The Role of Energy Efficiency in Productivity: Evidence from Canada

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Outline

Why Study Energy Misallocation?

- Resource misallocation $\rightarrow$ major source of productivity loss.
- Prior work: Focusing mainly on capital and labor misallocation.
- Energy: a central input in all sectors, yet much less studied.
- Increasingly important for both productivity and climate policy.

Sources: Hsieh and Klenow (2009); Restuccia and Rogerson (2017); Bartelsman et al. (2013); Chen and Irarrazabal (2015); Asker et al. (2019); Choi (2020); Tombe and Winter (2015).

Share of Manufacturing Sector

- ... However, most studies focus on manufacturing sector and firm level input inefficiencies.

Country	**Manufacturing Share (% of GDP)**
China (2023)	25.5
India (2023)	13.0
USA (2023)	10.3
Canada (2014–2020 avg.)	$\sim$10.0

Source: World Bank

- I rather examine **economy-wide** estimate of energy misallocation at **sector-by-province** level.

Why Canada? & Why Province-Sector Level?

- Provinces differ in energy policy $\rightarrow$ fragmented markets.
- High variation in energy prices, infrastructure, and regulation.
- Limited interprovincial trade $\rightarrow$ persistent inefficiencies.
- Internal trade studies show sizable productivity losses (3–7%).[a]
- Rich provincial input–output data (2014–2020).

Canada's Input Shares (Sector Level)

Input	**Share (%)**
Labor	60–65
Capital	25–30
Energy	5–10

Author's calculations.

[a] Albrecht and Tombe (2016); Alvarez et al. (2019)

Preview of the Results

- $\sim$5–8% potential TFP gains overall (2014–2020)
- **Decomposition: Most misallocation (more than half) comes from within-sector differences across provinces**
  - Capital dominates between-sector losses: $\sim$1–4% output loss
  - Energy accounts for $\sim$1–2% output loss (disproportionately large relative to its small share $\sim$8%)
  - Labor accounts for less than $\sim$1% output loss
- Per dollar, energy is more distortionary than capital or labor.
- Bottom line: Energy inefficiency acts as a persistent bottleneck, offsetting efficiency gains elsewhere.

Contribution

- Connects **output gaps and climate goals**: efficient energy use boosts **productivity** *and* reduces **emissions**.
- I focus on **energy** as an essential input and show its disproportionately large effect on aggregate productivity $\rightarrow$ **equally (even more) important to capital or labor**.
- First **economy-wide** estimate of energy misallocation (sector $\times$ province data).
- Quantifies productivity loss from energy misallocation across **regions** and sectors $\rightarrow$ **spatial dimension**
- Uses a tractable, flexible, and generalizable model $\rightarrow$ policy insights on energy pricing, infrastructure, climate policy.

Outline

Data Sources & Features

- Statistics Canada **Provincial Input–Output Tables** (2014–2020).
- Sectors: 230+ sectors, covering entire economy.
- Inputs: energy, capital, labor.
- Sector-by-province level variation.
- Energy share in inputs varies widely by province.
- Detailed enough (more than 230+ sectors for 10 provinces).

Who's Who in the Data: Energy Sectors

- 10 - Oil and gas extraction (except oil sands)
- 11 - Oil sands extraction
- 12 - Coal mining
- 22 - Natural gas extraction
- 23 - Support activities for oil and gas extraction
- 24 - Support activities for mining
- 25 - Electric power generation, transmission and distribution
- 30 - Transportation engineering construction
- 31 - Oil and gas engineering construction
- 57 - Petroleum refineries
- 58 - Petroleum and coal product manufacturing (except petroleum refineries)
- 148 - Crude oil and other pipeline transportation
- 149 - Pipeline transportation of natural gas

Who's Who in the Data: Capital and Labor

Capital:

- Single row: Gross Mixed Income

Labor:

- Two rows:
  - Wages and salaries
  - Employers' social contributions

Outline

Conceptual Framework

- Build on Hsieh–Klenow (2009) misallocation model.
- Provinces/sectors face distortions $\rightarrow$ marginal revenue products differ.
- Extend to include **energy** alongside capital and labor.
- Compare observed allocation vs. efficient benchmark.
- Fully tractable and flexible model allowing for clean decomposition: **within-sector (across provinces)** vs. **between-sector (within provinces)** misallocation.

Outline

Aggregate Output and Sectoral Shares

- National output is CES over sectoral outputs:

$$Y = \prod_{s=1}^{S} Y_s^{\theta_s}, \quad \theta_s = \frac{P_s Y_s}{PY}, \quad \sum_s \theta_s = 1$$

- Each sector s is CES across provinces i:

$$Y_s = \left(\sum_i Y_{si}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Associated price index:

$$P_s = \left(\sum_i P_{si}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

Production Technology

- Sector–province production follows Cobb–Douglas with three inputs:
$$Y_{si} = A_{si} K_{si}^{\alpha_s} L_{si}^{\beta_s} E_{si}^{\gamma_s}, \quad \alpha_s + \beta_s + \gamma_s = 1$$
- Inputs: capital K, labor L, energy E.
- Distortions enter as wedges on input prices.

Profit Maximization with Distortions

- Each sector s in province i maximizes profits:

$$\max_{K,L,E} P_{si} Y_{si} - (1+\tau_K) rK - (1+\tau_L) wL - (1+\tau_E) p_E E$$

- τ are wedges capturing distortions.
- Leads marginal revenue products (MRPs) to be distorted.

Marginal Revenue Products

From first-order conditions:

$$MRPK_{si} = \alpha_s \frac{P_{si} Y_{si}}{K_{si}} = (1 + \tau_{K_{si}})r$$

$$MRPL_{si} = \beta_s \frac{P_{si} Y_{si}}{L_{si}} = (1 + \tau_{L_{si}})w$$

$$MRPE_{si} = \gamma_s \frac{P_{si} Y_{si}}{E_{si}} = (1 + \tau_{E_{si}})p_E$$

- Equalization across provinces and sectors implies efficiency.
- Dispersion reflects misallocation.

Productivity Measures

- Physical TFP (TFPQ):

$$TFPQ_{si} = \frac{Y_{si}}{K_{si}^{\alpha_s} L_{si}^{\beta_s} E_{si}^{\gamma_s}}$$

- Revenue TFP (TFPR):

$$TFPR_{si} = \frac{P_{si} Y_{si}}{K_{si}^{\alpha_s} L_{si}^{\beta_s} E_{si}^{\gamma_s}}$$

$$\begin{aligned} TFPR_{si} &\propto (MRPK_{si})^{\alpha_s} (MRPL_{si})^{\beta_s} (MRPE_{si})^{\gamma_s} \\ &\propto (1 + \tau_{K_{si}})^{\alpha_s} (1 + \tau_{L_{si}})^{\beta_s} (1 + \tau_{E_{si}})^{\gamma_s} \end{aligned}$$

- Key insight: TFPR dispersion $\Rightarrow$ misallocation.

Sectoral Productivity under Misallocation

- **Sector TFP with distortions:**

$$A_s = \left[\sum_i \left(A_{si} \left(\frac{\overline{MRPK_s}}{MRPK_{si}} \right)^{\alpha_s} \left(\frac{\overline{MRPL_s}}{MRPL_{si}} \right)^{\beta_s} \left(\frac{\overline{MRPE_s}}{MRPE_{si}} \right)^{\gamma_s} \right)^{\sigma-1} \right]^{\frac{1}{\sigma-1}}$$

- **Efficient benchmark (no distortions):**

$$A_s^* = \left(\sum_i A_{si}^{\sigma-1} \right)^{\frac{1}{\sigma-1}}$$

$$\frac{A_s}{A_s^*} = \left[\sum_i \left(\frac{A_{si}}{A_s^*} \left(\frac{\overline{MRPK_s}}{MRPK_{si}} \right)^{\alpha} \left(\frac{\overline{MRPL_s}}{MRPL_{si}} \right)^{\beta} \left(\frac{\overline{MRPE_s}}{MRPE_{si}} \right)^{\gamma} \right)^{\sigma-1} \right]^{\frac{1}{\sigma-1}}$$

Productivity Decomposition

- National productivity loss decomposed into:

$$\frac{A}{A^*} = \underbrace{\prod_s \left(\frac{A_s}{A_s^*}\right)^{\theta_s}}_{\text{Within-sector misallocation}} \times \underbrace{\prod_s \left(\left(\frac{k_s}{k_s^*}\right)^{\alpha_s} \left(\frac{l_s}{l_s^*}\right)^{\beta_s} \left(\frac{e_s}{e_s^*}\right)^{\gamma_s}\right)^{\theta_s}}_{\text{Between-sector misallocation}}$$

- Within-sector: across provinces in a sector (interprovincial).
- Between-sector: across sectors in the economy (intersectoral).
- Can further decompose by input: capital, labor, energy.

Measuring Input-Specific Distortions

- Recall that (under Cobb-Douglas):

$$MRPK_{si} = \alpha_s \frac{\sigma - 1}{\sigma} \frac{P_{si} Y_{si}}{K_{si}} = (1 + \tau_{K_{si}}) r$$

- Taking logs and subtracting $\ln(r)$ and rearranging:

$$\underbrace{\ln(MRPK_{si})}_{\epsilon_{si}} - \underbrace{\ln(r) - \ln\left(\frac{\sigma - 1}{\sigma}\right)}_{\beta_0} - \underbrace{\ln(\alpha_s)}_{\text{sector FE}} = \ln\left(\frac{P_{si} Y_{si}}{r K_{si}}\right)$$

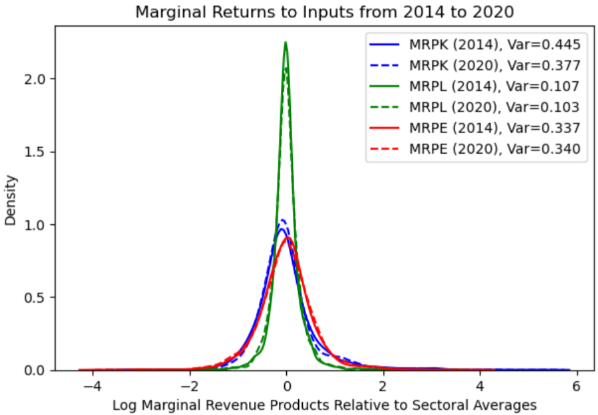
- **Regression:**

$$\ln\left(\frac{P_{si} Y_{si}}{r K_{si}}\right) = \beta_0 + \sum_s \beta_s \gamma_s + \epsilon_{si}$$

- **Interpretation:** Dependent variable = revenue-to-capital ratio; intercept = common parameters; sector FE absorb averages; residuals ϵ_{si} capture dispersion $\Rightarrow$ variance of residuals measures misallocation.

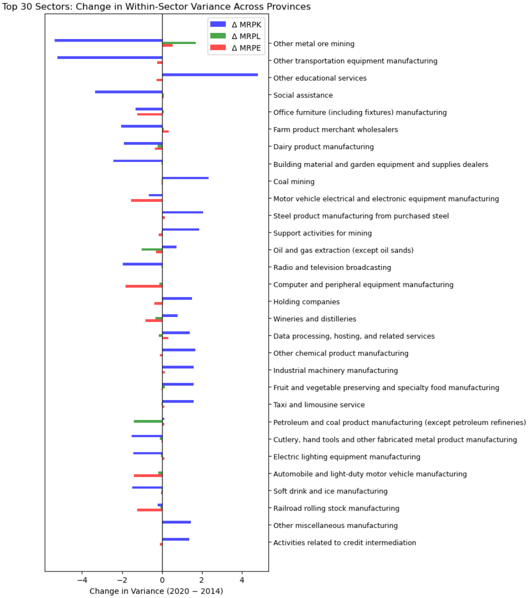
Outline

Dispersion of MRPs, 2014 vs. 2020



- Labor dispersion consistently lowest.
- Capital allocation improves modestly over time.
- Energy dispersion remains high $\Rightarrow$ persistent inefficiency.

Sector-Level Changes in MRP Dispersion



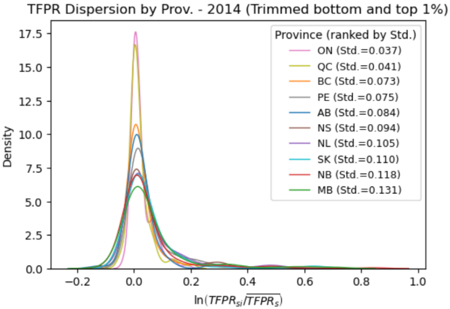
Relative TFPR Dispersion by Province

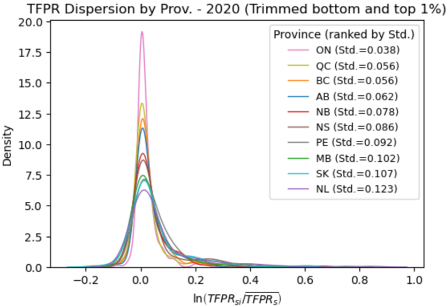
Recall that:

$$\begin{aligned} TFPR_{si} &\propto (MRPK_{si})^{\alpha_s}(MRPL_{si})^{\beta_s}(MRPE_{si})^{\gamma_s} \\ &\propto (1+\tau_{K_{si}})^{\alpha_s}(1+\tau_{L_{si}})^{\beta_s}(1+\tau_{E_{si}})^{\gamma_s} \end{aligned}$$

- TFPR = geometric average of MRPs under Cobb–Douglas.
- Measure dispersion relative to sectoral average.
- Higher dispersion $\Rightarrow$ greater productivity loss.

TFPR Dispersion Insights





- ON, QC: lowest misallocation, though QC worsens over time.
- AB, BC: some improvement.
- NB, MB, SK: persistently higher misallocation.
- Dispersion differs by up to $\approx 20\%$ from sectoral average.

Aggregate Productivity Gains ($\sigma = 3$)

Table: TFP Gains from Input Reallocation (in %), 2014–2020, $\sigma = 3$

Component	2014	2015	2016	2017	2018	2019	2020
Total Misallocation	8.05	6.46	4.90	4.84	5.28	5.74	5.08
Between-sector Misallocation	3.96	2.25	1.27	1.53	1.53	1.96	1.63
Capital	1.80	1.22	0.55	0.66	0.71	0.88	0.83
Labor	0.78	0.50	0.36	0.37	0.39	0.37	0.46
Energy	1.43	0.55	0.36	0.50	0.45	0.73	0.34
Within-sector Misallocation	4.26	4.31	3.67	3.37	3.81	3.86	3.50
Capital	1.33	1.27	1.75	1.36	1.71	1.85	1.33
Labor	2.55	2.76	1.26	1.54	1.69	1.54	1.73
Energy	1.53	1.67	1.14	0.93	1.09	0.98	0.81

- Potential gains: 8% (2014) $\rightarrow$ 5% (2020).
- Most loss from within-sector (interprovincial) misallocation.
- Capital and energy are the largest contributors.

Aggregate Productivity Gains ($\sigma = 7$)

Table: TFP Gains from Input Reallocation (in %), 2014–2020, $\sigma = 7$

Component	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Total Misallocation	9.40	7.51	5.81	5.72	6.85	6.52	5.81
Between-sector Misallocation	3.96	2.25	1.27	1.53	1.53	1.96	1.63
Capital	1.80	1.22	0.55	0.66	0.71	0.88	0.83
Labor	0.78	0.50	0.36	0.37	0.39	0.37	0.46
Energy	1.43	0.55	0.36	0.50	0.45	0.73	0.34
Within-sector Misallocation	5.66	5.39	4.60	4.26	5.40	4.65	4.25
Capital	5.12	3.30	4.89	4.29	7.28	4.41	3.51
Labor	5.85	5.51	3.35	4.21	5.49	3.75	3.82
Energy	3.27	3.36	2.36	2.23	3.37	2.07	1.85

- Potential gains: 9.4% (2014) $\rightarrow$ 5.8% (2020).
- Within-sector misallocation rises significantly.
- Energy misallocation peaks at 3.4pp in 2018.

Outline

Key Takeaways

- Energy misallocation plays outsized role despite its small ($\leq$10%) input share.
- Labor allocation relatively efficient.
- Interprovincial distortions (trade, regulation) $=$ major driver.
- Policy takeaway: energy coordination $+$ market integration could yield sizable productivity gains.

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Questions and comments are very welcome.

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