added in the BEA is aligned with labor stocks in the ACS. Details are Appendix A, but we essentially estimate labor output elasticities, β_j^L, using labor shares in the BEA, and then set wages to rationalize location-sector measures of

value-added, as well as location-sector employment. Given the labor share, the capital stock is defined as the difference between value added and the wage bill.[2]

Our recovery of energy prices and production-parameters is less standard, so we describe this in more detail. In the data, electricity prices can vary across space, and by end-use. In the current version of the model, there is one national price of electricity. We calculate this national price using aggregate data on electricity generation and electricity sales:

$$p_E = \frac{X_{HH}^{E,BEA} + \sum_{j \in J \cup F} X_j^{E,BEA}}{\sum_\ell \left(y_\ell^{E,R} + y_\ell^{E,F} \right)},$$

where $X_{HH}^{E,BEA}$ is household expenditure on energy and $X_j^{E,BEA}$ is the aggregate expenditure of sector j on energy, both from the BEA.

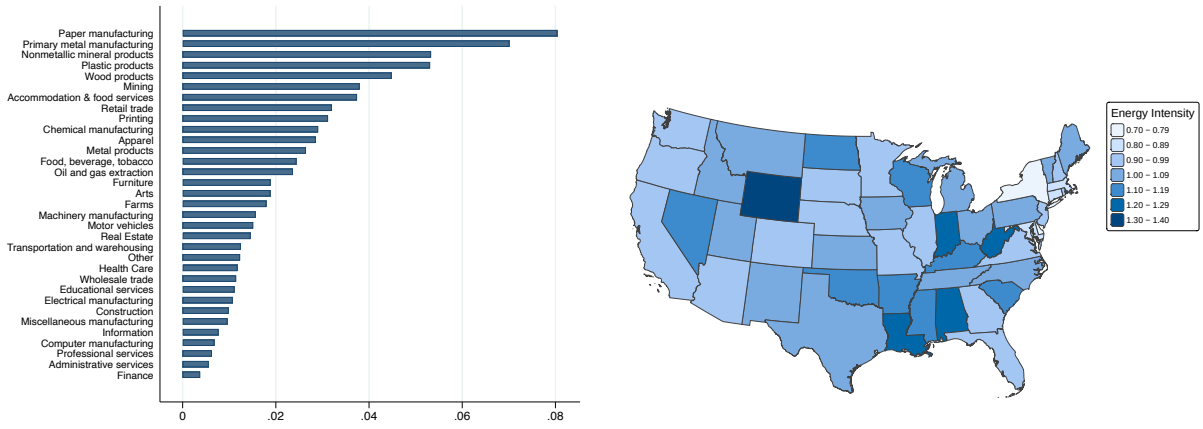
We can also recover production coefficients under both the Cobb-Douglas ($\sigma_j = 1$) and Leontief ($\sigma_j = 0$) assumptions:

$$\beta_j^E = \frac{X_j^{E,BEA}}{\sum_\ell VA_{\ell,j}^{BEA} + X_j^{E,BEA}} \qquad \text{(Cobb-Douglas)}$$

$$\beta_j^E = \frac{X_j^{E,BEA}/p_E}{X_j^{E,BEA}/p_E + \sum_\ell L_{\ell,j}^{\beta_j^L} \left(K_{\ell,j}^S \right)^{1-\beta_j^L}} \qquad \text{(Leontief)}$$

To visualize the extent of variation in electricity use across sectors, Figure 1a displays the expenditure shares β_j^E across all sector $j \in J$, and Figure 1b displays state-specific averages of β_j^E, weighted by value added. To understand better the variation across space, Appendix Table 3 displays the states that are the least and the most reliant on electricity, as well as their major industries.

[2]We thus assume that rental rates are identically one in each sector and location. We allow for the rental rate to endogenously respond in all counterfactuals.



(a) Across Industries (b) Across States

Figure 1: Expenditure shares on electricity by sector and across states.

Notes: Panel (a) reports industry-level expenditure shares on electricity, β_j^E. Panel (b) reports the value-added-weighted expenditure shares across industries for each state, $\sum_j VA_{j,\ell}/VA_\ell \times \beta_j^E$.

b) Productivities

Denote the unit cost of production in location ℓ and sector j as $\overline{c}_{\ell,j}/z_{\ell,j}$. We obtain productivities, $\{z_{\ell,j}\}$ by using fixed point iteration to solve the following system:

$$\sum_{k\in\mathcal{L}} p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = \mu_j \sum_{k\in\mathcal{L}} I_k \frac{\left(\frac{\overline{c}_{\ell,j}}{z_{\ell,j}}\tau_{\ell,k,j}\right)^{1-\rho_j}}{\sum_i \left(\frac{\overline{c}_{i,j}}{z_{i,j}}\tau_{i,k,j}\right)^{1-\rho_j}},$$

Where Income I_k in the right hand side is imposed to be consistent with the rest of the model. The left hand side is the value added in location $\ell \in \mathcal{L}$ and sector $j \in J$ and is treated as data.

c) Fuel-Based Energy Productivities

Given data on fuel-based energy production $y_\ell^{E,F}$, fuel-based capital K_ℓ^F and the energy price p_E, we can recover fuel-based energy productivity using:

$$z_{\ell,E} = \frac{\left(y_\ell^{E,F}\right)^\alpha}{\left(K_\ell^F\right)^\alpha \left((1-\alpha)\frac{p_E}{p_F}\right)^{1-\alpha}}.$$

d) Renewable Capital Productivity

The productivity of renewable capital is obtained using $\theta_\ell^R = \frac{y_\ell^{E,R}}{K_\ell^R}$, where $y_\ell^{E,R}$ and K_ℓ^R are observed data.

e) Final Goods Aggregation

The Cobb-Douglas coefficients μ_F, μ_E and μ_j are recovered using:

$$\begin{aligned}\mu_F =& \frac{\sum_\ell VA_{\ell,F}^{BEA} + X_F^{E,BEA} - p_F \sum_\ell F_\ell^D}{\sum_\ell I_\ell} \\ \mu_j =& \frac{\sum_\ell VA_{\ell,j}^{BEA} + X_j^{E,BEA}}{\sum_\ell I_\ell}, \; j \in J \\ \mu_E =& \frac{X_{HH}^{E,BEA}}{\sum_\ell I_\ell}\end{aligned}$$

Where $VA_{\ell,j}^{BEA}$, $X_j^{E,BEA}$ and $X_{HH}^{E,BEA}$ are observed data and I_ℓ and F_ℓ^D are computed within the model. Fuel is set to be the numeraire such that $p_F = 1$.

f) Trade Costs

We use the Commodity Flow Survey (CFS) and the Head and Ries (2001) formula to obtain trade costs across all pairs of locations. Under symmetric trade costs, and with knowledge of the trade elasticity, ρ_j, trade costs can be calculated from observed flows as:

$$\tau_{\ell,k,j} = \left(\frac{X_{k,\ell,j}}{X_{k,k,j}} \frac{X_{\ell,k,j}}{X_{\ell,\ell,j}} \right)^{\frac{1}{2\left(1-\rho_j\right)}},$$

where $X_{\ell,k,j}$ are total trade flows in sector j from location ℓ to location k. If $X_{\ell,k,j}$ or $X_{k,\ell,j} = 0$, we impose $\tau_{\ell,k,j} = +\infty$. Moreover, we assume that fuel is traded freely, with $\tau_{\ell,k,F} = 1$ for all ℓ and k.

A number of sectors are not surveyed by the CFS, especially in tradeable services. In order to impute these costs we first project the costs that we *do* observe onto a location fixed effects and a distance term:

$$\log\left(\tau_{\ell,k,j}\right) = \zeta_j \log\left(distance_{\ell,k}\right) + \phi_\ell + \psi_k + \varepsilon_{\ell,k,j}.$$

To guarantee symmetry, we impose $\phi_\ell = \psi_\ell$ for all ℓ in the above specification. We then

impute trade costs using the formula:

$$\log(\tau_{\ell,k,j}) = \zeta \log(distance_{\ell,k}) + \widehat{\phi}_\ell + \widehat{\phi}_k.$$

In estimation, we allow for sector-specific distance elasticities.[3] In our fit, we set $\zeta = -1.6 \times (1-\rho)$, and follow Eckert (2019), who estimated the distance elasticity for service sectors.

g) Labor Supply Parameters

Worker Flows

Before describing how we calibrate the labor supply parameters, we need to discuss how we obtain worker flows across regions and sectors. Unfortunately, there is no publicly available data on the full matrix of worker flows across region and industry pairs. However, we combine data from the ACS and the CPS to impute such flows in a way that guarantees that the economy is initially in steady state—an assumption we impose in our calibration procedure. Appendix A.2 contains a complete description of the algorithm we employ. It bears a resemblance to *raking* in the statistics literature.

Migration Elasticity

We follow Artuç and McLaren (2015) who estimate ν as a semi-elasticity of worker flows with respect to wage differentials. We correct this estimate to account for differences in the granularity of choices workers face as well as differences in baseline wages.

Mobility Costs and Sector-Specific Utilities

Impose $C_{\ell,j,\ell,j} = 0$ (no cost of not moving) for all $\ell \in \mathcal{L}$ and $j \in J \cup F$, $C_{\ell,j,\ell,u} = 0$ (no cost of moving locally to unemployment) and $\eta_{\ell,u} = 0$ (unemployment gives zero utility) for all regions ℓ. We obtain for all ℓ, j:

If $m_{\ell,j,\ell,j} > 0$ and $L^{ACS}_{\ell,j} > 0$:

$$\eta_{\ell,j} = -\frac{\nu}{\beta}\log\left(\frac{m_{\ell,j,\ell,u}}{m_{\ell,j,\ell,j}}\right) - \nu\log\left(\frac{m_{\ell,u,\ell,u}}{m_{\ell,j,\ell,u}}\right) - \left(\frac{w_{\ell,j}+b}{P_\ell}\right)$$

[3] We are agnostic on the source of this variation, as we simply need a good fit to the data on observed costs. One interpretation of the sector-specific elasticity, is that there is a single distance elasticity *in weight*, and so the sector-specific component captures an average weight-to-value ratio.

If $m_{\ell,j,\ell,j} = 0$ or $L_{\ell,j}^{ACS} = 0$:

$$\eta_{\ell,j} = -\infty.$$

We can then recover mobility costs using:

If $m_{\ell,j,\ell,j} > 0$, $L_{\ell,j}^{ACS} > 0$ and $m_{\ell,j,k,n} > 0$:

$$C_{\ell,j,k,n} = -\frac{\nu}{1-\beta}\log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right) - \frac{\nu\beta}{(1-\beta)}\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right) + \frac{\beta}{1-\beta}\left(\frac{w_{k,n}+b}{P_k} - \frac{w_{\ell,j}+b}{P_\ell}\right) + \frac{\beta}{1-\beta}\left(\eta_{k,n} - \eta_{\ell,j}\right),$$

else

$$C_{\ell,j,k,n} = +\infty.$$

5 Results and Counterfactuals

5.1 Carbon Tax

In our first counterfactual exercise, we simulate the impacts of a once-and-for-all 20% tax on fossil-fuel sales.[4] The tax is rebated to workers in a lump sum fashion according to equation (20).[5] In discussing results we focus on three dimensions: (1) aggregate outcomes, such as real output and employment; (2) the degree of spatial reallocation, and resulting distributional differences across regions; (3) how different factors of production are affected by the fuel tax.

First, we look at the direct impact of the carbon tax on fuel consumption. The full dynamic path of fuel output is plotted below in Figure 2. The effect of the carbon tax is a sharp decline in fuel output. The overall reduction in fuel consumption is 2.5%, and about

[4]We purposefully chose a modest tax on fuels to show that even a small carbon tax can have non-trivial implications for allocations across space. At reasonable estimates for the social cost of carbon (SCC), the optimal tax may be substantially higher. For example, carbon emissions from oil are approximately .4 tonnes per barrel. At the cost of 60 dollars per barrel and an estimate of the SCC at 100 dollars, the optimal tax is closer to 67%(= $.4 \times 50/60$). 20% is commensurate with a substantially more mild SCC of 30 dollars. It is also in line with carbon taxes that have been applied. For example, Metcalf & Stock (2023) study a carbon tax of 40 dollars per tonne in the EU. At our conversion factors, this is approximately a 27% fuel tax (30% in their estimate).

[5]This redistribution scheme implicitly induces transfers across space, and in continuing work we are exploring different assumptions on how taxes are rebated.

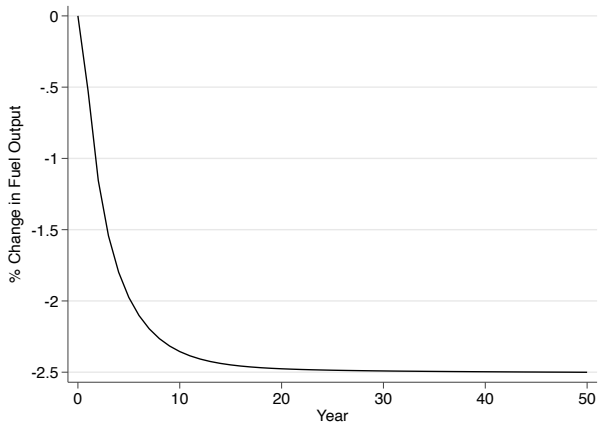
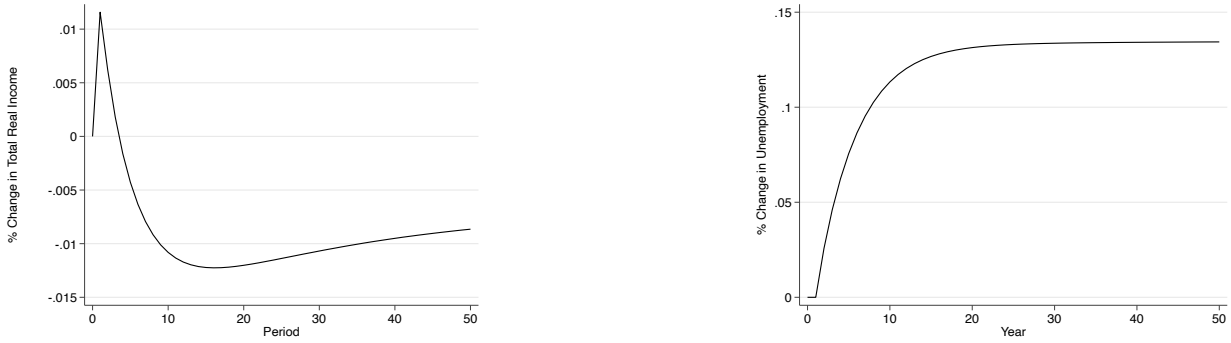


Figure 2: Change in Fuel Output

90% of this reduction is reached after 10 periods. While there is not a constant elasticity of fuel to the carbon tax in our model, we would calculate an elasticity of aggregate fuel consumption to a fuel tax of .125. In the EU, Metcalf & Stock (2023) find that a 40 dollar per ton carbon tax—an approximately 26% tax on fuels—lowered emissions 4 to 6%, translating to an elasticity of around .2. We think it is comforting that our model's aggregate predictions for fuel output are in line with direct evidence.



(a) % Changes in Real Income

(b) Unemployment

Figure 3: % Changes in Aggregates

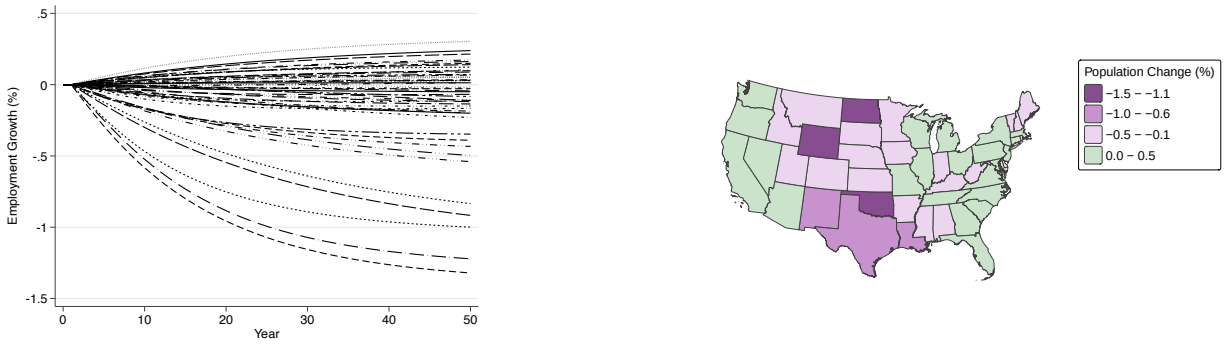
In order to analyze aggregate outcomes we focus on two measures: unemployment, as well as aggregate real output, which we define as:

$$\bar{Y}_t = \sum_{\ell} \frac{I_{\ell,t}}{P_{\ell,t}}.$$

These aggregate impacts are plotted in Figure 3. In both figures (and all figures henceforth)

we plot 100 times the log deviation from the initial steady state.

The aggregate change in real output is larger in the short run than the long run, consistent with a slow reallocation of resources.[6] However, in magnitudes this change is minuscule—less than 1 hundredth of a percent. This is in line with electricity being a small component of aggregate expenditure, and fuel only a fraction of total electricity costs. The effect on unemployment is similarly modest—raising the overall level of unemployment by around .125% in the long run.



(a) Transition Dynamics

(b) Steady State Changes

Figure 4: % Changes in Population

Nevertheless, the trivial aggregate impacts of the carbon tax obscure large disparities in the incidence of the shock. Figure plots changes in population across space and over time, while 4b maps the long-run changes. The responsiveness of relative population is orders of magnitude larger than the effect on either real output or aggregate unemployment. It is also a protracted process, requiring some 40 periods to converge to steady state. The largest declines are driven by a handful of states with large employment in the fuel sector. For example, Alaska, Oklahoma and North Dakota all lose over 1% of their population, and there is generally a small population decline in the midwest. On the other hand, the states that grow the most—Florida, New York, and California—do so by about .25%. It is worth noting that most of this reallocation is *not* due to changes in electricity costs, but rather

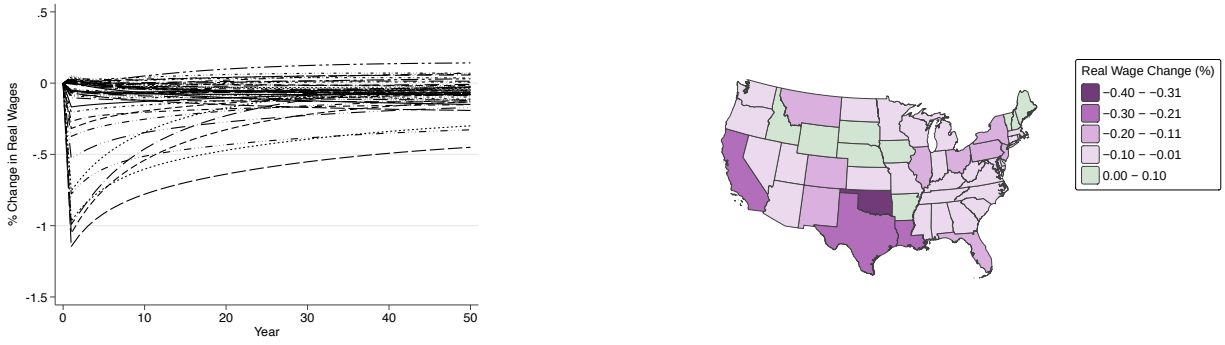
[6]The short lived burst is due to changing composition in incomes, as the tax rebate shifts consumption across space. Concretely, it turns out to be the case (but does not have to be) that there is a negative correlation between cost of living, P_ℓ, and the size of the fuel sector across states. Hence, when carbon taxes are rebated lump sum, there is a transfer from high-cost fuel-intensive states to low-cost states. Mathematically,

$$\frac{I_1 - b}{P_1} + \frac{I_2 + b}{P_2},$$

can increase in b, even if I_1 and I_2 decline.

the direct impact on the fuel sector—which shrinks by 11%—and the resulting depression in local demand that this causes.

These long-run population changes are related to long-run changes in real earnings across space. Figure 5 plots changes in real earnings across space. As in the previous figure, panel (a) plots transitions, while panel (b) is a map of long-run changes. The decline in real earnings is larger and more dispersed on impact, and slowly differences are arbitraged away (but not completely) as workers reallocate. While real earnings decline in nearly all states, the decline is pronounced in the same states that saw the largest outflows of workers. That is to say, the states with the largest fossil fuels industries.



(a) Transition Dynamics

(b) Steady State Changes

Figure 5: % Changes in Real Earnings

In understanding the distributional consequences across space, it is important to understand that transfers accrue specifically to workers, rather than to capital or profit income. If one takes account of transfers across space, nearly *all* states see increases in labor income. Indeed, if one looks at the change in value functions after the shock, 99.5% of workers see an increase in welfare. To gauge the redistributive role of the carbon tax, Figure 6 plots a map of transfers across space as a fraction of labor income in the initial steady state, $b/\sum_s w_{s\ell 0} L_{s\ell 0}$. The largest transferring states are the states producing the most fossil fuels. Meanwhile most other states receive transfer payments, otherwise softening the loss in real earnings in those states. Transfers across space are quite large. They are on the order of .5% of initial income, which is the same order of magnitude as changes in real earnings.

Finally, we move away from the distributional consequences across workers and to the distributional consequences across factors. Figure 7a plots the spatial distribution of long-run changes in real capital income (not including the returns to owners of energy capital), while 7b plots long-run changes in real profits accruing to the operators of electricity plants.

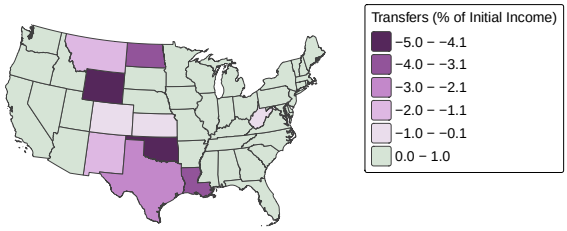
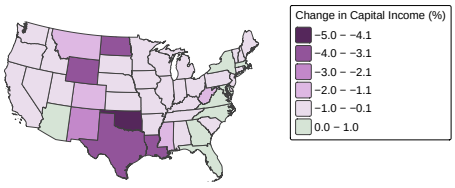
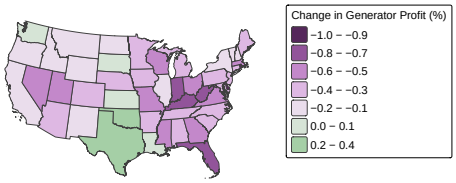


Figure 6: Transfers Across Space



(a) Change in Real Capital Income



(b) Change in Real Profits

Figure 7: Long-Run Changes in Real Factor Returns

In line with the intuition of the Ricardo-Viner model, capital income, which is a fixed and immobile factor, absorbs much more of the negative impact of the carbon tax than labor, the mobile factor. For example, in the most affected states, capital income declines by 10 times more than does labor earnings. In states that receive inflows of workers, there are more muted or even slightly positive changes, but on the whole real capital income declines .6%. Real profits of generators generally decline, but the response is small, with substantial heterogeneity across space.

In summarizing the impacts of a carbon tax in our setting, we highlight three major takeaways. First, the overall incidence of the shock is small, suggesting that a tax on fuels may effectively deter fuel use with minimal impacts on total output. Second, this effect on total output masks a great deal of heterogeneity across space, and across factors of production. Capital returns, especially, decline as a result of being immobile. Third and finally, how the tax is rebated can shape the distributional consequences, as we find that the implied post-tax transfer to workers ensures that welfare improves for all but half a percent of the population.

5.2 Capital Investment

In this subsection we consider an alternative situation whereby the stock of renewables capital increases by 25% uniformly across space.[7] First, to illustrate the geography of renewable energy, Figure 8 is a map of renewable generation capacity in each state.[8] The highest capacity for renewables generation is in larger states and the American south.

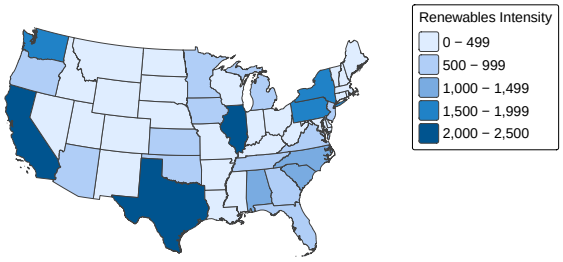


Figure 8: Renewables Generation

We repeat many of the same exercises as in the first counterfactual. The increase in

[7] In ongoing work we are working on endogenizing the investment decision into renewable energy.
[8] Our index is relative to the minimum value across states, so that Delaware is normalized to 1.

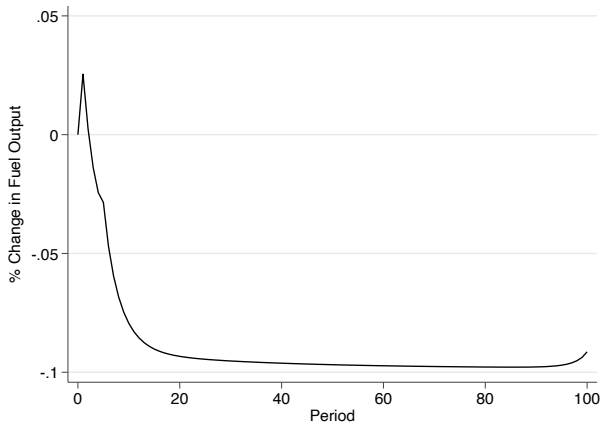
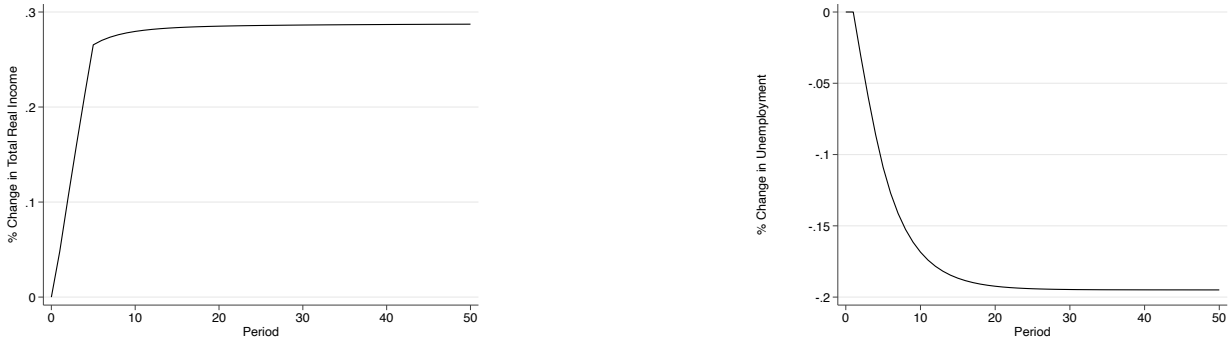


Figure 9: Change in Fuel Output

renewables energy has a *substantially* smaller impact on fuel use. While it is hard to compare the magnitudes of the shocks, we will see that other impacts are on a similar order of magnitude. Thus, what drives this more muted response is not that the shock is smaller in its effects on the economy, but rather it arises from an income effect. More capital increases incomes and consumption, raising total energy demand, heavily attenuating substitution towards renewables.



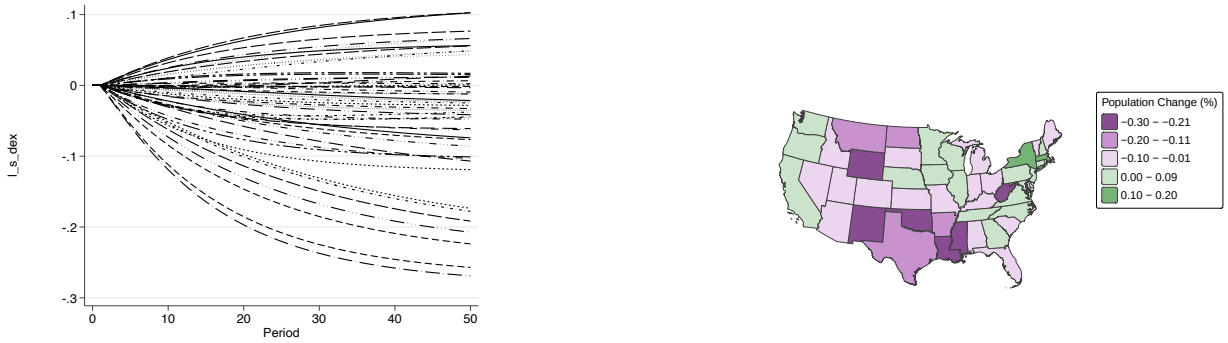
(a) % Changes in Real Income

(b) Unemployment

Figure 10: % Changes in Aggregates

Turning to aggregate impacts, Figure 10 plots real output and unemployment. Real output increases by .3% in the long run, and unemployment declines .2%. As hinted above, these are similar in magnitude to—indeed slightly larger than—the effects of the carbon tax.

Now turning to distributional consequences, Figure 11 plots changes in labor over time and across space. Reallocation is slow, but there is substantially less than in the case of the carbon tax. It is difficult to pinpoint the reason that larger aggregate consequences do



(a) Transition Dynamics

(b) Steady State Changes

Figure 11: % Changes in Population

not align with larger movements across space. However, in the model electricity is freely traded across space, so that more generation of electricity does not necessarily drive workers to move. What spatial reallocation is observed may be due to a Rybczynski effect, whereby more electricity favors electricity-intensive industries, which are not uniformly distributed across space. To investigate this possibility, Figure 12 plots the relationship between industry growth and electricity intensity. There is a weak but clearly positive relationship.

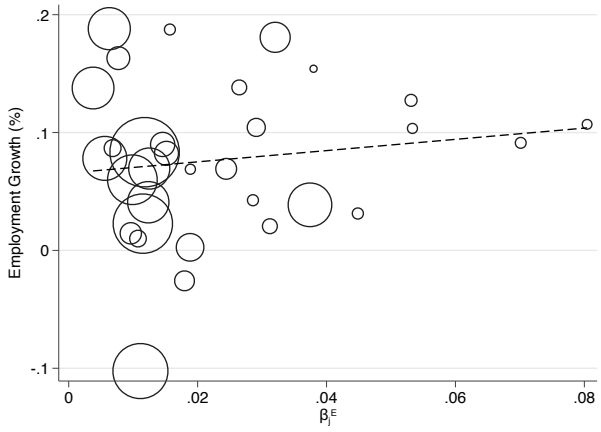
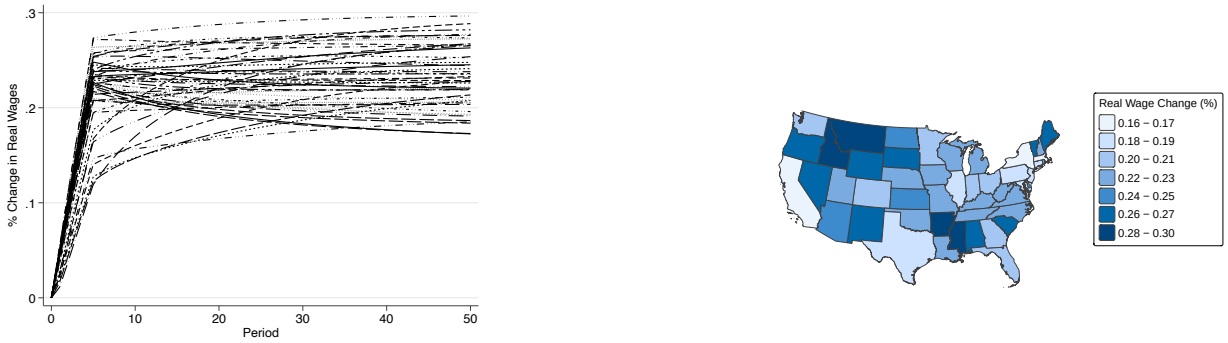


Figure 12: Relating Industry Growth and Energy Intensity

Turning to wages, Figure 13 plots real earnings over time and across space. As electricity prices decline, real wages also rise, leaving all workers better off.

In concluding, we highlight that increasing renewables generation leads to small positive aggregate impacts on the economy, with more limited reallocation than brought about by a carbon tax. However, through the lens of the model, more renewables capacity does not appear to be effective at lowering total fuel use, leading to a minimal impact on carbon.



(a) Transition Dynamics

(b) Steady State Changes

Figure 13: % Changes in Real Earnings

Essentially, the increase in income from more capital simply leads to an increase in demand for energy that nearly offsets the increase in capacity. That said, the current exercise is an exogenous once-and-for-all increase in renewables capital across space. In reality, capital accumulation is a dynamic process, and policies aimed at spurring investment (for example, diverting carbon tax revenue to clean energy investment subsidies) are likely to lead to differences in accumulation across space and over time. We are exploring such policies in ongoing work.

6 Next Steps and Timeline

The model we outlined above incorporates key features of the U.S. economy and its energy sector. Our calibration highlights sizable differences across sectors in their reliance on electricity, and our data work documents equally stark heterogeneity across states in how energy is generated—whether from renewables or fossil fuels. In addition, worker-flow data from the ACS and CPS allow us to discipline labor mobility frictions across regions and sectors.

Given these elements, the current framework is well suited to simulate the consequences of climate policies such as a carbon tax and to study the distributional impacts across regions and sectors, as examined in Section 5.1. Still, we believe that three extensions are needed to fully capture the salient channels of the decarbonization process.

First, we will endogenize the accumulation of region- and sector-specific physical capital by introducing forward-looking capitalists who choose consumption and investment. Capital evolves according to a standard law of motion with sector-specific depreciation rates, and new investment adds to the capital stock. We also impose capital irreversibility, which

can slow down the contraction of fossil-fuel-based electricity generation as well as fossil-fuel production.

This extension matters for two reasons. On the one hand, the mobility of capital interacts in non-trivial ways with worker mobility across regions and sectors (see, e.g., Dix-Carneiro, 2014; Dix-Carneiro and Kovak, 2017; Kleinman, Liu and Redding, 2023). On the other hand, incorporating capital dynamics allows us to analyze counterfactuals that are central to current policy debates, such as the effects of renewable-capital subsidies.

Second, we will incorporate worker demographics and allow them to affect the frictions workers face when switching regions and sectors. This extension is essential for providing a richer description of the distributional consequences of climate policies and lies at the core of their political repercussions. A central objective of the paper is to identify the winners and losers from climate policies and to understand which government interventions could help smooth their labor-market transitions.

Third, we will follow Arkolakis and Walsh (2023) in allowing for imperfect transmission of electricity across regions. This feature implies that different parts of the United States face different electricity prices. As a result, climate policies may affect electricity costs unevenly across space, further amplifying (or mitigating) the distributional consequences of decarbonization and leading to a more realistic assessment of policy impacts.

Finally, we will incorporate intersectoral linkages in production for two reasons. First, by modeling supply chains, we allow localized shocks to propagate beyond their initial region and sector. Second, these linkages can amplify the effects of shocks, as illustrated by Caliendo and Parro (2015).

Our timeline for completing the paper is as follows. We are currently implementing intersectoral linkages and the endogenous accumulation of capital and expect to have results from this expanded version within two to three months. We will then incorporate worker heterogeneity in wages and mobility costs, a step we believe can be completed by May or June. This leaves the final extension—imperfect transmission of electricity—to be added during the summer of 2026. With this schedule, we are confident that a full draft of the paper will be ready before the conference.

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A Calibration Details

A.1 Production Function and Productivity

In this subsection, we briefly describe the details of how we combine the ACS and the BEA to measure wages, labor stocks, and then estimate output elasticities. We also describe how we measure productivity, and present some additional facts about the distribution of electricity use across space.

Production function coefficients are calibrated making use of sector-specific wage bill and sector-region-specific value added (net of expenditures with energy) from the BEA ($WageBill_j^{BEA}$ and $VA_{\ell,j}^{BEA}$, respectively):

$$\beta_j^L = \frac{WageBill_j^{BEA}}{\sum_\ell VA_{\ell,j}^{BEA}}$$

Wages are then recovered using employment from the ACS:

$$w_{\ell,j} = \frac{\beta_j^L VA_{\ell,j}^{BEA}}{L_{\ell,j}^{ACS}}$$

Capital stocks are recovered by setting $r_{\ell,j} = 1$ in the initial steady state.

$$K_{\ell,j}^S = \left(1 - \beta_j^L\right) VA_{\ell,j}^{BEA}$$

To obtain productivities $z_{\ell,j}$, we first define:

$$c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right) = \left(\frac{w_{\ell,j}}{\beta_j^L}\right)^{\beta_j^L} \left(\frac{r_{\ell,j}}{1-\beta_j^L}\right)^{\left(1-\beta_j^L\right)}$$

and

$$\overline{c}_{\ell,j} = p_E^{\beta_j^E} c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right)^{1-\beta_j^E} \qquad \text{(Cobb-Douglas)}$$

$$\overline{c}_{\ell,j} = \beta_j^E p_E + \left(1-\beta_j^E\right) c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right) \qquad \text{(Leontief)}$$

Use fixed point iteration to find $\{z_{\ell,j}\}$ that solves the system below:

$$\sum_{k\in\mathcal{L}} p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = \mu_j \sum_{k\in\mathcal{L}} I_k \frac{\left(\frac{\bar{c}_{\ell,j}}{z_{\ell,j}}\tau_{\ell,k,j}\right)^{1-\rho_j}}{\sum_i \left(\frac{\bar{c}_{i,j}}{z_{i,j}}\tau_{i,k,j}\right)^{1-\rho_j}},$$

Where Income I_k in the right hand side is imposed to be consistent with the rest of the model. The left hand side is value added in location $\ell \in \mathcal{L}$ and sector $j \in J$ and is treated as data.

With Cobb-Douglas

$$\sum_{k\in\mathcal{L}} p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = \frac{VA^{BEA}_{\ell,j}}{1-\beta^E_j}$$

With Leontief

$$\sum_{k\in\mathcal{L}} p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = VA^{BEA}_{\ell,j}\left(1 + \frac{p_E}{c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right)}\frac{\beta^E_j}{1-\beta^E_j}\right)$$

Table 3 contains more information on which states are most and least energy intensive, and also the biggest industries in these states.

	States (β_ℓ^E)	Overrepresented sectors (β_j^E)
Least reliant on electricity	Delaware (0.012)	Finance (0.004) Real estate (0.015) Chemical manufacturing (0.031)
	New York (0.012)	Finance (0.004) Information (0.008) Educational services (0.011)
	Massachussets (0.013)	Computer manufacturing (0.007) Educational services (0.011) Professional services (0.006)
Most reliant on electricity	Wyoming (0.020)	Mining (0.038) Oil and gas extraction (0.024) Transportation and Warehousing (0.012)
	West Virginia (0.019)	Mining (0.038) Chemical manufacturing (0.031) Primary metal manufacturing (0.071)
	Indiana (0.018)	Primary metal manufacturing (0.071) Chemical manufacturing (0.031) Motor vehicles (0.015)

Table 3: States More and Less Reliant on Electricity

A.2 Worker Flows Imputation Procedure

We employ the following data:

- $f_{o,\ell n}^{ACS}$: 1-year flows from region o to region ℓ sector n from the ACS (simple averages between 2015 and 2019).
- $f_{p,n}^{CPS}$: 1-year flows from industry p to industry n from the CPS (simple averages between 2015 and 2019).

Let $t = -1$ denote the initial period and $t = 0$ denote the final period.

The ACS distribution of employment at $t = 0$ is obtained as

$$L_{\ell n}^{ACS,0} = \sum_{o} f_{o,\ell n}^{ACS}.$$

We take it as the "true" observed distribution of employment across regions and industries in 2017.

We wish to obtain a full *imputed* matrix of 1-year flows $\widehat{f}_{op,\ell n}$ with the following properties:

- Imputed flows imply the "true" observed distribution of employment at $t = 0$: $\sum_o \sum_p \widehat{f}_{op,\ell n} = L_{\ell n}^{ACS,0}$
- Imputed flows from region o to region ℓ and industry n, $\sum_p \widehat{f}_{op,\ell n}$, are "close" to $f_{o,\ell n}^{ACS}$ (which is data)
- Imputed flows from industry p to industry n, $\sum_o \sum_\ell \widehat{f}_{op,\ell n}$, are "close" to $f_{p,n}^{CPS}$ (which is data)
- Imputed flows imply steady state: the implied distribution of employment at $t = -1$ replicates the observed distribution of employment at $t = 0$. That is, $\sum_\ell \sum_n \widehat{f}_{op,\ell n} = \widehat{L}_{op}^{ACS,-1}$ where $\widehat{L}_{op}^{ACS,-1} = L_{op}^{ACS,0}$

Note that there is a tension between $f_{o,\ell n}^{ACS}$ and $f_{p,n}^{CPS}$. Given that these flows come from different datasets, they will tend to generate different distributions of employment at the sector level at $t = 0$. Consider the heuristic method below, which addresses this tension.

S*tep 1*: Let $\widehat{f}_{p,n}^{i} = \alpha_n \beta_p f_{p,n}^{CPS}$ where α_n and β_p are determined such that $\widehat{f}_{p,n}^{i}$ is consistent with industry-specific employments $L_p^{ACS,-1}$ and $L_n^{ACS,0}$. That is:

$\beta_p \sum_n \alpha_n f_{p,n}^{CPS} = L_p^{ACS,-1}$

$\alpha_n \sum_p \beta_p f_{p,n}^{CPS} = L_n^{ACS,0}$

Note: This step ensures that flows $\widehat{f}_{p,n}^{i}$ are consistent with the distributions of employment we impose at $t = -1$ and $t = 0$.

Step 2: Let $\widehat{f}_{o,\ell n} = \xi_o \zeta_{\ell n} f^{ACS}_{o,\ell n}$ where ξ_o and $\zeta_{\ell n}$ are determined such that $\widehat{f}_{o,\ell n}$ is consistent with both $L^{ACS,-1}_o$ and $L^{ACS,0}_{\ell n}$. That is:

$\sum_\ell \sum_n \widehat{f}_{o,\ell n} = \xi_o \sum_\ell \sum_n \zeta_{\ell n} f^{ACS}_{o,\ell n} = L^{-1}_o$

$\sum_o \widehat{f}_{o,\ell n} = \zeta_{\ell n} \sum_o \xi_o f^{ACS}_{o,\ell n} = L^0_{\ell n}$

Note: Similarly, this step ensures that flows $\widehat{f}_{o,\ell n}$ are consistent with the distributions of employment we impose at $t = -1$ and $t = 0$.

Step 3: Solve for flows $\widehat{f}_{op,\ell n} = w_{o,\ell n} x_{op} y_{pn}$ satisfying all the following conditions:

1. $\sum_\ell \sum_n \widehat{f}_{op,\ell n} = x_{op} \sum_\ell \sum_n w_{o,\ell n} y_{pn} = L^{ACS,-1}_{o,p}$
2. $\sum_o \sum_\ell \widehat{f}_{op,\ell n} = y_{pn} \sum_o \sum_\ell w_{o,\ell n} x_{op} = \widehat{f}^i_{p,n}$
3. $\sum_p \widehat{f}_{op,\ell n} = w_{o,\ell n} \sum_p x_{op} y_{pn} = \widehat{f}_{o,\ell n}$

Once we have impute worker flows $\widehat{f}_{op,\ell n}$ we obtain transition rates $m_{op,\ell n} = \frac{\widehat{f}_{op,\ell n}}{L^{ACS,-1}_{o,p}}$ across all location-sector pairs.

A.3 Parameter Extraction Procedure

This algorithm jointly extracts the following parameters: $\left\{\beta^E_j\right\}_{j\in J}$, $\left\{\beta^L_j\right\}_{j\in J}$, $\{\mu_j\}_{j\in J\cup E}$, $\{z_{\ell,E}\}_{\ell\in\mathcal{L}}$, $\{z_{\ell,j}\}_{\ell\in\mathcal{L},j\in J}$, $\left\{K^S_{\ell,j}\right\}_{\ell\in\mathcal{L},j\in J}$ $\{C_{\ell,j,n,k}\}_{\ell,n\in\mathcal{L},j,k\in J\cup u}$ and $\{\eta_{\ell,j}\}_{\ell\in\mathcal{L},j\in J\cup u}$ conditional on the following data.

- $L^{ACS}_{\ell,j}$ – ACS labor allocations (state and sector specific)
- $VA^{BEA}_{\ell,j}$ – Value added from the BEA (state and sector specific), which **subtracts** expenditures with electricity
- $X^{E,BEA}_j$ – Energy expenditures from the BEA (sector specific) from the production side
- $X^{E,BEA}_{HH}$ – Energy expenditures from the BEA (sector specific) from households
- $WageBill^{BEA}_j$ – The wage bill at the industry level can be constructed using BEA data directly or using "inflated" ACS data.

- $y_\ell^{E,R}$, $y_\ell^{E,F}$ – Energy production (based on renewables and fossil fuels) by location from the EIA
- K_ℓ^R, K_ℓ^F – Renewable energy capital and fossil-fuel-based capital by location from the EIA
- θ_ℓ^R – Local productivity of reneable capital from the EIA
- $m_{\ell,j,k,n}$ – imputed yearly transition rates from the ACS and CPS
- $\tau_{\ell,k,j}$ – Head and Ries indices (state to state and sector specific)
- σ_j – elasticity of substitution in production (sector specific)
- ρ_j – Amington elasticity (sector specific)
- χ_j – output taxes are all set to 0
- α – expenditure share on fuel in electricity production
- β – intertemporal discount factor
- ν – the migration elasticity

Consider two cases: Cobb-Douglas ($\sigma_j = 1$) and Leontief ($\sigma_j = 0$) production functions .

$$y_{\ell,j} = \frac{z_{\ell,j}}{\left(\beta_j^E\right)^{\beta_j^E}\left(1-\beta_j^E\right)^{\left(1-\beta_j^E\right)}} E_{\ell,j}^{\beta_j^E}\left(L_{\ell,j}^{\beta_j^L} K_{\ell,j}^{1-\beta_j^L}\right)^{1-\beta_j^E} \qquad \text{(Cobb-Douglas)}$$

$$y_{\ell,j} = z_{\ell,j} \min\left\{\frac{E_{\ell,j}}{\beta_j^E}, \frac{L_{\ell,j}^{\beta_j^L} K_{\ell,j}^{1-\beta_j^L}}{1-\beta_j^E}\right\} \qquad \text{(Leontief)}$$

Fossil fuels is the numeraire: $p_F = 1$

Step 1: Start with $VA_{\ell,j}^{BEA}$ read directly from the data.

Step 2: Obtain β_j^L for all $j \in J \cup F$:

$$\beta_j^L = \frac{WageBill_j^{BEA}}{\sum_\ell VA_{\ell,j}^{BEA}}$$

Step 3: Compute wages $w_{\ell,j}$ for all $\ell \in \mathcal{L}$ and $j \in J \cup F$ with $VA_{\ell,j}^{BEA} > 0$ and $L_{\ell,j}^{ACS} > 0$.

$$w_{\ell,j} = \frac{\beta_j^L VA_{\ell,j}^{BEA}}{L_{\ell,j}^{ACS}}$$

Step 4: Reconcile $VA_{\ell,j}^{BEA}$ and $L_{\ell,j}^{ACS}$.

If $VA_{\ell,j}^{BEA} = 0$ and $L_{\ell,j}^{ACS} > 0$ then impute

$$VA_{\ell,j}^{BEA} = \frac{\widehat{w}_{\ell,j} L_{\ell,j}^{ACS}}{\beta_j^L}$$

where

$$\widehat{w}_{\ell,j} = \frac{w_{\ell,j}^{ACS}}{\overline{w}_{\ell,-j}^{ACS}} w_{\ell,-j}$$

Here, $\overline{w}_{\ell,-j}^{ACS}$ is the ACS employment-weighted average wage in location ℓ outside of sector j.

$$\overline{w}_{\ell,-j}^{ACS} = \frac{1}{L_{\ell,-j}} \sum_{k \in J \setminus \{j\}} L_{\ell,k} w_{\ell,k}^{ACS}$$

with

$$L_{\ell,-j} = \sum_{k \in J \setminus \{j\}} L_{\ell,k}$$

That is, we impute $\widehat{w}_{\ell,j}$ to preserve the wage in sector j in region ℓ relative to the average ACS wage in region ℓ, excluding sector j.

$$w_{\ell,-j} = \frac{1}{L_{\ell,-j}} \sum_{k \in J \setminus \{j\}} L_{\ell,k} w_{\ell,k}$$

Set

$$w_{\ell,j} = \widehat{w}_{\ell,j}$$

If $VA_{\ell,j}^{BEA} > 0$ and $L_{\ell,j}^{ACS} = 0$ then impute $VA_{\ell,j}^{BEA} = 0$

Step 5: Recompute β_j^L for all $j \in J \cup F$ with the updated values of $VA_{\ell,j}^{BEA}$:

$$\beta_j^L = \frac{WageBill_j^{BEA}}{\sum_\ell VA_{\ell,j}^{BEA}}$$

Step 6: Obtain the supply of capital (using $r_{\ell,j} = 1$):

$$K^S_{\ell,j} = \left(1 - \beta^L_j\right) VA^{BEA}_{\ell,j}$$

Step 7: Compute

$$p_E = \frac{X^{E,BEA}_{HH} + \sum_{j \in J \cup F} X^{E,BEA}_j}{\sum_\ell \left(y^{E,R}_\ell + y^{E,F}_\ell\right)}$$

Step 8: Obtain β^E_j for all $j \in J \cup F$ with the updated values of $VA^{BEA}_{\ell,j}$:

$$\beta^E_j = \frac{X^{E,BEA}_j}{\sum_\ell VA^{BEA}_{\ell,j} + X^{E,BEA}_j} \qquad \text{(Cobb-Douglas)}$$

$$\beta^E_j = \frac{X^{E,BEA}_j / p_E}{X^{E,BEA}_j / p_E + \sum_\ell L^{\beta^L_j}_{\ell,j} \left(K^S_{\ell,j}\right)^{1-\beta^L_j}} \qquad \text{(Leontief)}$$

Step 9: Obtain $z_{\ell,E}$ that rationalizes $y^{E,F}_\ell$:

$$z_{\ell,E} = \frac{\left(y^{E,F}_\ell\right)^\alpha}{\left(K^F_\ell\right)^\alpha \left((1-\alpha)\frac{p_E}{p_F}\right)^{1-\alpha}}$$

Step 10: Compute revenues of energy capitalists across locations

$$\Pi^R_\ell = p_E \theta^R_\ell K^R_\ell$$
$$\Pi^F_\ell = \alpha p_E y^{E,F}_\ell$$

Step 11: Compute income across all locations $\ell \in \mathcal{L}$:

$$I_\ell = \sum_{j \in J \cup F} \left[w_{\ell,j} L^{ACS}_{\ell,j} + r_{\ell,j} K^S_{\ell,j}\right] + \Pi^R_\ell + \Pi^F_\ell$$

Step 12: Compute

$$F_\ell^D = \left(K_\ell^F\right)^{-\frac{\alpha}{1-\alpha}} \left(\frac{y_\ell^{E,F}}{z_{\ell,E}}\right)^{\frac{1}{1-\alpha}}$$

across all locations $\ell \in \mathcal{L}$ – $F_\ell^D = 0$ if $K_\ell^F = 0$.

Step 13: Obtain

$$\mu_F = \frac{\sum_\ell VA_{\ell,F}^{BEA} + X_F^{E,BEA} - p_F \sum_\ell F_\ell^D}{\sum_\ell I_\ell}$$

$$\mu_j = \frac{\sum_\ell VA_{\ell,j}^{BEA} + X_j^{E,BEA}}{\sum_\ell I_\ell},\ j \in J$$

$$\mu_E = \frac{X_{HH}^{E,BEA}}{\sum_\ell I_\ell}$$

Step 14: Compute for all $\ell \in \mathcal{L}$ and $j \in J \cup F$:

$$c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right) = \left(\frac{w_{\ell,j}}{\beta_j^L}\right)^{\beta_j^L} \left(\frac{r_{\ell,j}}{1-\beta_j^L}\right)^{\left(1-\beta_j^L\right)}$$

$$\overline{c}_{\ell,j} = p_E^{\beta_j^E} c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right)^{1-\beta_j^E} \qquad \text{(Cobb-Douglas)}$$

$$\overline{c}_{\ell,j} = \beta_j^E p_E + \left(1-\beta_j^E\right) c_{KL}\left(w_{\ell,j}, r_{\ell,j}\right) \qquad \text{(Leontief)}$$

Step 15: For Fuel, compute for all $\ell \in \mathcal{L}$:

$$z_{\ell,F} = \frac{\overline{c}_{\ell,F}}{p_F}$$

Step 16: Use fixed point iteration to find $\{z_{\ell,j}\}$ that solves the system below:

$$\sum_k p_{\ell,j} \tau_{\ell,k,j} q_{\ell,k,j} = \mu_j \sum_k I_k \frac{\left(\frac{\overline{c}_{\ell,j}}{z_{\ell,j}} \tau_{\ell,k,j}\right)^{1-\rho_j}}{\sum_i \left(\frac{\overline{c}_{i,j}}{z_{i,j}} \tau_{i,k,j}\right)^{1-\rho_j}}$$

Income I_k in the right hand side comes from Step 10. The left hand side is value added in location $\ell \in \mathcal{L}$ and sector $j \in J$ and is data.

With Cobb-Douglas

$$\sum_k p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = \frac{VA^{BEA}_{\ell,j}}{1-\beta^E_j}$$

With Leontief

$$\sum_k p_{\ell,j}\tau_{\ell,k,j}q_{\ell,k,j} = VA^{BEA}_{\ell,j}\left(1+\frac{p_E}{c_{KL}\left(w_{\ell,j},r_{\ell,j}\right)}\frac{\beta^E_j}{1-\beta^E_j}\right)$$

Given a guess of productivities $\{z_{\ell,j}\}$ obtain updates using:

$$z^{new}_{\ell,j} = \overline{c}_{\ell,j}\left(\frac{\frac{VA^{BEA}_{\ell,j}}{\mu_j\left(1-\beta^E_j\right)}}{\sum_k I_k\frac{\left(\tau_{\ell,k,j}\right)^{1-\rho_j}}{\sum_i\left(\frac{\overline{c}_{i,j}}{z_{i,j}}\tau_{i,k,j}\right)^{1-\rho_j}}}\right)^{\frac{1}{\rho_j-1}} \quad \text{(Cobb-Douglas)}$$

$$z^{new}_{\ell,j} = \overline{c}_{\ell,j}\left(\frac{\frac{VA^{BEA}_{\ell,j}\left(1+\frac{p_E}{c_{KL}\left(w_{\ell,j},r_{\ell,j}\right)}\frac{\beta^E_j}{1-\beta^E_j}\right)}{\mu_j}}{\sum_k I_k\frac{\left(\tau_{\ell,k,j}\right)^{1-\rho_j}}{\sum_i\left(\frac{\overline{c}_{i,j}}{z_{i,j}}\tau_{i,k,j}\right)^{1-\rho_j}}}\right)^{\frac{1}{\rho_j-1}} \quad \text{(Leontief)}$$

Step 17: Compute prices for all $\ell \in \mathcal{L}$ and $j \in J$:

$$p_{\ell,j} = \frac{\overline{c}_{\ell,j}}{z_{\ell,j}}$$

Step 18: Compute price indices for all $\ell \in \mathcal{L}$ and $j \in J$

$$P_{\ell,j} \equiv \left(\sum_{k=1}^{L}\left(p_{k,j}\tau_{k,\ell,j}\right)^{1-\rho_j}\right)^{\frac{1}{1-\rho_j}}$$

$$P_{\ell,F} = p_F$$

$$P_{\ell,E} = p_E$$

$$P_\ell = \prod_{j\in J\cup F\cup E}\left(\frac{P_{\ell,j}}{\mu_j}\right)^{\mu_j}$$

Step 19: Impose $C_{\ell,j,\ell,j} = 0$ (no cost of not moving) for all $\ell \in \mathcal{L}$ and $j \in J \cup F$, $C_{\ell,j,\ell,u} = 0$ (no cost of moving locally to unemployment) and $\eta_{\ell,u} = 0$ (unemployment gives zero utility) for all regions ℓ:

we obtain for all ℓ, j:

If $m_{\ell,j,\ell,j} > 0$ and $L_{\ell,j}^{ACS} > 0$:

$$\eta_{\ell,j} = -\frac{\nu}{\beta} \log\left(\frac{m_{\ell,j,\ell,u}}{m_{\ell,j,\ell,j}}\right) - \nu \log\left(\frac{m_{\ell,u,\ell,u}}{m_{\ell,j,\ell,u}}\right) - \left(\frac{w_{\ell,j} + b}{P_\ell}\right)$$

If $m_{\ell,j,\ell,j} = 0$ or $L_{\ell,j}^{ACS} = 0$:

$$\eta_{\ell,j} = -\infty$$

We can then recover mobility costs using:

If $m_{\ell,j,\ell,j} > 0$, $L_{\ell,j}^{ACS} > 0$ and $m_{\ell,j,k,n} > 0$:

$$\begin{aligned} C_{\ell,j,k,n} = &-\frac{\nu}{1-\beta} \log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right) - \frac{\nu\beta}{(1-\beta)} \log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right) \\ &+ \frac{\beta}{1-\beta}\left(\frac{w_{k,n} + b}{P_k} - \frac{w_{\ell,j} + b}{P_\ell}\right) + \frac{\beta}{1-\beta}\left(\eta_{k,n} - \eta_{\ell,j}\right) \end{aligned}$$

Else

$$C_{\ell,j,k,n} = +\infty$$

B Algorithm for Steady State Counterfactuals

Consider two cases: Cobb-Douglas ($\sigma_j = 1$) and Leontief ($\sigma_j = 0$) production functions .

$$y_{\ell,j} = \frac{z_{\ell,j}}{\left(\beta_j^E\right)^{\beta_j^E}\left(1-\beta_j^E\right)^{\left(1-\beta_j^E\right)}} E_{\ell,j}^{\beta_j^E}\left(L_{\ell,j}^{\beta_j^L} K_{\ell,j}^{1-\beta_j^L}\right)^{1-\beta_j^E} \qquad \text{(Cobb-Douglas)}$$

$$y_{\ell,j} = z_{\ell,j}\min\left\{\frac{E_{\ell,j}}{\beta_j^E}, \frac{L_{\ell,j}^{\beta_j^L} K_{\ell,j}^{1-\beta_j^L}}{1-\beta_j^E}\right\} \qquad \text{(Leontief)}$$

Fossil fuels is the numeraire: $p_F = 1$.

Step 0: For Leontief $\sigma_F = 0$, we need to ensure that for all ℓ with $K_{\ell,F}^S > 0$:

$$\frac{(1-\chi_F)\, p_F z_{\ell,F}}{\beta_F^E} > p_E$$

Compute:

$$UpperBound_{p_E} = \min_{\ell} \frac{(1-\chi_F)\, p_F z_{\ell,F}}{\beta_F^E}$$

With Cobb-Douglas ($\sigma_F = 1$), no bound must be computed.

Step 1: Guess $\{I_\ell\}_{\ell \in \mathcal{L}}$

Step 2: Guess the price of the capital-labor bundle, $\{c_{KL,\ell,j}\}$ for all $\ell \in \mathcal{L}$ and $j \in J$, as well as wages in Fuels $\{w_{\ell,F}\}$. Recall that the price of the capital-labor bundle is defined as:

$$c_{KL,j}(w_{\ell,j}, r_{\ell,j}) = \left(\frac{w_{\ell,j}}{\beta_j^L}\right)^{\beta_j^L}\left(\frac{r_{\ell,j}}{1-\beta_j^L}\right)^{1-\beta_j^L},$$

although we only make use of this definition in a later step.

If $K_{\ell F}^S = 0$, then set a very high value for $w_{\ell,F}$.

Step 3: Guess p_E.

Step 4: Get supply of electricity y_ℓ^E for all ℓ

$$p_E = mc_\ell \Rightarrow y_\ell^E = \theta_\ell^R K_\ell^R + (z_{\ell,E})^{\frac{1}{\alpha}} \left((1-\alpha) \frac{p_E}{p_F} \right)^{\frac{1-\alpha}{\alpha}} K_\ell^F$$

and obtain the demand for fuel F_ℓ^D from electricity generation for all ℓ

$$F_\ell^D = \left(K_\ell^F\right)^{-\frac{\alpha}{1-\alpha}} \left(\frac{y_\ell^E - \theta_\ell^R K_\ell^R}{z_{\ell,E}} \right)^{\frac{1}{1-\alpha}}$$

Step 5: Compute prices for all $\ell \in \mathcal{L}$ and $j \in J$:

$$p_{\ell,j} = \frac{p_E^{\beta_j^E} \, c_{KL,\ell,j}^{(1-\beta_j^E)}}{(1-\chi_j) z_{\ell,j}} \qquad \text{(Cobb-Douglas)}$$

$$p_{\ell,j} = \frac{p_E \, \beta_j^E + c_{KL,\ell,j} \, (1-\beta_j^E)}{(1-\chi_j) z_{\ell,j}} \qquad \text{(Leontief)}$$

For fuels, impose:

$$p_{\ell F} = p_F = 1.$$

Step 6: Compute price indices for all $\ell \in \mathcal{L}$ and $j \in J$

$$P_{\ell,j} \equiv \left(\sum_{k=1}^{L} \left(p_{k,j} \tau_{k,\ell,j} \right)^{1-\rho_j} \right)^{\frac{1}{1-\rho_j}}$$

Step 7: Compute quantities for all $j \in J$ and all location pairs k and $\ell \in \mathcal{L}$:

$$q_{k,\ell,j} = \frac{\mu_j I_\ell}{P_{\ell,j}^{1-\rho_j}} \left(p_{k,j} \tau_{k,\ell,j} \right)^{-\rho_j}$$

Note: $q_{k,\ell,j}$ is the quantity that actually arrives in location ℓ. Location k needs to produce $\tau_{k,\ell,j} q_{k,\ell,j}$.

Step 8: Obtain production for all $\ell \in \mathcal{L}$ and $j \in J$

$$y_{\ell,j} = \sum_k \tau_{\ell,k,j} q_{\ell,k,j}$$

Step 9: Compute electricity demand for all $\ell \in \mathcal{L}$ and $j \in J$

$$E^D_{\ell,j} = \frac{\beta^E_j \left(1 - \chi_j\right) p_{\ell,j} y_{\ell,j}}{p_E} \qquad \text{(Cobb-Douglas)}$$

$$E^D_{\ell,j} = \frac{\beta^E_j \, y_{\ell,j}}{z_{\ell,j}} \qquad \text{(Leontief)}$$

Step 10: For fuels, back out $c_{KL}\left(w_{\ell,F}, r_{\ell,F}\right)$:

$$c_{KL,\ell,F} = \left(\frac{\left(1 - \chi_F\right) p_F z_{\ell,F}}{p_E^{\beta^E_F}} \right)^{\frac{1}{1-\beta^E_F}} \qquad \text{(Cobb-Douglas)}$$

$$c_{KL,\ell,F} = \frac{\left(1 - \chi_F\right) p_F z_{\ell,F} - \beta^E_F p_E}{1 - \beta^E_F} \qquad \text{(Leontief)}$$

And obtain:

$$r_{\ell,F} = \left(1 - \beta^L_F\right) \left(c_{KL,\ell,F} \left(\frac{\beta^L_F}{w_{\ell,F}} \right)^{\beta^L_F} \right)^{\frac{1}{1-\beta^L_F}}$$

Then to obtain the demand for electricity compute:

$$E^D_{\ell,F} = \frac{\beta^E_F}{1 - \beta^E_F} \left(\frac{\beta^L_F}{1 - \beta^L_F} \right)^{\beta^L_F} \left(\frac{c_{KL,\ell,F}}{p_E} \right) \left(\frac{r_{\ell,F}}{w_{\ell,F}} \right)^{\beta^L_F} K^S_{\ell,F} \qquad \text{(Cobb-Douglas)}$$

$$E^D_{\ell,F} = \frac{\beta^E_F}{1 - \beta^E_F} \left(\frac{\beta^L_F}{1 - \beta^L_F} \right)^{\beta^L_F} \left(\frac{r_{\ell,F}}{w_{\ell,F}} \right)^{\beta^L_F} K^S_{\ell,F} \qquad \text{(Leontief)}$$

Step 11: Update the price of electricity

$$p'_E = \left(1 - \lambda_E\right) p_E + \lambda_E p_E \frac{\sum_\ell \sum_{j \in J \cup F} E^D_{\ell,j} + \frac{\mu_E I_\ell}{p_E}}{\sum_\ell y^E_\ell}$$

$$p^{new}_E = \min\left(p'_E,\, 0.999 \times UpperBound_{p_E}\right)$$

Go back to Step 3 until convergence of p_E.

Step 12: Compute capital rental rates for all $\ell \in \mathcal{L}$ and $j \in J$ by imposing that capital supply equals capital demand and that $p = mc$:

$$r_{\ell,j} = \frac{1 - \beta^L_j}{K^S_{\ell,j}} \left(p_{\ell,j} y_{\ell,j} - p_E E^D_{\ell,j} \right)$$

Step 13: Recover wages for all $\ell \in \mathcal{L}$ and $j \in J$:

$$w_{\ell,j} = \beta_j^L \left[\frac{c_{KL,\ell,j}}{(r_{\ell,j}/(1-\beta_j^L))^{1-\beta_j^L}} \right]^{\frac{1}{\beta_j^L}}$$

Compute labor demand for all $\ell \in \mathcal{L}$ and $j \in J \cup F$:

$$L_{\ell,j}^D = K_{\ell,j}^S \times \frac{\beta_j^L}{1-\beta_j^L} \times \frac{r_{\ell,j}}{w_{\ell,j}}$$

Step 14: Given $L_{\ell,F}^D$, $E_{\ell,F}^D$ and $K_{\ell,F}^S$, compute $y_{\ell,F}$ for all $\ell \in \mathcal{L}$.

$$y_{\ell,F} = \frac{z_{\ell,F}}{\left(\beta_F^E\right)^{\beta_F^E}\left(1-\beta_F^E\right)^{\left(1-\beta_F^E\right)}} E_{\ell,F}^{\beta_F^E} \left(L_{\ell,F}^{\beta_F^L} K_{\ell,F}^{1-\beta_F^L} \right)^{1-\beta_F^E} \qquad \text{(Cobb-Douglas)}$$

$$y_{\ell,F} = z_{\ell,F} \min \left\{ \frac{E_{\ell,F}}{\beta_F^E}, \frac{L_{\ell,F}^{\beta_F^L} K_{\ell,F}^{1-\beta_F^L}}{1-\beta_F^E} \right\} \qquad \text{(Leontief)}$$

Step 15: Compute revenues of capitalists for all $\ell \in \mathcal{L}$.

$$\Pi_\ell^R = p_E \theta_\ell^R K_\ell^R$$
$$\Pi_\ell^F = \alpha p_E y_\ell^{E,F}$$

Step 16: Compute tax revenues and rebates

$$T_\ell = \sum_{j \in J \cup F} \chi_j p_{\ell,j} y_{\ell,j}$$

$$b = \frac{\sum_{\ell \in \mathcal{L}} T_\ell}{\overline{L}}$$

Step 17: Compute local price indices for all $\ell \in \mathcal{L}$

$$P_\ell = \prod_{j \in J \cup F \cup E} \left(\frac{P_{\ell,j}}{\mu_j} \right)^{\mu_j}$$

where

$$P_{\ell,F} = p_F$$
$$P_{\ell,E} = p_E$$

Step 18: Solve the Bellman equation for workers for all $\ell \in \mathcal{L}$ and $j \in J \cup F \cup u$:

$$\mathcal{V}_{\ell,j} = \frac{w_{\ell,j} + b}{P_\ell} + \eta_{\ell,j} + \nu \log \left(\sum_{k \in \mathcal{L}, n \in J \cup F \cup u} \exp \left(\frac{-C_{\ell j,kn} + \beta \mathcal{V}_{k,n}}{\nu} \right) \right),$$

and recover the policy functions:

$$m_{\ell,j,k,n} = \frac{\exp\left(\frac{-C_{\ell,j,k,n} + \beta \mathcal{V}_{k,n}}{\nu}\right)}{\sum_{k',n'} \exp\left(\frac{-C_{\ell,j,k',n'} + \beta \mathcal{V}_{k',n'}}{\nu}\right)}.$$

Step 19: Labor supply solves the system below:

$$(I - m')\, L = 0$$
$$L'e = \overline{L}$$

where e is a column vector of 1's.

Step 20: Update the price of the capital-labor bundle for all $\ell \in \mathcal{L}$ and all $j \in J$:

$$c^{new}_{KL,\ell,j} = (1 - \lambda_c)\, c_{KL,\ell,j} + \lambda_c c_{KL,\ell,j} \frac{L^D_{\ell,j}}{L^S_{\ell,j}}$$

For Fuel, update $w_{\ell,F}$ for all $\ell \in \mathcal{L}$ (with $K^S_{\ell,F} > 0$) according to:

$$w^{new}_{\ell,F} = (1 - \lambda_c)\, w_{\ell,F} + \lambda_w w_{\ell,F} \frac{L^D_{\ell,F}}{L^S_{\ell,F}}$$

Go back to Step 2 until convergence.

Step 21: Update income

$$I'_\ell = \sum_{j \in J \cup F} \left[(w_{\ell j} + b)\, L_{\ell,j} + r_{\ell,j} K^S_{\ell,j} \right] + b L_{\ell,u} + \Pi^R_\ell + \Pi^F_\ell$$

$$I^{new}_\ell = (1 - \lambda_I)\, I_\ell + \lambda_I I'_\ell$$

Go back to Step 1 until convergence.

C Algorithm for Transitional Dynamics

Consider production functions

$$y_{\ell,j,t} = \frac{z_{\ell,j}}{\left(\beta_j^E\right)^{\beta_j^E}\left(1-\beta_j^E\right)^{\left(1-\beta_j^E\right)}} E_{\ell,j,t}^{\beta_j^E}\left(L_{\ell,j,t}^{\beta_j^L} K_{\ell,j,t}^{1-\beta_j^L}\right)^{1-\beta_j^E} \qquad \text{(Cobb-Douglas)}$$

$$y_{\ell,j,t} = z_{\ell,j}\min\left\{\frac{E_{\ell,j,t}}{\beta_j^E}, \frac{L_{\ell,j}^{\beta_j^L} K_{\ell,j,t}^{1-\beta_j^L}}{1-\beta_j^E}\right\} \qquad \text{(Leontief)}$$

and shock $\{\chi_{j,t}\}_{t=1}^T$.

Step 1: Solve for the initial steady state $\{L_{\ell,j,0}^S, \mathcal{V}_{\ell,j,0}\}$.

Step 2: Solve for the final steady state $\{L_{\ell,j,\infty}^S, \mathcal{V}_{\ell,j,\infty}\}$.

Step 3: Guess a path of continuation values $\{\mathcal{V}_{\ell,j,t}\}$ for $t = 1, ..., T$, using an immediate jump the final steady state $\mathcal{V}_{\ell,j,\infty}$ as the initial guess.

Step 4: For each period t, starting with $t = 1$ and working forward:

(a) Conditional on $\left\{L_{\ell,j,t}^S\right\}$ (which is determined at $t-1$) and $\{\mathcal{V}_{\ell,j,t+1}\}$, solve for the within-period problem described below to obtain $\{L_{\ell,j,t+1}^S\}$, the vector of labor supply at $t+1$. For $t = T$, use the final steady state $\{\mathcal{V}_{\ell,j,\infty}\}$ as the continuation value.

(b) Use $\{L_{\ell,j,t+1}^S\}$ found in Step 4.(a) as the vector of labor supply for the next period and repeat the procedure until we reach $t = T$.

When complete, this procedure returns a sequence of aggregate labor supply decisions $\left\{L_{\ell,j,t}^S\right\}$, wages $\{w_{\ell,j,t}\}$, prices $\{P_{\ell,t}\}$ and transfers $\{b_t\}$ for periods $t = 1$ to $t = T$.

Step 5: Update the path of the value functions.

Compute the value functions $\widehat{\mathcal{V}}_{\ell,j,t}$ implied by the current guesses $\mathcal{V}_{\ell,j,t}$, wages $w_{\ell,j,t}$, prices $P_{\ell,t}$ and transfers b_t obtained in Step 4.

$$\widehat{\mathcal{V}}_{\ell,j,T} = \frac{w_{\ell,j,T} + b_T}{P_{\ell,T}} + \eta_{\ell,j} + \nu \log\left(\sum_{k\in\mathcal{L}, n\in J\cup F\cup u} \exp\left(\frac{-C_{\ell j,kn} + \mathcal{V}_{k,n,\infty}}{\nu}\right)\right)$$

Sequentially compute backwards starting at $t = T - 1$ down to $t = 1$:

$$\widehat{\mathcal{V}}_{\ell,j,t} = \frac{w_{\ell,j,t} + b_t}{P_{\ell,t}} + \eta_{\ell,j} + \nu \log \left(\sum_{k \in \mathcal{L}, n \in J \cup F \cup u} \exp \left(\frac{-C_{\ell j,kn} + \mathcal{V}_{k,n,t+1}}{\nu} \right) \right)$$

Update the path for $\mathcal{V}_{\ell,j,t}$ using:

$$\mathcal{V}_{\ell,j,t}^{new} = \lambda_V \mathcal{V}_{\ell,j,t} + (1 - \lambda_V) \widehat{\mathcal{V}}_{\ell,j,t}$$

For all $t = 1, ..., T$.

Step 6: Go back to Step 3 until convergence of $\{\mathcal{V}_{\ell,j,t}\}$.

Within-Period Problem – Step 4

Input: $L^S_{\ell,j,t}$ and $\mathcal{V}_{\ell,j,t+1}$.

Output: $L^S_{\ell,j,t+1}$, $P_{\ell,t}$, b_t, $w_{\ell,j,t}$.

Steps i to xviii compute equilibrium $P_{\ell,t}$, b_t, $w_{\ell,j,t}$, $p_{E,t}$, $I_{\ell,t}$ conditional on $L^S_{\ell,j,t}$ and $\mathcal{V}_{\ell,j,t+1}$. Step xix obtains $L^S_{\ell,j,t+1}$ conditional on $L^S_{\ell,j,t}$ and $\mathcal{V}_{\ell,j,t+1}$. Fuel prices are set $p_{F,t} = 1$ for all t.

For Leontief $\sigma_F = 0$, we need to ensure that for all ℓ with $K^S_{\ell,F} > 0$:

$$\frac{(1-\chi_{F,t})\, p_{F,t} z_{\ell,F}}{\beta^E_F} > p_{E,t}$$

Compute:

$$UpperBound_{p_{E,t}} = \min_{\ell} \frac{(1-\chi_{F,t})\, p_{F,t} z_{\ell,F}}{\beta^E_F}$$

With Cobb-Douglas ($\sigma_F = 1$), no bound must be computed.

Step i: Guess $\{I_{\ell,t}\}$

Step ii: Guess the price of the capital-labor bundle, $\{c_{KL,\ell,j,t}\}$ for $j \in J$ and $w_{\ell,F,t}$. Remember that

$$c_{KL,j,t} = \left(\frac{w_{\ell,j,t}}{\beta^L_j}\right)^{\beta^L_j} \left(\frac{r_{\ell,j,t}}{1-\beta^L_j}\right)^{1-\beta^L_j}.$$

Step iii: Guess $p_{E,t}$.

Step iv: Obtain the supply of electricity $y^E_{\ell,t}$ for all $\ell \in \mathcal{L}$:

$$y^E_{\ell,t} = \theta^R_\ell K^R_\ell + (z_{\ell,E})^{\frac{1}{\alpha}} \left(\frac{(1-\alpha)\, p_{E,t}}{p_{F,t}}\right)^{\frac{1-\alpha}{\alpha}} K^F_\ell.$$

Step v: Compute prices for all $\ell \in \mathcal{L}$ and $j \in J$:

$$p_{\ell,j,t} = \frac{p^{\beta^E_j}_{E,t} c^{1-\beta^E_j}_{KL,\ell,j,t}}{(1-\chi_{j,t}) z_{\ell,j}} \qquad \text{(Cobb-Douglas)}$$

$$p_{\ell,j,t} = \frac{p_{E,t}\beta^E_j + c_{KL,\ell,j,t}\left(1-\beta^E_j\right)}{(1-\chi_{j,t})\, z_{\ell,j}} \qquad \text{(Leontief)}$$

Step vi: Compute price indices for all $\ell \in \mathcal{L}$ and $j \in J$:

$$P_{\ell,j,t} \equiv \left(\sum_{k=1}^{L} \left(p_{k,j,t} \tau_{k,\ell,j} \right)^{1-\rho_j} \right)^{\frac{1}{1-\rho_j}}$$

and

$$P_{\ell,F,t} = 1$$

Step vii: Compute quantities for all $j \in J$ and all location pairs k and $\ell \in \mathcal{L}$:

$$q_{k,\ell,j,t} = \frac{\mu_j I_{\ell,t}}{P_{\ell,j,t}^{1-\rho_j}} \left(p_{k,j,t} \tau_{k,\ell,j} \right)^{-\rho_j}$$

Step viii: Obtain production for all $\ell \in \mathcal{L}$ and $j \in J$:

$$y_{\ell,j,t} = \sum_{k \in \mathcal{L}} \tau_{\ell,k,j} q_{\ell,k,j,t}$$

Step ix: Compute electricity demand for all $\ell \in \mathcal{L}$ and $j \in J$:

$$E_{\ell,j,t}^{D} = \frac{\left(1 - \chi_{j,t}\right) \beta_j^E p_{\ell,j,t} y_{\ell,j,t}}{p_{E,t}} \qquad \text{(Cobb-Douglas)}$$

$$E_{\ell,j,t}^{D} = \frac{\beta_j^E y_{\ell,j,t}}{z_{\ell,j}} \qquad \text{(Leontief)}$$

Step x: For fuels, use

$$\left(1 - \chi_{F,t}\right) p_{F,t} = \frac{1}{z_{\ell,F}} p_{E,t}^{\beta_F^E} c_{KL,\ell,F,t}^{1-\beta_F^E}$$

to back out $c_{KL,\ell,F,t}$:

$$c_{KL,\ell,F,t} = \left(\frac{\left(1 - \chi_F\right) p_{F,t} z_{\ell,F}}{p_{E,t}^{\beta_F^E}} \right)^{\frac{1}{1-\beta_F^E}} \qquad \text{(Cobb-Douglas)}$$

$$c_{KL,\ell,F,t} = \frac{\left(1 - \chi_{F,t}\right) p_{F,t} z_{\ell,F} - \beta_F^E p_{E,t}}{1 - \beta_F^E} \qquad \text{(Leontief)}$$

And obtain:

$$r_{\ell,F,t} = \left(1 - \beta_F^L\right) \left(c_{KL,\ell,F,t} \left(\frac{\beta_F^L}{w_{\ell,F,t}} \right)^{\beta_F^L} \right)^{\frac{1}{1-\beta_F^L}}$$

Then to obtain the demand for electricity compute:

$$E^D_{\ell,F,t} = \frac{\beta^E_F}{1-\beta^E_F}\left(\frac{\beta^L_F}{1-\beta^L_F}\right)^{\beta^L_F}\left(\frac{c_{KL,\ell,F,t}}{p_E}\right)\left(\frac{r_{\ell,F,t}}{w_{\ell,F,t}}\right)^{\beta^L_F} K^S_{\ell,F} \qquad \text{(Cobb-Douglas)}$$

$$E^D_{\ell,F,t} = \frac{\beta^E_F}{1-\beta^E_F}\left(\frac{\beta^L_F}{1-\beta^L_F}\right)^{\beta^L_F}\left(\frac{r_{\ell,F,t}}{w_{\ell,F,t}}\right)^{\beta^L_F} K^S_{\ell,F} \qquad \text{(Leontief)}$$

Step xi: Update the price of electricity

$$p'_{E,t} = (1-\lambda_E)\, p_{E,t} + \lambda_E p_{E,t} \frac{\sum_\ell \sum_{j\in J\cup F} E^D_{\ell,j,t} + \frac{\mu_E I_{\ell,t}}{p_{E,t}}}{\sum_\ell y^E_{\ell,t}}$$

$$p^{new}_{E,t} = \min\left(p'_{E,t},\, 0.999 \times UpperBound_{p_{E,t}}\right)$$

Go back to Step iii until convergence of $p_{E,t}$.

Step xii: Compute rental rates:

$$r_{\ell,j,t} = \frac{1-\beta^L_j}{K^S_{\ell,j}}\left(p_{\ell,j,t} y_{\ell,j,t} - p_{E,t} E^D_{\ell,j,t}\right)$$

Step xiii: Recover wages for all $\ell \in \mathcal{L}$ and $j \in J$:

$$w_{\ell,j,t} = \beta^L_j \left[\frac{c_{KL,\ell,j,t}}{(r_{\ell,j,t}/(1-\beta^L_j))^{1-\beta^L_j}}\right]^{\frac{1}{\beta^L_j}}$$

Compute for all $\ell \in \mathcal{L}$ and $j \in J \cup F$:

$$L^D_{\ell,j,t} = K^S_{\ell,j} \times \frac{\beta^L_j}{1-\beta^L_j} \times \frac{r_{\ell,j,t}}{w_{\ell,j,t}}$$

Step xiv: Update the price of the capital-labor bundle for all $\ell \in \mathcal{L}$ and all $j \in J$:

$$c^{new}_{KL,\ell,j,t} = (1-\lambda_c)\, c_{KL,\ell,j,t} + \lambda_c c_{KL,\ell,j,t} \frac{L^D_{\ell,j,t}}{L^S_{\ell,j,t}}$$

For Fuel, update $w_{\ell,F,t}$ for all $\ell \in \mathcal{L}$ (with $K^S_{\ell,F} > 0$) according to:

$$w^{new}_{\ell,F,t} = (1-\lambda_c)\, w_{\ell,F,t} + \lambda_c w_{\ell,F,t} \frac{L^D_{\ell,F,t}}{L^S_{\ell,F,t}}$$

Go back to step iii until covergence of $c_{KL,\ell,j,t}$ and $w_{\ell,F,t}$.

Step xv: Compute revenues of energy capitalists

$$\Pi^R_{\ell,t} = p_{E,t}\theta^R_\ell K^R_\ell$$
$$\Pi^F_{\ell,t} = \alpha p_{E,t}\left(y^E_{\ell,t} - \theta^R_\ell K^R_\ell\right)$$

Step xvi: Given $L^D_{\ell,F,t}$, $E^D_{\ell,F,t}$ and $K^S_{\ell,F}$, compute $y_{\ell,F,t}$ for all $\ell \in \mathcal{L}$.

$$y_{\ell,F,t} = \frac{z_{\ell,F}}{\left(\beta^E_F\right)^{\beta^E_F}\left(1-\beta^E_F\right)^{\left(1-\beta^E_F\right)}} E^{\beta^E_F}_{\ell,F,t}\left(L^{\beta^L_F}_{\ell,F,t} K^{1-\beta^L_F}_{\ell,F,t}\right)^{1-\beta^E_F} \qquad \text{(Cobb-Douglas)}$$

$$y_{\ell,F,t} = z_{\ell,F} \min\left\{\frac{E_{\ell,F,t}}{\beta^E_F}, \frac{L^{\beta^L_F}_{\ell,F} K^{1-\beta^L_F}_{\ell,F,t}}{1-\beta^E_F}\right\} \qquad \text{(Leontief)}$$

Step xvii: Compute tax revenues and rebates

$$T_{\ell,t} = \sum_{j\in J\cup F} \chi_{j,t} p_{\ell,j,t} y_{\ell,j,t}$$

$$b_t = \frac{\sum_\ell T_{\ell,t}}{\overline{L}}$$

Step xviii: Update income

$$I'_{\ell,t} = \sum_{j\in J\cup F}\left[\left(w_{\ell,j,t}+b_t\right) L_{\ell,j,t} + r_{\ell,j,t} K^S_{\ell,j}\right] + bL_{\ell,u,t} + \Pi^R_{\ell,t} + \Pi^F_{\ell,t}$$

$$I^{new}_{\ell,t} = (1-\lambda_I)\, I_{\ell,t} + \lambda_I I'_{\ell,t}$$

Go back to Step ii until convergence of $\{I_{\ell,t}\}$.

Step xix: Obtain labor transition rates between t and $t+1$,

$$m_{\ell,j,k,n,t} = \frac{\exp\left(\frac{-C_{\ell,j,k,n}+\beta\mathcal{V}_{\ell,j,t+1}}{\nu}\right)}{\sum_{k'\in\mathcal{L},n'\in J\cup F\cup u}\exp\left(\frac{-C_{\ell,j,k',n'}+\beta\mathcal{V}_{k',n',t+1}}{\nu}\right)},$$

and compute the vector of next-period labor supply:

$$L^S_{t+1} = m'_t L^S_t.$$

Step xx: Obtain local price indices:

$$P_{\ell,t} = \prod_{j\in J\cup F\cup E}\left(\frac{P_{\ell,j,t}}{\mu_j}\right)^{\mu_j}$$

where

$$P_{\ell,F,t} = p_{F,t}$$
$$P_{\ell,E,t} = p_{E,t}$$

A Derivation of Labor and Electricity Demand in the Fuel Sector

In our algorithm, labor demand in the fuel sector across locations is computed conditional on the fuel price p_F—which is the numeraire and set to 1—the energy price p_E, and local wages in the fuel sector $w_{\ell,F}$.

Consider the production function in the fuel sector:

$$y_{\ell,F} = z_{\ell,F}\left(\left(\beta_F^E\right)^{\frac{1}{\sigma_F}} E_{\ell,F}^{\frac{\sigma_F-1}{\sigma_F}} + \left(1-\beta_F^E\right)^{\frac{1}{\sigma_F}}\left(L_{\ell,F}^{\beta^L} K_{\ell,F}^{1-\beta^L}\right)^{\frac{\sigma_F-1}{\sigma_F}}\right)^{\frac{\sigma_F}{\sigma_F-1}}.$$

The unit cost function is given by:

$$c_{\ell,F}(w_{\ell,F}, r_{\ell,F}, p_E) = \frac{1}{z_{\ell,F}}\left(\beta_F^E\, p_E^{1-\sigma_F} + (1-\beta_F^E) c_{KL}\left(w_{\ell,F}, r_{\ell,F}\right)^{1-\sigma_F}\right)^{\frac{1}{1-\sigma_F}},$$

where

$$c_{F,KL}\left(w_{\ell,F}, r_{\ell,F}\right) = \left(\frac{w_{\ell,F}}{\beta_F^L}\right)^{\beta_F^L}\left(\frac{r_{\ell,F}}{1-\beta_F^L}\right)^{1-\beta_F^L}$$

If production occurs in the Fuel sector in location ℓ, then under perfect competition, it must be the case that:

$$(1-\chi_F)\, p_F = c_{\ell,F}(w_{\ell,F}, r_{\ell,F}, p_E).$$

In turn, this implies:

$$\left((1-\chi_F)\, p_F z_{\ell,F}\right)^{1-\sigma_F} = \beta_F^E\, p_E^{1-\sigma_F} + (1-\beta_F^E) c_{F,KL}\left(w_{\ell,F}, r_{\ell,F}\right)^{1-\sigma_F}$$

Note that, conditional on p_F, p_E, and $w_{\ell,F}$, this equation pins down the rental rate of capital $r_{\ell,F}$. However, since the left-hand side is fixed (as fuel is the numeraire), if $\beta_F^E\, p_E^{1-\sigma_F}$ exceeds $\left((1-\chi_F)\, p_F z_{\ell,F}\right)^{1-\sigma_F}$, no positive value of $c_{F,KL}\left(w_{\ell,F}, r_{\ell,F}\right)^{1-\sigma_F}$ can be found to ensure zero profits.

To understand this, suppose that $\sigma_F > 1$, that is, electricity and the capital-labor bundle are substitutes. In that case, if p_E is very low, no matter how high $r_{\ell,F}$ is, firms will always make positive profits, contradicting perfect competition.

Suppose instead that $\sigma_F < 1$, that is, electricity and the capital-labor bundle are complements. In that case, if p_E is very large, no matter how low $r_{\ell,F}$ is, firms will always make negative profits, once again contradicting perfect competition—unless production is zero. But in that case, fuel-specific capital would be idle.

Going forward, we will work under the assumption that

$$\left((1-\chi_F)\, p_F z_{\ell,F}\right)^{1-\sigma_F} - \beta_F^E\, p_E^{1-\sigma_F} > 0$$

across all locations with $K_{\ell,F} > 0$. Note that if $\sigma_F = 1$ (i.e., Cobb-Douglas), this condition is always satisfied and can be ignored. If instead $\sigma_F = 0$ (i.e., Leontief), then we must ensure that our guesses of p_E in the algorithm satisfy

$$p_E < \frac{(1-\chi_F)\, p_F z_{\ell,F}}{\beta_F^E}$$

for all locations $\ell \in \mathcal{L}$ with $K_{\ell,F} > 0$. Therefore, our algorithm will impose an **upper bound** on the guesses of p_E:

$$\text{Bound}_{p_E} = \min_{\ell} \frac{(1-\chi_F)\, p_F z_{\ell,F}}{\beta_F^E}$$

In the derivation below, we obtain labor demand for the Fuel sector in location ℓ **conditional** on p_F, p_E, and $w_{\ell F}$. We also assume that p_E satisfies the bound above, so that we focus on equilibria in which fuel production is positive whenever $K_{\ell,F} > 0$ and fuel sector profits are zero.

For conciseness, we drop the F and ℓ subscripts in the subsequent derivation. Under zero profits, we can express r as a function of w, p_E, and p:

$$r = \left[\frac{\left(\beta^L\right)^{\beta^L} \left(1-\beta^L\right)^{1-\beta^L}}{w^{\beta^L}} \left(\frac{\left((1-\chi)\, pz\right)^{1-\sigma} - \beta^E\, p_E^{1-\sigma}}{1-\beta^E} \right)^{\frac{1}{1-\sigma}} \right]^{\frac{1}{1-\beta^L}}$$

Once we compute r, we can obtain unit factor demands. Let a_L denote the unit labor

demand. Using Shephard's Lemma we obtain:

$$\begin{aligned} a_L &= \frac{\partial}{\partial w} c(w, r, p_E) \\ &= (1-\beta^E) \left(\frac{\beta^L}{1-\beta^L} \right)^{1-\beta^L} z^{\sigma-1} c(w, r, p_E)^{\sigma} c_{KL}(w, r)^{-\sigma} \left(\frac{r}{w} \right)^{1-\beta^L} \end{aligned}$$

Again, by Shephard's Lemma, we obtain a_K, the unit capital demand.

$$\begin{aligned} a_K &= \frac{\partial}{\partial r} c(w, r, p_E) \\ &= (1-\beta^E) \left(\frac{1-\beta^L}{\beta^L} \right)^{\beta^L} z^{\sigma-1} c(w, r, p_E)^{\sigma} c_{KL}(w, r)^{-\sigma} \left(\frac{w}{r} \right)^{\beta^L} \end{aligned}$$

Finally, the unit electricity demand a_E is given by:

$$\begin{aligned} a_E &= \frac{\partial}{\partial p_E} c(w, r, p_E) \\ &= \beta^E z^{\sigma-1} c(w, r, p_E)^{\sigma} p_E^{-\sigma} \end{aligned}$$

The demand of labor (L^D) relative to capital (K^D) is given by:

$$\frac{L^D}{K^D} = \frac{a_L \times y}{a_K \times y} = \frac{\beta^L}{1-\beta^L} \left(\frac{r}{w} \right)$$

where y is the total production of Fuel.

Imposing $K^D = K^S$, where K^S is the fixed supply of Fuel-specific capital, we obtain labor demand as:

$$L^D = \frac{\beta^L}{1-\beta^L} \left(\frac{r}{w} \right) \times K^S$$

In turn, the relative demand for electricity (E^D) is given by:

$$\frac{E^D}{K^D} = \frac{a_E \times y}{a_K \times y} = \frac{\beta^E}{1-\beta^E} \left(\frac{\beta^L}{1-\beta^L} \right)^{\beta^L} \left(\frac{c_{KL}(w, r)}{p_E} \right)^{\sigma} \left(\frac{r}{w} \right)^{\beta^L}.$$

Imposing $K^D = K^S$ we obtain:

$$E^D = \frac{\beta^E}{1-\beta^E} \left(\frac{\beta^L}{1-\beta^L} \right)^{\beta^L} \left(\frac{c_{KL}(w, r)}{p_E} \right)^{\sigma} \left(\frac{r}{w} \right)^{\beta^L} K^S.$$

Bringing back location and Fuel subscripts, the procedure to obtain labor demand in the Fuel sector in location ℓ is given by:

Compute $r_{\ell,F}$:

$$r_{\ell,F} = \left[\frac{\left(\beta_F^L\right)^{\beta_F^L} \left(1-\beta_F^L\right)^{1-\beta_F^L}}{w_{\ell,F}^{\beta_F^L}} \left(\frac{\left(\left(1-\chi_F\right) p_F z_{\ell,F}\right)^{1-\sigma_F} - \beta_F^E \, p_E^{1-\sigma_F}}{1-\beta_F^E} \right)^{\frac{1}{1-\sigma_F}} \right]^{\frac{1}{1-\beta_F^L}}$$

Then compute $L_{\ell,F}^D$:

$$L_{\ell,F}^D = \frac{\beta_F^L}{1-\beta_F^L} \left(\frac{r_{\ell,F}}{w_{\ell,F}} \right) \times K_{\ell,F}^S$$

Finally, sequentially compute:

$$c_{F,KL}\left(w_{\ell,F}, r_{\ell,F}\right) = \left(\frac{w_{\ell,F}}{\beta_F^L} \right)^{\beta_F^L} \left(\frac{r_{\ell,F}}{1-\beta_F^L} \right)^{1-\beta_F^L}$$

$$E_{\ell,F}^D = \frac{\beta_F^E}{1-\beta_F^E} \left(\frac{\beta_F^L}{1-\beta_F^L} \right)^{\beta^L} \left(\frac{c_{KL}\left(w_{\ell,F}, r_{\ell,F}\right)}{p_E} \right)^{\sigma_F} \left(\frac{r_{\ell,F}}{w_{\ell,F}} \right)^{\beta_F^L} K_{\ell,F}^S.$$

B Derivation of the recovery of labor supply parameters

In steady state we have:

$$\mathcal{V}_{\ell,j} = \frac{w_{\ell,j} + b}{P_\ell} + \eta_{\ell,j} + \nu \log\left(\sum_{k,n} \exp\left(\frac{-C_{\ell,j,k,n} + \beta \mathcal{V}_{k,n}}{\nu}\right)\right)$$

Steady state transition rates from region-pair ℓ, j to region-pair k, n are given by:

$$m_{\ell,j,k,n} = \frac{\exp\left(\frac{-C_{\ell,j,k,n}+\beta\mathcal{V}_{k,n}}{\nu}\right)}{\sum_{k',n'} \exp\left(\frac{-C_{\ell,j,k',n'}+\beta\mathcal{V}_{k',n'}}{\nu}\right)}$$

We derive how to obtain mobility costs and preferences for sectors based on data on migration rates $m_{\ell,j,k,n}$, real wages and knowledge of ν.

We obtain the two equations below:

$$\log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right) = \frac{-C_{\ell,j,k,n} + \beta\left(\mathcal{V}_{k,n} - \mathcal{V}_{\ell,j}\right)}{\nu}$$

$$\begin{aligned}\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right) = \frac{C_{\ell,j,k,n}}{\nu} &- \log\left(\sum_{k',n'} \exp\left(\frac{-C_{k,n,k',n'} + \beta\mathcal{V}_{k',n'}}{\nu}\right)\right) \\ &+ \log\left(\sum_{k',n'} \exp\left(\frac{-C_{\ell,j,k',n'} + \beta\mathcal{V}_{k',n'}}{\nu}\right)\right)\end{aligned}$$

Use

$$\log\left(\sum_{k,n} \exp\left(\frac{-C_{\ell,j,k,n} + \beta\mathcal{V}_{k,n}}{\nu}\right)\right) = \frac{\mathcal{V}_{\ell,j} - \frac{w_{\ell,j}}{P_\ell} - \eta_{\ell,j}}{\nu}$$

To obtain

$$\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right) = \frac{C_{\ell,j,k,n}}{\nu} + \frac{\left(\frac{w_{k,n}+b}{P_k} - \frac{w_{\ell,j}+b}{P_\ell}\right) + \left(\eta_{k,n} - \eta_{\ell,j}\right) - \left(\mathcal{V}_{k,n} - \mathcal{V}_{\ell,j}\right)}{\nu}$$

Implying

$$-\log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right)-\beta\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right)=(1-\beta)\,\frac{C_{\ell,j,k,n}}{\nu}-\frac{\beta}{\nu}\left(\frac{w_{k,n}+b}{P_k}-\frac{w_{\ell,j}+b}{P_\ell}\right)-\frac{\beta}{\nu}\left(\eta_{k,n}-\eta_{\ell,j}\right)$$

Rearranging:

$$\begin{aligned}C_{\ell,j,k,n}=&-\frac{\nu}{1-\beta}\log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right)-\frac{\nu\beta}{(1-\beta)}\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right)\\&+\frac{\beta}{1-\beta}\left(\frac{w_{k,n}+b}{P_k}-\frac{w_{\ell,j}+b}{P_\ell}\right)+\frac{\beta}{1-\beta}\left(\eta_{k,n}-\eta_{\ell,j}\right)\end{aligned}$$

Imposing $C_{\ell,j,\ell,j}=0$ (no cost of not moving), $C_{\ell,j,\ell,u}=0$ (no cost of moving locally to unemployment) and $\eta_{\ell,u}=0$ (unemployment gives zero utility) for all regions ℓ:

we obtain for all ℓ, j:

If $m_{\ell,j,\ell,j}>0$ and $L_{\ell,j}^{ACS}>0$:

$$\eta_{\ell,j}=-\frac{\nu}{\beta}\log\left(\frac{m_{\ell,j,\ell,u}}{m_{\ell,j,\ell,j}}\right)-\nu\log\left(\frac{m_{\ell,u,\ell,u}}{m_{\ell,j,\ell,u}}\right)-\left(\frac{w_{\ell,j}+b}{P_\ell}\right)$$

If $m_{\ell,j,\ell,j}=0$ or $L_{\ell,j}^{ACS}=0$:

$$\eta_{\ell,j}=-\infty$$

We can then recover mobility costs using:

If $m_{\ell,j,\ell,j}>0$, $L_{\ell,j}^{ACS}>0$ and $m_{\ell,j,k,n}>0$:

$$\begin{aligned}C_{\ell,j,k,n}=&-\frac{\nu}{1-\beta}\log\left(\frac{m_{\ell,j,k,n}}{m_{\ell,j,\ell,j}}\right)-\frac{\nu\beta}{(1-\beta)}\log\left(\frac{m_{k,n,k,n}}{m_{\ell,j,k,n}}\right)\\&+\frac{\beta}{1-\beta}\left(\frac{w_{k,n}+b}{P_k}-\frac{w_{\ell,j}+b}{P_\ell}\right)+\frac{\beta}{1-\beta}\left(\eta_{k,n}-\eta_{\ell,j}\right)\end{aligned}$$

Else

$$C_{\ell,j,k,n}=+\infty$$