Green and Brown Sectors in a Rigid Network

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Motivation

- Economic shocks transmit rapidly across sectors, amplifying global financial risks.
- Sectors make rigid input decisions that are not state-dependent.
- Governments increasingly enforce regulations to drive green transition.
- Natural disasters increasingly harm sector productivity and economic stability.
- Transition shocks are meant to switch to a greener production in all sectors.

Rigidity

In this paper we formalize rigidity in sectors' decision-making.

- Sectors take into account possible realization of shocks.
- This rigidity prevents firms from adapting their decisions to real-world scenarios.
- Rigidity is a common friction, especially in global supply chains.

This Paper

This paper investigates how physical and transition shocks affect production networks, focusing on the interplay between green and brown sectors.

Key Features of the Paper:

1. **Firm Rigidity:** Sectors' inability to adapt magnifies the impact of shocks.
2. **Transition Shocks:** Regulatory changes disproportionately affect brown sectors.
3. **Physical Risk Shocks:** Natural disasters, impacting all sectors on their TFP.
4. **Network Effects:** Production networks amplify and diffuse shocks.

This paper examines the conditions under which government regulations are most effective in transitioning the economy to greener production.

Contribution to the Literature

- **Long and Plosser (1983); Acemoglu et al. (2012):** Perfectly-competitive Cobb-Douglas economy; ex-post production adjustment.
- **Devulder and Lisack (2020); Abbasi and Choukolaei (2023):** Carbon tax in a production network.

Our Contribution: We incorporate rigidity, transition shocks, and TFP shocks into a network framework to examine conditions under which regulations drive a shift to greener production.

Empirical Analysis

Dataset

- **Compustat Capital IQ (WRDS):** Annual firm-level data, 1985–2024.
- **NBER-CES Manufacturing Database:** Annual industry-level data, 1958–2018.
- **S&P ESG Measures:** Annual data on ESG performance, 2013–2024.
  - Assume a distribution of firms with ESG score, take the 50 percentile as a threshold.
- **Data Integration:** Merged firm-level financial statements with ESG performance.

From the Data: TFP ζ^B vs TFP ζ^G

- Merge NBER-CES (cost shares) with Compustat (firm-level data).
- Apply the formula to compute TFP for each firm, then aggregated at NAICS5.

$$\zeta = \log(\text{VA}) - [s_L \cdot \log(L) + s_K \cdot \log(K)]$$

where:

- VA: Value added (firm-level).
- s_L: Labor share (industry-year, from NBER-CES); L: Employment (firm-level).
- s_K: Capital share (industry-year, from NBER-CES); K: Capital stock (firm-level).

How it works:

- Assumes a Cobb-Douglas production function:

$$Y = A \cdot K^\alpha \cdot L^\beta$$

- Cost shares s_K and s_L approximate elasticities (α, β).
- Assumes perfect competition and constant returns to scale.

From the Data: ζ^{B}_{ESG} vs ζ^{G}_{ESG}

	Brown Raw (1)	Green Raw (2)	Brown Model (3)	Green Model (4)
Leverage	0.317	0.337	0.315	0.339
	(0.311)	(0.212)	(0.305)	(0.221)
TFP	1.919	1.433	1.908	1.426
	(1.926)	(2.060)	(1.894)	(2.095)
Size	2.493	4.004	2.598	3.893
	(1.421)	(1.247)	(1.442)	(1.345)
Tobin's Q	1.078	1.049	1.077	1.050
	(0.534)	(0.491)	(0.532)	(0.492)
EBITDA	4.184	28.517	4.701	28.466
	(13.539)	(73.126)	(15.225)	(73.592)
ROE	0.280	0.138	0.295	0.120
	(14.846)	(9.644)	(14.807)	(9.653)
ROA	-0.035	0.040	-0.028	0.033
	(0.307)	(0.147)	(0.303)	(0.156)
ROI	-0.105	0.081	-0.058	0.033
	(3.018)	(0.686)	(1.872)	(2.542)
COGS/AT	0.589	0.583	0.599	0.572
	(0.582)	(0.564)	(0.588)	(0.557)
N	4586	4318	4623	4281

Observation of TFP limited to Manufacturing Sectors

From the Data: ζ_E^B vs ζ_E^G

	Brown Raw (1)	Green Raw (2)	Brown Model (3)	Green Model (4)
Leverage	0.316	0.339	0.318	0.336
	(0.300)	(0.228)	(0.301)	(0.226)
TFP	1.996	1.240	1.928	1.364
	(1.920)	(2.046)	(1.899)	(2.094)
Size	2.573	3.929	2.615	3.863
	(1.446)	(1.306)	(1.452)	(1.356)
Tobin's Q	1.083	1.043	1.075	1.052
	(0.531)	(0.494)	(0.529)	(0.496)
EBITDA	5.570	27.724	6.105	26.983
	(20.227)	(72.838)	(23.898)	(71.578)
ROE	0.271	0.144	0.297	0.118
	(14.811)	(9.584)	(14.772)	(9.717)
ROA	-0.029	0.035	-0.025	0.030
	(0.301)	(0.159)	(0.301)	(0.162)
ROI	-0.060	0.035	-0.057	0.031
	(1.864)	(2.553)	(1.871)	(2.542)
COGS/AT	0.585	0.587	0.598	0.573
	(0.570)	(0.577)	(0.580)	(0.566)
N	4660	4244	4616	4288

Observation of TFP limited to Manufacturing Sectors

Model Setup

Framework

- Two-period economy with $n \geqslant 1$ sectors and a unit mass of consumers.
- A sector can be either **green** or **brown**.
- Each sector produces a single homogeneous good.
- Firms can be affected by TFP (physical risk) shocks.
- This model has a similar structure to Como et al. (2024), with the exception of the heterogeneous structure in the production function and no banks.

Key Assumptions

- A fraction $\xi = 0.5$ of sectors are **brown**, a fraction $1 - \xi$ are **green**.
- Brown sectors have a productivity of $\zeta^B > \zeta G$ which is higher than green ones.
  - Empirical evidence aligns with Bosi et al. 2024.
- 2 shocks affect the economy: **transition shock** (ε) and **physical risk shock** (η).
- Brown sectors are hit by both shocks, while green ones are only hit by the latter.
- Transition shocks on brown sectors are solely negative, since it limits their TFP.

Production Sectors

Production Sectors and Production Variables

Each sector $k \in \mathcal{V}$ has the following variables:

- y_k – production output.
- c_k – consumption of produced goods.
- l_k – employed labor.
- z_{jk} – quantity of product j used in firm k's production.

Key Assumptions:

- Decisions (by firms, consumers) are made at time 0.
- Shocks to productivity η_k, physical risk, and ε_k, transition, are realized at time 1.
- Shocks as $\eta, \varepsilon : \Omega \to \mathbb{R}^n$, defined under the complete probability space $(\Omega, \mathcal{F}, \mathbb{P})$.

Leontief Matrix and Series Expansion

Leontief Matrix:

$$L = (I - A')^{-1}$$

$$L = \sum_{h=0}^{\infty} (A')^h = I + A' + (A')^2 + (A')^3 + \cdots$$

Implications:

- The Leontief matrix captures how shocks propagate through the production network.
- The assumption $\rho(A) < 1$ ensures that this infinite series converges.

Properties of Matrix A:

- $A_{kk} \geqslant 0$, and the sum per column of A is $\leqslant 1$, making A a column-substochastic matrix.
- We assume $\rho(A) < 1$, ensuring that the Leontief matrix is well-defined.

Production Functions

- Brown firms have the following production function:

$$y_k^B = \zeta_k^B e^{\rho_{\varepsilon k} + \rho_{\eta k}} l_k^\beta \prod_j z_{jk}^{A_{jk}}$$

- Gren firms have the following production function:

$$y_{k'}^G = \zeta_{k'}^G e^{\rho_{\eta k'}} l_{k'}^\beta \prod_j z_{jk'}^{A_{jk'}}$$

Notice that $\rho_\varepsilon = L\varepsilon$, $\rho_\eta = L\eta$, $k \in \mathcal{V}(B)$ and $k' \in \mathcal{V}(G)$, where $\mathcal{V}(B) \bigcup \mathcal{V}(G) = \mathcal{V}$.

Market Clearing Conditions:

1. Goods Market: $y_k = \sum_j z_{kj} + c_k, \quad \forall k = 1, \ldots, n$
2. Labor Market: $\sum_k l_k = 1$

Consumers

Consumer Assumptions and Utility

- Consumers have a Cobb-Douglas utility function:

$$U(c) = \prod_k c_k^{\gamma_k}$$

where $\gamma_k \geqslant 0$ represents the preference weight for good k, with $\sum_k \gamma_k = 1$.

- Consumers earn income through wages and dividends as workers and owners of firms and the bank.
- Consumption maximization is subject to:

$$\sum e^{\rho_k} c_k p_k \leqslant E^\eta$$

where E^η denotes total income.

Equilibrium

Theorem 1: Existence and Uniqueness of Equilibrium

In a Cobb-Douglas economy $(\mathcal{V}, A, \beta, \gamma, \zeta)$ satisfying merket clearing conditions with $\rho(A) < 1$ and assuming both a primitive log-productivity shock distribution P and a primitive log-transitivity shock Q, a unique rigid Walrasian equilibrium (y, z, c, l, p, w) exists, where y, c, l, z, and p/w are fully determined.

- **Labor and Intermediate Quantities of Brown Sectors**:

$$l_k = \frac{\beta_k \mathbb{E}[e^{\rho_{\varepsilon k} + \rho_{\eta k}}]}{w}, \quad z_{jk} = \frac{A_{jk} \mathbb{E}[e^{\rho_{\varepsilon k} + \rho_{\eta k}}]}{w}$$

- **Labor and Intermediate Quantities of Green Sectors**:

$$l_k = \frac{\beta'_k \mathbb{E}[e^{\rho_{\eta k'}}]}{w}, \quad z_{jk} = \frac{A_{jk'} \mathbb{E}[e^{\rho_{\eta k'}}]}{w}$$

Corollary 1: In a rigid Walrasian equilibrium, we have the following expressions for actual profits:

$$\Pi_k^{\eta,\varepsilon} = \frac{wve^{\rho_{\eta k + \varepsilon k}}}{\lambda_k \mathbb{E}[e^{\rho_{\eta k + \varepsilon k}}]} - \xi_k$$

where

$$\xi_k := \mathbb{E}[e^{\rho_{\eta k + \varepsilon k}}] \left(\beta_k + \sum_j A_{jk} \frac{\mathbb{E}[e^{\rho_{\eta j + \varepsilon j}}]}{\lambda_k \mathbb{E}[e^{\rho_{\eta k + \varepsilon k}}]} \right)$$

$$\Pi_k^{\eta,\varepsilon} = \frac{wve^{\rho_{\eta k'}}}{\lambda_{k'} \mathbb{E}[e^{\rho_{\eta k'}}]} - \xi_k'$$

where

$$\xi_k' := \mathbb{E}[e^{\rho_{\eta k'}}] \left(\beta_k + \sum_j A_{jk} \frac{\mathbb{E}[e^{\rho_{\eta j'}}]}{\lambda_k \mathbb{E}[e^{\rho_{\eta k'}}]} \right)$$

Conclusions

What is Next

Main result:

- Brown sectors are subject to higher default probability because hit by both shocks.

What is next:

- Add one more period to the economy, where brown sectors can opt to stay brown or become green.
- Study how transition is accelerated by realizations of both physical risk and transition shocks.

Goal of the paper:

- Analyze how the interaction of these shocks drives sectors to transition toward greener operations.