The Role of Energy Efficiency in Productivity: Evidence from Canada

(Job Market Paper)

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Research Question

- What are the productivity losses from **energy misallocation,** and how do they compare with those from capital and labor?

Why Study Energy Misallocation?

- Capital(K) and labor(L) misallocation $\rightarrow$ drivers 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**
  - **Climate policy.**

See Key Literature

Why Study Energy Misallocation?

Energy differs from K & L in several characteristics that make its misallocation costlier

- Low mobility compared to K & L $\rightarrow$ limited adjustment
- Heavily regulated $\rightarrow$ distorted prices
- Global shocks make prices volatile unlike capital and labor $\rightarrow$ more distortions
- Electricity is non-storable $\rightarrow$ demand driven price volatility
- Energy is an essential input to production $\rightarrow$ distortions propagate to the whole economy, making productivity more responsive to distortions

Share of Manufacturing Sector

- Earlier studies focus on manufacturing and firm-level input misallocation due to data availability
- While services, transport, and utilities are energy-intensive, they are excluded from the analysis

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

- This paper covers **entire economy** with provincial input-output tables to examine 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 spatial misallocation.
- Internal trade studies show sizable productivity losses (3–7%) $\rightarrow$ **Spatial dimension** is important in this context.[a]

Canada's Input Shares (Sector Level)

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

Author's calculations.

[a] See Key Literature

Preview of the Results

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

Contribution

- First **comprehensive** estimate of productivity loss **due to energy misallocation** in Canada at sector-by-province level.
- 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**.
- Quantifies productivity loss from energy misallocation across **regions** and sectors $\rightarrow$ **adding spatial dimension**
- Connects **output gaps and climate goals**: Optimal energy use boosts **productivity** *and* reduces **emissions**.
- Uses a tractable, flexible, and generalizable model $\rightarrow$ policy insights on energy pricing, infrastructure, climate policy.

Data Sources & Features

- Statistics Canada **Provincial Input–Output Tables** (2014–2020).
- Sectors: 230+ sectors, covering entire economy.
    - Detailed enough (more than 230+ sectors for 10 provinces).
- Inputs: **Money** spent on
    - Energy (Oil and Gas, Electricity, Coal etc.),
    - Capital (Gross mixed income),
    - Labor (Wages and salaries, Employers' social contributions).
- Sector-by-province level variation.
- Energy share in inputs varies widely by province and sector.

Conceptual Framework

- Natural extension of Hsieh–Klenow (2009) misallocation model $\rightarrow$ Extend to include **energy** alongside capital and labor.
- **Provinces/sectors** face distortions **instead of firms** $\rightarrow$ marginal revenue products differ at province-sector level.
- Wedges coming from policy, prices, infrastructure, regulation
- Compare observed allocation vs. efficient benchmark.
  - Efficient benchmark is where MRPs are equalized
- Fully tractable and flexible model, HK(2009), allowing for clean decomposition of misallocation:
  - **Within-sector (across provinces or interprovincial)**
  - **Between-sector (within provinces or intersectoral)**.

Economic Environment Assumed

- National output is single final good produced by Cobb-Douglas technology 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:

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

$\rightarrow$ Note that σ is constant and representing imperfect substitution parameter between provinces.

Production Technology

- Sector-by-province output also have Cobb–Douglas technology 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. Then profit, π_{si}, is given by:

$$\pi_{si} = P_{si} Y_{si} - (1 + \tau_{K\,si}) rK - (1 + \tau_{L\,si}) wL - (1 + \tau_{E\,si}) p_E E$$

- Distortions (τs) enter as wedges in input prices.
  $\rightarrow$ Marginal revenue products (MRP) are distorted.

Productivity Measures

- Revenue Total Factor Productivity (TFPR):

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

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

- TFPR = geometric average of MRPs under Cobb–Douglas.
- Higher dispersion $\Rightarrow$ greater productivity loss.
- **Key insight:** TFPR dispersion $\Rightarrow$ misallocation.

Sectoral Productivity Loss Under Misallocation

Observed Sectoral TFP, A_s, to efficient benchmark TFP, A_s^* ratio.

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

$$\overline{MRPX}_s = \frac{\sum_i X_{si}\, MRPX_{si}}{\sum_i X_{si}}, \quad \text{where } X \in \{K, L, E\}$$

$$\frac{\overline{MRPX_s}}{MRPX_{si}} = \frac{1}{(1+\tau_{X_{si}}) \sum_i \frac{1}{(1+\tau_{X_{si}})} \frac{P_{si} Y_{si}}{P_s Y_s}}, \quad \text{where } X \in \{K, L, E\}$$

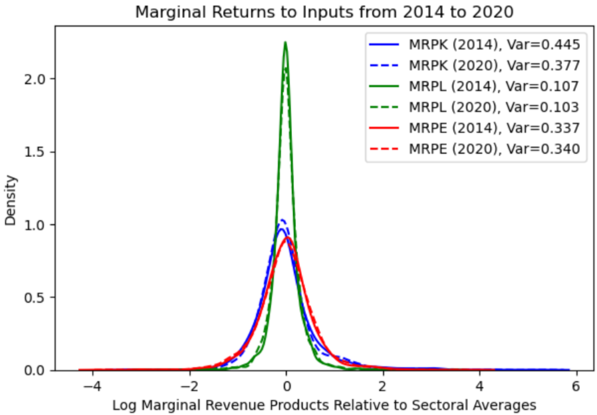
Aggregate Productivity Loss (and Decomposition)

- 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).
- TFPR dispersion $\rightarrow$ misallocation
- Larger dispersion $\rightarrow$ larger loss
- Decomposition possible by input and province (spatial level)

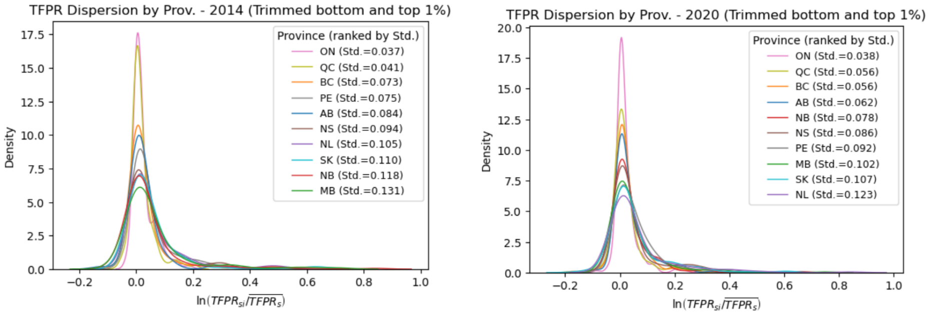
Dispersion of MRPs 2014 vs. 2020



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

Details in Appendix

TFPR Dispersion by Province



- 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.

Results when $\sigma = 7$ in Appendix

What would fix energy misallocation

- Removing interprovincial barriers including energy trade
- Energy policy & pricing harmonization
- Infrastructure investment
- More aligned decarbonization policies
- Energy efficiency is not just about emissions—it's about productivity.

Measurement Error

Table: Regression of Revenue on Input, 2014–2020

Variable	Coefficient	Std. Error
Constant	-0.0590	0.0031
log(inputs)	0.9694	0.0011
Observations	13594	
R^2	0.982	

Notes: The table reports coefficients from regressing log revenue, $\ln(P_{si}Y_{si})$, directly on log inputs, $\ln((rK_{si})^{\alpha_s}(wL_{si})^{\beta_s}(p_E E_{si})^{\gamma_s})$. All years are pooled for estimation. All variables are measured relative to the sectoral mean, with sectors weighted by value-added shares.

→ Up to 3% is due to measurement error. See Hsieh and Klenow (2009) for more details.

Measurement Error

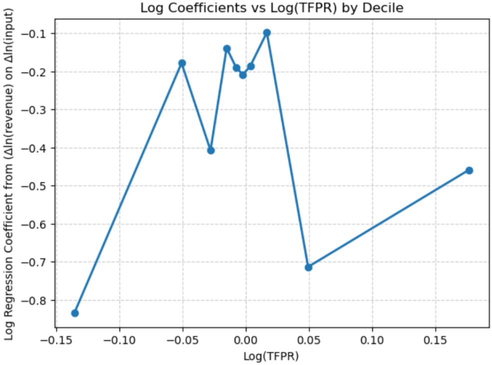


Figure: Log Coefficients vs Log(TFPR) by Decile

Notes: The figure plots the regression coefficients estimated from regressing revenue growth, $\Delta \ln(P_{si} Y_{si})$, on input growth, $\Delta \ln((rK_{si})^{\alpha_s}(wL_{si})^{\beta_s}(p_E E_{si})^{\gamma_s})$, across deciles of log TFPR. See Bils et al. (2021) for further details.

Key Takeaways

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

Thank You! ☺

Questions and comments are very welcome.

References I

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Key Literature

- Restuccia and Rogerson (2008); Hsieh and Klenow (2009); Jones (2011); Bartelsman et al. (2013); Chen and Irarrazabal (2015); Restuccia and Rogerson (2017); Gopinath et al. (2017); Restuccia (2019); Carrillo et al. (2023).
- Tombe and Winter (2015); Choi (2020)
- Albrecht and Tombe (2016); Alvarez et al. (2019)

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Appendix: 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.

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Appendix: 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.
- Capital + energy = key sources of inefficiency.

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