The Role of Energy Efficiency in Productivity: Evidence from Canada

Anil Gogebakan
Research Associate, Cardiff Business School & Wales Productivity Forum
Ph.D. Candidate in Economics, University of Calgary

February 27, 2026

Funded by Environment and Climate Change Canada's Economics & Environmental Policy Research Network (EEPRN)

Productivity and Misallocation

- Living standards largely determined by productivity (output per input)
- We observe big productivity differences across countries
- Most of this productivity differences are due to inefficient use of resources
- How you use your inputs sets your living standards
- If your inputs doesn't flow to their most productive uses: **Misallocation**
- But what prevents them flowing to their most productive uses? **Distortions**

Potential Causes of Misallocation

- Different **taxation** of the producers of the same good
- Tax code that is different across producer characteristics (size / age of the firm)
- Tariffs on specific products
- Labor market regulations
- Land regulations
- Financial choices: low interest loans to some specific firms, subsidies, etc.
- Market imperfections: Monopoly power, market frictions, property rights

Is Our Spending on Energy Maximizing Productivity?

- Energy is a key input to production!
- Provinces and sectors face different energy prices due to
  - regulation,
  - infrastructure,
  - energy policy.
- Do these price differences reduce productivity? If so, by how much?
- How do these reductions compare to those from capital and labor?

Why Study Energy Misallocation?

- Energy policy affects both **emissions** and **productivity**.
- Energy policy differs across provinces, setting how much money goes into energy.
- If energy cannot flow to where it is most productive, output is lower.
- Output losses persist if energy policy makes sectoral and provincial prices different.
- In Canada, climate policy is getting tighter while productivity growth is weak.

See Key Literature

Why Study Energy Misallocation?

Energy is unique in several ways

- Energy is less mobile, so price differences are persistent.
- Regulation, infrastructure, and market design shape energy prices
- Energy prices are more sensitive to global shocks
- It is difficult and costly to store electricity $\rightarrow$ demand-driven price volatility
- Energy is a key input: Price distortions lower productivity in the entire economy.

Share of Manufacturing Sector

- Manufacturing sector is in the focus, but Canada's economy is service-based.
- Services, transportation, and utilities play a key role in emissions and productivity.

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 cover **full economy** & **sector-by-province** level & provincial input-output tables.

Why Canada? & Why Province-Sector Level?

- Provinces differ in energy policy → fragmented markets.
- High variation in energy prices, infrastructure, and regulation. (carbon-pricing heterogeneity)
- Limited interprovincial trade → persistent spatial misallocation due to infrastructure bottlenecks and vast geography
- Internal trade studies show sizable productivity losses (3–7%) → **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

How large are the losses?

- $\sim$5–8% potential productivity loss overall (2014–2020)
- **Decomposition:** More than half of the loss comes from **interprovincial frictions**
- **Further decomposition:**
  - 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

Preview of the Results

Why energy matters?

- Energy accounts for $\leq$10% of costs
- But up to 2% of aggregate output loss is due to energy misallocation (of 5 - 8%)
- Per dollar, energy misallocation generates larger productivity losses (than misallocation of capital or labor).
- **Energy misallocation acts as a persistent bottleneck, offsetting productivity gains elsewhere.**

Why This Matters

- Efficient spending on energy could improve productivity while reducing emissions
- Interprovincial differences and inefficiencies are very costly
- Coordination is as important as having advanced technology for productivity
- Harmonized energy policy could yield large productivity gains and reduce emissions

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**.

Data

- StatsCan **Provincial Input–Output Tables** (2014–2020).
- Coverage: 230+ sectors across 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: Intuition

- In an efficient economy, inputs are used where they generate the highest value.
- In practice, input prices differ across provinces and sectors.
- As a result, similar sectors with similar technologies use energy in different amounts.
- These differences make the economy operate below its full productive potential.

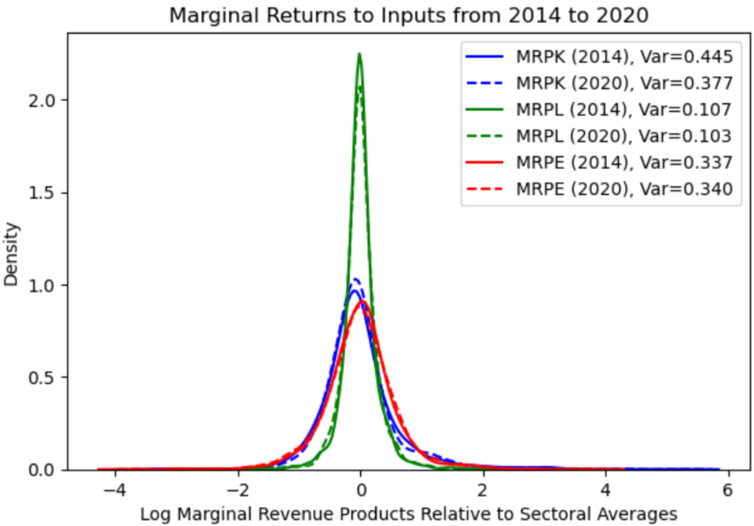
Conceptual Framework: Method

- I compare observed productivity to a benchmark, where productivity is maximized
  - **Benchmark:** Each **additional** input yields the same value in each province-sector.
- This allocates inputs based on the value they create.
  - Inputs should flow to province-sectors where they create the highest value.
- When the same input generates different values across units, it is misallocation.
- The larger differences correspond to larger productivity losses in the model.

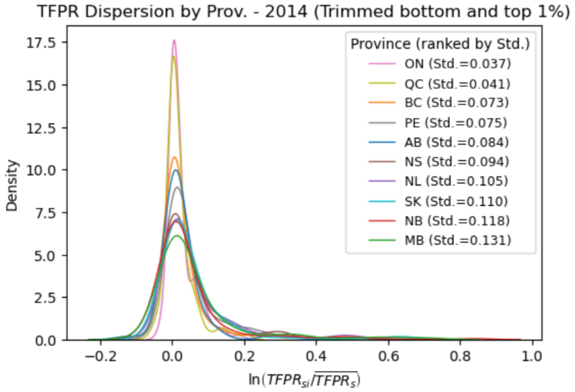
Conceptual Framework: Model Background

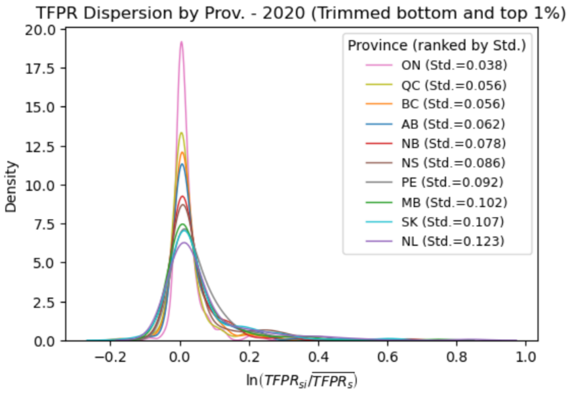
- The analysis builds on the Hsieh–Klenow (2009) misallocation framework.
- The model is extended to include **energy** alongside capital and labour.
- Distortions operate at the **province–sector** level rather than the firm level.
- These distortions reflect differences in policy, prices, infrastructure, and regulation.
- The model allows a clean decomposition of productivity losses into:
  - **Interprovincial (within-sector) effects**
  - **Intersectoral (within-province) effects**

Dispersion of Marginal Productivity 2014 vs. 2020



Total Productivity (TFPR) Dispersion by Province





- ON, QC: lowest misallocation, though QC worsens over time.
- AB, BC: some improvement.
- NB, MB, SK: persistently higher misallocation.

Aggregate Productivity Gains

Table: TFP Gains from Input Reallocation (in %), 2014–2020

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

Notes: Results are based on a conservative elasticity of substitution across provinces assumption, $\sigma = 3$, yielding lower-bound estimates of potential gains.

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 is a key productivity issue.

Key Takeaways

- **Total productivity loss** due to misallocation: **5 - 8%**
- Most of this loss comes from **interprovincial distortions** (trade, regulation)
- Energy accounts for one-third of the loss (2%) with an input share $\leq$ 10%.
- Labor is the most efficiently used input: **Less than 1% of the loss**
- Energy coordination + market integration $\rightarrow$ productivity gains + low emissions

Anil Gogebakan
Research Associate, Cardiff Business School & Wales Productivity Forum
PhD Candidate in Economics, University of Calgary

Webpage: https://anilgogebakan.github.io/

Email: anil.gogebakan@ucalgary.ca | GogebakanA@cardiff.ac.uk

Thank You! ☺

Questions and comments are very welcome.

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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: 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.

Appendix: 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.

Appendix: 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.

Appendix: Sectoral Productivity Loss Under Misallocation

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

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

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

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

Appendix: 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)

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.

Appendix: 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.

Appendix: Measurement Error

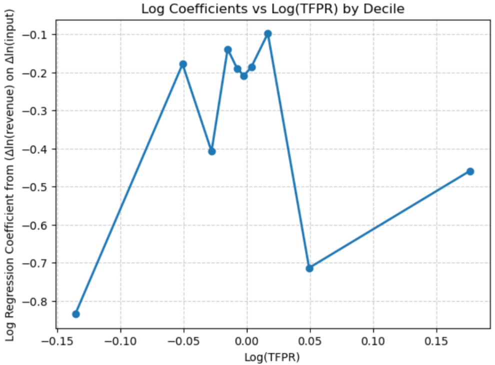

Figure: Log Coefficients vs Log(TFPR) by Decile

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.