The Role of Firms in Green Transition

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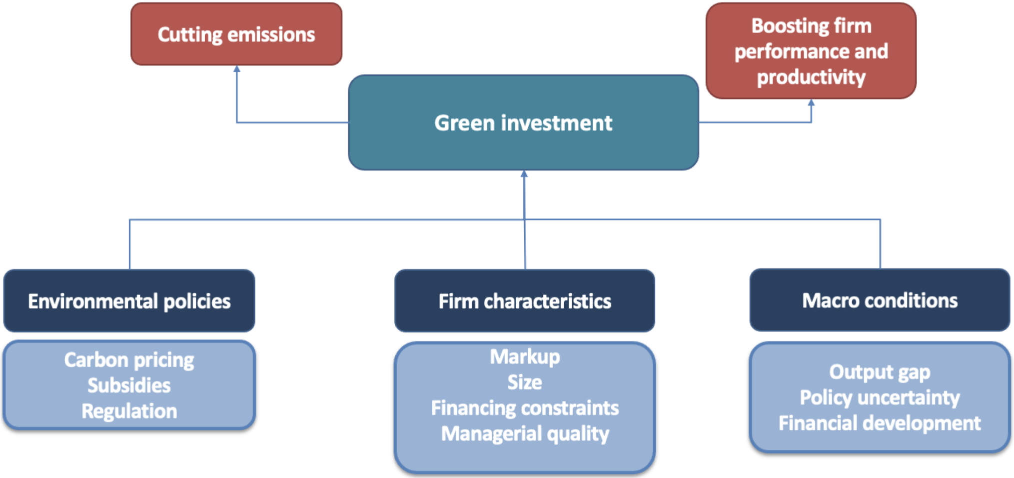
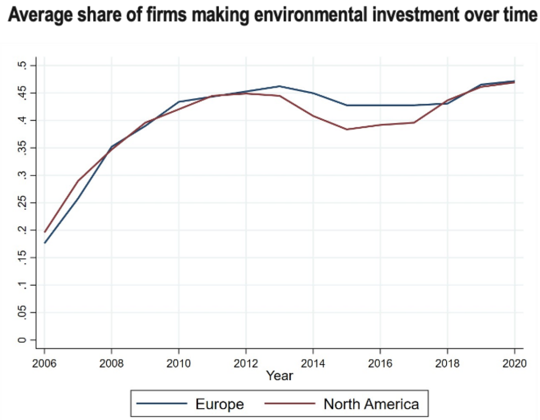
Green investment is at the core of the green transition

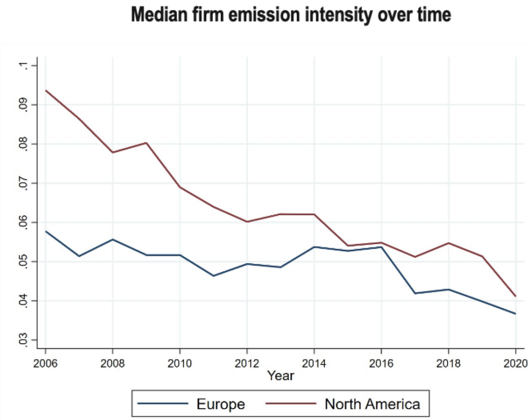
- IEA
  - Global energy investment will need to almost double to 4.5% of GDP by 2030.
  - Around 70% of green investment will have to be carried out by the private sector.
- . . . Yet, investment is so far behind what is needed to reach the zero-emission scenario (IEA, 2022; ECB, 2023). Why?

Green investment has potential to deliver a double dividend



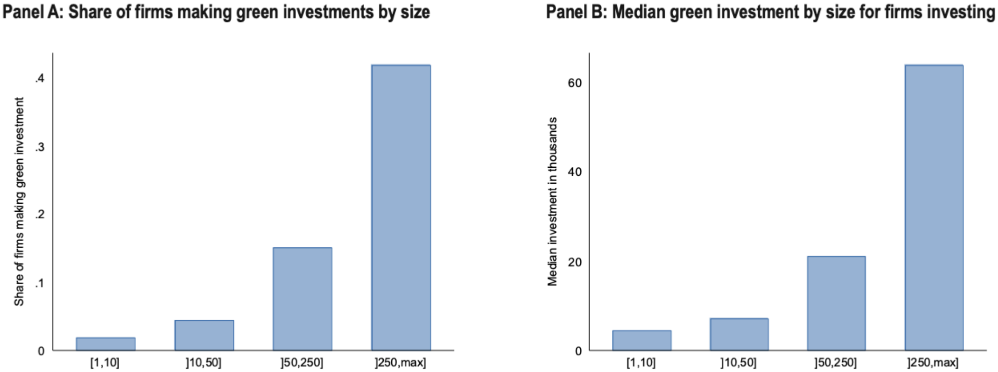
Green investment and reduced emission intensity are linked





Source: OECD calculations based on Refinitiv ESG data matched to Orbis Financials. Sample restricted to firms observed each year over the whole period.

Larger firms invest more



Source: Costa et al. (2024), based on data from the Portuguese Statistics Institute and the Portuguese Ministry for Education. Single country (PRT) data, from 2010 to 2020.

This Paper

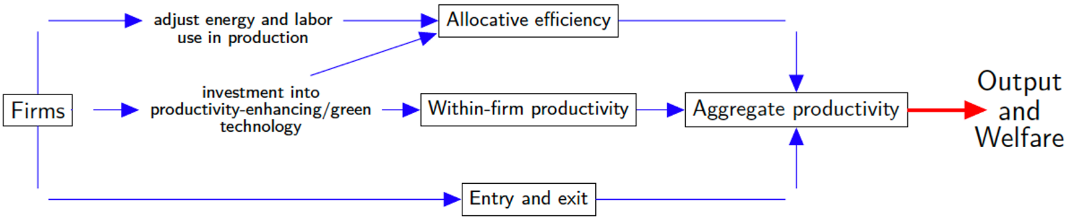
- We investigate how investment into green technology affects productivity and firm performance...
  - ...but also to dig deeper by exploring the drivers of green investment decisions and highlighting the heterogeneity of the relationship depending on firm characteristics, macroeconomic conditions and policy settings.

Questions

- What are the macroeconomic implications of implementing a carbon tax?
- What is the role of heterogeneities in firm-level decisions regarding output, price-setting, green investment, and entry-exit to environmental policies.
- What role do carbon tax-induced changes in market structure play in shaping macroeconomic outcomes via business dynamism and investment decisions?

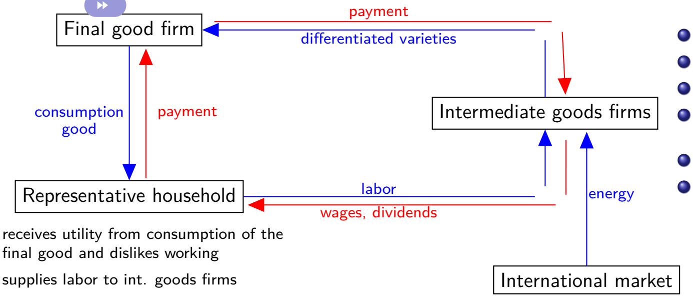
Overview of the Conceptual Framework

- A dynamic general equilibrium framework with
  - Firm-level heterogeneity in productivity (Ghironi and Melits 2005) and size-dependent variable markups (Baqaee and Farhi 2020; Edmond, Midrigan, and Xu 2023)
  - Endogenous technology choice
    - ⋆ Firms decide on investing into resource-saving green technology and its level (Acemoglu et al. 2016)
    - ⋆ A firm can operate a traditional technology or an advanced technology by sacrificing a per-period fixed cost as compensation for lowering the marginal cost of production (Altomonte et al. 2021; De Ridder 2019; Hsieh and Rossi-Hansberg 2023; Korinek, Ng, and Hopkins 2019).
  - Endogenous entry



Model Structure

- aggregates a continuum of intermediate varieties to produce the composite consumption good
- perfectly competitive



- monopolist of differentiated varieties
- heterogeneous firms
- size-dependent markups
- chooses the type (and the level) of the technology every period
- uses labor and energy
- entry/exit

- receives utility from consumption of the final good and dislikes working
- supplies labor to int. goods firms
- owns all firms

- supplies energy at an exogenous price

Intermediate Goods Firms

Production

- Each producer is the monopolist of a differentiated variety.
- has access to two production technologies
  - a traditional technology with a CRTS production function
  - or may invest in green technology that that lowers the marginal cost of production by choosing to operate an advanced technology
- The production function takes the following form:

$$y = \phi g^{\alpha_g} l^{\alpha_l} e^{\alpha_e}, \tag{1}$$

  where $g = 1$ if the firm uses the traditional technology. When the firm adopts the advanced technology, ϕg^{α_g} represents the firm-level effective productivity.
- Two factors of production: firms use labor and energy in production

Intermediate Goods Firms

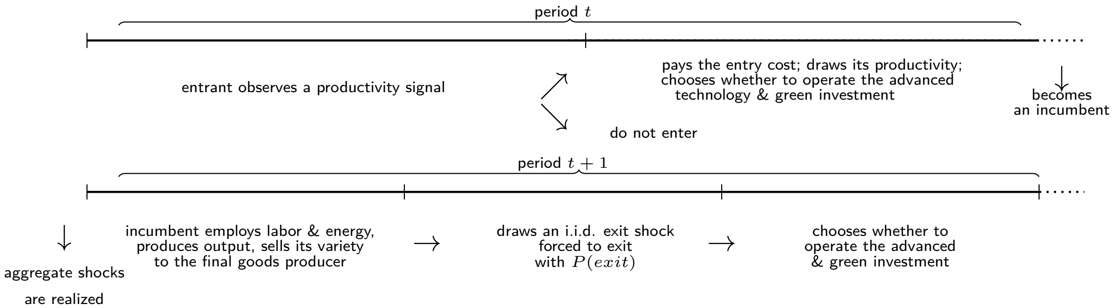


Fig. 1 Timing of Decisions for Intermediate Goods Firms

Intermediate Goods Firms

Entry

- There is free entry into the market which requires an initial entry cost f^e.
- Each period, there is a unit mass M_t of ex-ante homogeneous potential entrants which enter into the market depending on their expected profitability. Each potential entrant observes an idiosyncratic signal $s \sim H$ about their future idiosyncratic productivity before deciding on whether to enter.
- The free entry condition implies that entry occurs until the value of entry equals the entry cost:

$$V^e(\mathbf{s}) = f^e \tag{2}$$

where the value of entry is

$$V^e(\mathbf{s}) = \int_{\phi} \max \beta(1-s)E\left[V(\phi)|s\right] dE(\phi|s) \tag{3}$$

Intermediate Goods Firms

Entry

- After making the decision on entry and paying the fixed entry costs, entrants obtain a random draw of their idiosyncratic productivity ϕ from a known distribution $E(\phi|s)$.
- There is a lag to build assumption for the entrants and they start producing following the period of entry.
- Upon entering the market, the firm joins the pool of incumbent firms

Intermediate Goods Firms

- Firms decide how much variable input to employ to maximize its per-period profits:

$$\hat{\pi}(\phi; S) = \max_{p_t(j), y_t(j), l_t(j), e_t(j)} \left\{ p_t(j) y_t(j) - W_t l_t(j) - P_t^{e*} e_t(j) - f^o \right\} \tag{4}$$

  where S represents the state of firm j.

- The choice of the variable input is static, and it is not subject to any friction. The first-order condition for (4) is:

$$p(j) = \mu(\rho(j)) mc(j) \tag{5}$$

- Firm-level markup, $\mu(\rho(j))$, is increasing in relative firm size.

Intermediate Goods Firms

Exit

- After the production occurs, each firm draws and i.i.d exit shock and forced to exit with probability P^{exit}.
- If the firm exits, it is liquidated, and the surplus returns to the household.
- The value of the firm that exits from the market:

$$V^{\text{exit}} = \hat{\pi}(\phi; S) \tag{6}$$

Intermediate Goods Firms

Technology Choice

- Selection of the type of technology

$$
\begin{aligned}
V(\phi, g; S) &= \max_{d,I} \left[d + \beta(1 - P^{exit}) V(\phi, g'; S') \right], && (7)\\
\text{subject to} \quad d &= \hat{\pi}(\phi; S) - c(I) - \mathbb{I} f^{g} && (8)\\
d &\leq 0 && (9)\\
g' &= (1 - \delta) g + I && (10)
\end{aligned}
$$

where $c(I)$ is the variable cost and f^g is the fixed cost of green capital. $\mathbb{I}$ is an indicator function taking 1 if the firm adopts the advanced technology, i.e. $g > 0$, and zero when $g = 0$.

Intermediate Goods Firms

Technology Choice

- We rewrite the firm's problem as follows:

$$V(\phi, g; S) = \hat{\pi}(\phi; S) + \max\{V^g(\phi, g; S), V^t(\phi, g; S)\}, \tag{11}$$

where $V^g(\phi, g; S)$ denotes for the value of investing in *green* technology defined as:

$$V^g(\phi, g; S) \quad = \quad \max_I\{-c(I) - f^g + \beta E(1 - P^{exit})V(\phi, g'; S')\} \tag{12}$$

and $V^t(\phi, g; S)$ is the value of operating the *traditional* technology given by

$$V^t(\phi, g; S) \quad = \quad \max \beta E(1 - P^{exit})V(\phi, (1-\delta)g; S') \tag{13}$$

- The optimization implies that a firm invests in the tangible capital if and only if the fixed cost of the advanced technology is smaller than the profit gain from the technology:

$$f \leq f^* := \left[V^g(\phi, g; S) - V^t(\phi, g; S)\right] \tag{14}$$

A Recursive Stationary Equilibrium

- A recursive competitive equilibrium consists of aggregate allocations Y, N, I, C, Π, W, the wage rate W and a demand index D; firm-level policy functions $n(j)$, $e(j)$, $I(j)$ and firm-level prices $p(j)$; value functions $V^{\text{exit}}, V, V^a, V^n, V^e$ an incumbents measure Ω and an entrants measure M such that
  1. Given the wage rate W, aggregate consumption C, labor supply N satisfy the representative household's optimality condition (25).
  2. Given W and Y, the firm-level allocations and prices solve (11), (12), (13) and (3).

Aggregation

- Firm entry and exit implies the total number of firms is equal to number of surviving firms (Ω') and number of entrants (M). The mass of firms evolves according to:

$$\Omega = \Omega' + M \tag{15}$$

- Net earnings from the ownership of firms are given as:

$$\Pi = \int_{j \in \Omega'} V(j)\, dj + \int_{j \in \Omega \setminus \Omega'} V^{exit}(j)\, dj. \tag{16}$$

- Labor market clearing requires that all labor demanded by firms producing at time t is supplied by the household:

$$N = \int_{j \in \Omega} l(j)\, dj \tag{17}$$

Aggregation

- Energy market clearing implies that all energy demanded by firms producing at time t is supplied by the international market (at an exogenous price P_e^*):

$$E = \int_{j\in\Omega} e(j)\,dj. \tag{18}$$

- Aggregate stock of green capital is

$$G \equiv \int_{j\in\Omega} g(j)\,dj, \tag{19}$$

- Aggregate resource constraint of the economy is given by:

$$C + c(I)I + \int_{\Omega} f + P_e^* E = Y. \tag{20}$$

Quantifying the Model

- We parameterize the model in order to match key features of the cross-section distribution of producers as well as within-producer dynamics. (Calibration Strategy)
- We use detailed data from Integrated Company Accounts System (Sistema de Contas Integradas das Empresas – SCIE) between 2008-2020, collected by Statistics Portugal (INE).
  - on total sales, total wage bill, expenditure on energy use, cost of goods and services, the number of firms, and balance sheet data for the universe of Portuguese non-financial firms and 2-digit industry in which the firm operates.
- We also use the survey information on environmental statistics from Environmental Management and Protection Business Survey (Inquerito as Empresas Gestao e Protecao do Ambiente-IEGPA) between the years 2010-2020 by INE.
  - on firms' activities including management and protection of environmental, and human resources working in the environmental area.
  - We use data on firms' investment in technologies to control pollution as a proxy for green investment.

Quantifying the Model

Model Validation

- We solve the steady-state equilibrium of the model based on the calibrated parameters.
- Model's fit is summarized below:

Matched Moments

Moments	Model	Data
Sales-markup regression	0.84	0.75
Average markup	1.09	1.12
Sales share of investing firms %	35	17
Fraction of green investment %	15	9.22

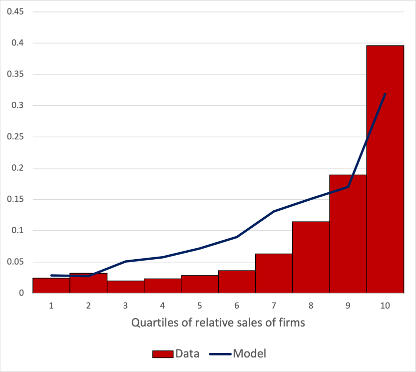
Note: This table shows the targeted data moments and the simulated moments by the model.

- The calibrated model matches the targeted moments reasonably well for revenue-markup regression and average markup. However, the model slightly overestimates the sales share of investing firms and the fraction of green investment.

Quantifying the Model

Model Validation

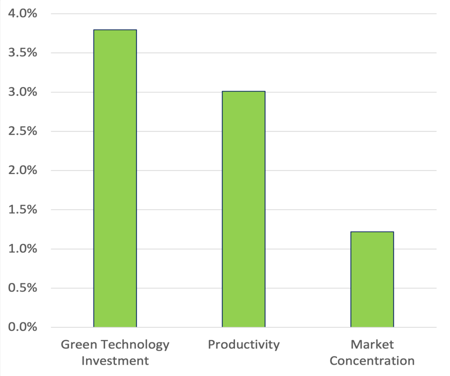
- The distribution of firms that invest in green technology in Portuguese data and the fraction of firms that produce with green technology.



Distribution of green investment

- The model closely aligns with the distribution of green investments.
- In both the data and the model, the utilization of green technology is heavily skewed towards the largest firms.
- For the remaining firms, only a small fraction of firms invest in green technology.

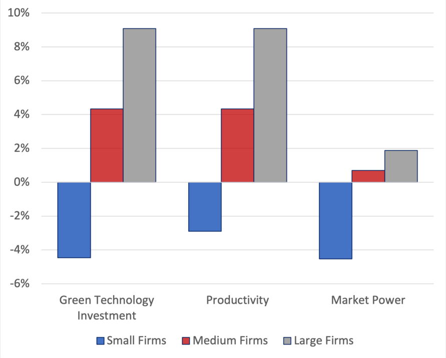
Carbon pricing boosts aggregate productivity by promoting increased green technology investment



Steady-state results aggregated over individual firms.

- `Intensive margin effect:` Investment into productivity-enhancing green technology rises, improving total factor productivity.
- `Extensive margin effect:` More firms invest in green technology.
- Market concentration rises.

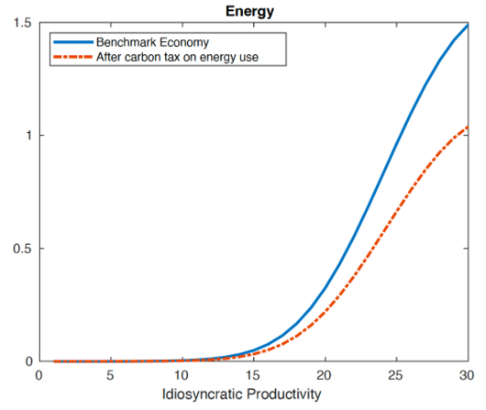
Larger firms gain from the green transition, at the expense of small firms



*Note:*Steady-state results aggregated over small, medium-sized and large firms.

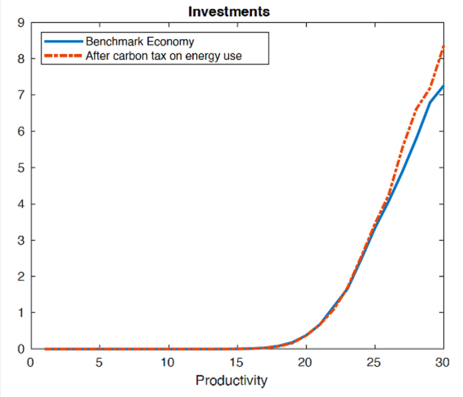
- Due to the fixed costs of green technology investment, larger firms invest more.
- Green investment boosts productivity of large firms and increase their market share.
- Higher market concentration may affect business dynamism and prices in longer term, impacting output and welfare.

Firms' energy use has decreased significantly after carbon tax, as targeted by policy



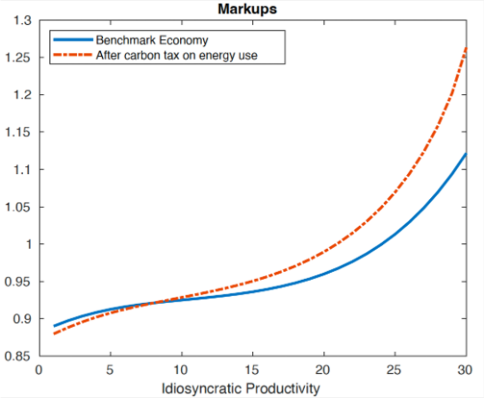
- Higher energy prices dampen energy used by firms.

Carbon pricing boosts investment, especially among more productive firms



- A large set of firms with low productivity does not invest in green technology.
- Productivity gains from investment is higher for larger firms.

Carbon tax reallocates production towards firms with higher markups, incentivizing green investment



- As energy prices rise, production falls but average markup rises.
- An increase in the average markup is caused primarily by the reallocation of resources between firms.

Welfare implications

- Ad-hoc social welfare function

$$E_t \sum_{s=0}^{\infty} \beta^s \lambda_U \left\{ u(C_t, N_t) - \lambda_E x(E_t) \right\} \tag{21}$$

- Welfare gains (losses) from carbon taxing under alternative importance of environmental concerns

Welfare Analysis

	Relative weight of environmental externality		
	0.25	0.50	0.75
Change in social welfare	-23.58%	12 %	47.58 %

  - When environmental concerns are low, carbon tax may result in welfare losses.
  - As the social cost of carbon emissions increases, social welfare can be improved in the medium term.

Policy Implications

- While there are short-term transition costs, firms adapt to energy price shifts through green investment, potentially boosting productivity.
- Yet, there are marked differences across firms on how they adjust to higher energy prices through green investment.
- More productive, larger firms increase green investment and achieve higher productivity, while increasing their market share.
- Support small and financially constrained firms to avoid productivity losses.
- Monitor market concentration and its effects on prices/consumers.

Work Agenda

- A new Macro-structural framework of climate adaptation and mitigation
  - Macroeconomic frictions and externalities
  - Fiscal policy and debt sustainability
    - consideration of future liabilities
  - Policy-relevant horizon
    - gains/losses from (no) policy action in 5-10 years (and beyond)
  - Two-way causality between climate and economy
    - incorporates possibility of tipping points and nonlinearities
  - Firm's endogenous (green) investment & innovation decisions
  - Unified model with adaptation and mitigation policies, and multiple tools
    - including carbon pricing, various subsidies, regulatory measures, and public resilient investments

A new Macro-structural framework of climate adaptation and mitigation

Market Failures and Externalities

- Climate externalities
- Sectoral labor mismatches
- Learning-by-doing externalities
- Innovation externalities
- Missing demand externalities
- Network externalities
- Financial frictions
- Mark up distortions

Economic Structure

- Climate risks and shocks
- Sectoral composition
- Factor shares
- Fiscal space/debt levels
- Import dependence

Policy Tools

- Carbon pricing
- Subsidies
- Regulatory measures
- Public resilient investment

Macroeconomic Outcomes

- Output
- Debt
- Welfare

No-action scenario

Appendix

Representative Household

- Representative hh receives utility from consumption of a consumption good and dislikes working. household chooses consumption C_t and the supply of labor N_t to maximize her lifetime utility:

$$E_t \sum_{s=0}^{\infty} \beta^s u(C_t, N_t), \tag{22}$$

$$u(C_t, N_t) = \left\{ lnC_{t+s} - \nu_n \frac{N_{t+s}^{1+\eta}}{1+\eta} \right\} \tag{23}$$

subject to the following budget constraint:

$$W_t N_t + \Pi_t = P_t C_t \tag{24}$$

- We normalize $P_t \equiv 1$ so that the aggregate price index is taken as the numeraire. The intertemporal first-order condition of household's utility maximization problem implies the following optimality condition:

$$-\frac{u'(C_t)}{u'(N_t)} = \frac{1}{W_t} \tag{25}$$

Go back

Final Good Firm

- A representative final good producer aggregates a continuum of measure (or an endogenous mass of varieties) Ω_t of intermediate varieties $y_t(j)$ to produce one unit of composite consumption good Y_t according to the Kimball aggregator[1]:

$$Y_t = \int_0^{\Omega_t} \Gamma\left(\rho_t(j)\right) dj = 1, \quad \rho_t(j) \equiv \frac{y_t(j)}{Y_t} \tag{26}$$

- The cost minimization problem of the perfectly competitive final goods producer yields the following demand for each differentiated variety $j \in \Omega$:

$$p_t(j) = \Gamma'(\rho_t(j))D_t \tag{27}$$

where D_t is a demand shifter defined as $D_t \equiv \left(\int_0^{\Omega_t} \Gamma'(\rho_t(j))\rho_t(j)\, dj \right)^{-1}$.

Go back

[1] $\Gamma(\rho)$ is assumed to be specified according to Klenow and Willis 2016 specification, implying $\mu(j) = \sigma(j)/\sigma(j) - 1, \quad \sigma(\rho(j)) = \sigma\rho(j)^{-\frac{\varepsilon}{\sigma}}$.

Quantifying the Model

Calibration Strategy

- We fix certain parameters and and select remaining parameters to ensure model consistency with data features.

Fixed Parameters		
Subjective discount factor	β	0.96
Inverse Frisch elasticity	η	0.5
Probability of exit	P^{exit}	0.1
Relative price of energy	P_e^*	1.2
Green capital depreciation rate	δ	0.25
Share of green tech.	α^g	0.225
Share of labor	α^l	0.54
Share of energy	α^g	0.135

Go back

Quantifying the Model

Calibration Strategy

Calibrated Parameters			
Superelasticity	ε/σ	0.20	Sales-markup relationship
Elasticity	σ	15	Average markup
TFP persistence	ρ_ϕ	0.85	Concentration on firm sales
TFP dispersion	σ_ϕ	0.15	Concentration on firm sales
Fixed Cost of green technology	f	2	Fraction of green investment
User cost of green technology	$c(I)$	0.2	Fraction of green investment

Go back