The Role of Energy Efficiency in Productivity: Evidence from Canada

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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, and 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 not only emissions, but also productivity.
- Energy policy differs significantly across provinces and determines what portion of the money goes into energy.
- If energy cannot flow to where it is most productive, output is lower.
- These losses persist if energy policy differentiates prices across provinces and sectors
- This matters because Canada is moving toward tighter climate policy while still facing weak productivity growth.

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
- Because energy is a key input in nearly all production, price distortions affect productivity across the entire economy.

Share of Manufacturing Sector

- Many studies focus on manufacturing, but Canada is primarily a service-based economy.
- Energy use in services, transportation, and utilities plays a central 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

- This paper covers **entire economy** with provincial input-output tables to study 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. (carbon-pricing heterogeneity)
- Limited interprovincial trade $\rightarrow$ persistent spatial misallocation due to infrastructure bottlenecks and vast geography
- 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

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 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).
- Bottom line: **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 help 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 due to policy, infrastructure, and market conditions.
- As a result, similar sectors with similar technologies use energy in very different amounts across provinces.
- These differences indicate that the economy is operating below its full productive potential.

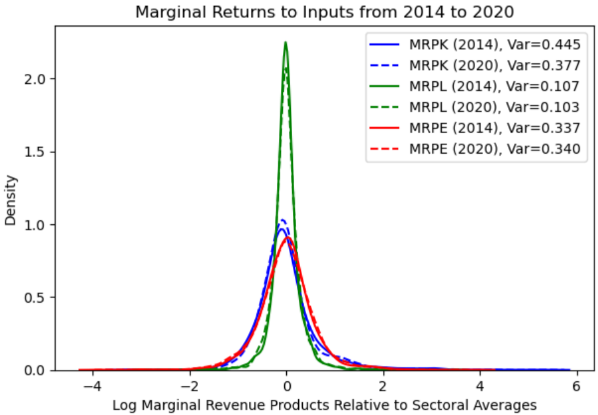
Conceptual Framework: Method

- I compare observed productivity to a benchmark where each additional input generates the same value across provinces and sectors, which maximizes productivity.
- This allocates inputs based on the value they create $\rightarrow$ the more value an input generates in a province-sector, the more it should be used there.
- When the same input generates different values across provinces or sectors, it indicates frictions in allocation.
- 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**

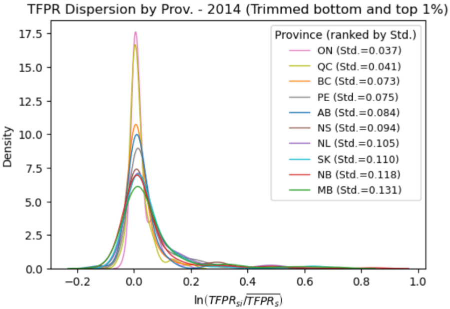
Dispersion of Marginal Productivity 2014 vs. 2020

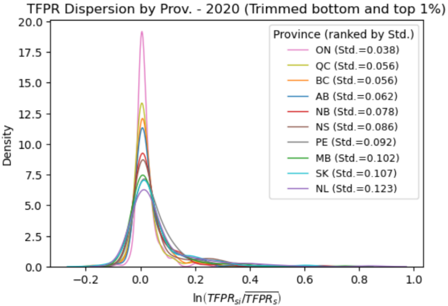


- Labor dispersion consistently lowest.
- Capital allocation improves modestly over time.
- Energy dispersion remains high ⇒ persistent inefficiency.

Details in Appendix

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.
- 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 is a key productivity issue.

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 while reducing emissions.

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:

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

- **Regression:**

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

- **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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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.

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

Appendix: Measurement Error

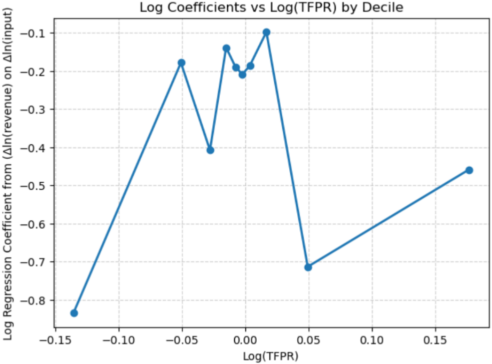

Figure: Log Coefficients vs Log(TFPR) by Decile

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.