

The Role of Energy Efficiency in Productivity: Evidence from Canada

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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**
- **Distortions** prevent inputs flowing to their most productive uses?

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
- If energy cannot flow to where it is most productive, output is lower.
- In Canada, climate policy is getting tighter while productivity growth is weak.
Energy is unique in several ways
- Energy is less mobile, so price differences are persistent.
- Energy prices are more sensitive to global shocks
- It is difficult and costly to store electricity → demand-driven price volatility

See Key Literature

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?

- ~5–8% potential productivity loss overall (2014–2020)
- **Province-sector level decomposition:** Most of the loss comes from **interprovincial frictions**
- **Input-level decomposition:**
 - Capital dominates between-sector losses: **up to 4%** output loss
 - Energy accounts for **up to 2%** output loss → **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.**

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 → **equally (even more) important to capital or labor**.
- Quantifies productivity loss from energy misallocation across **regions** and sectors → **adding spatial dimension**
- Connects **output gaps and climate goals**: Optimal energy use boosts **productivity** *and* reduces **emissions**.

- 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.

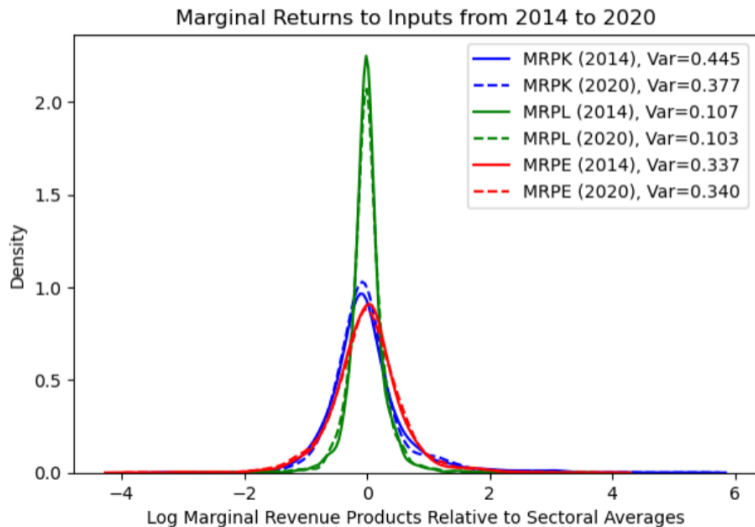
Conceptual Framework: Method

- 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

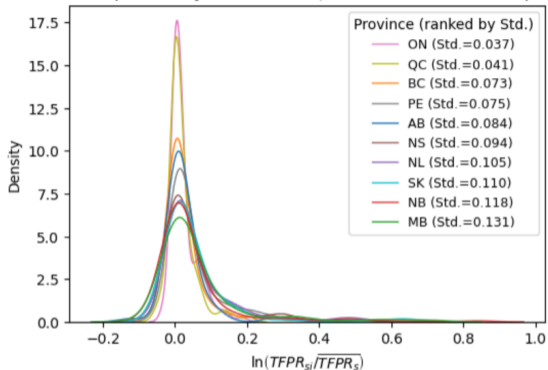
- The analysis builds on the Hsieh–Klenow (2009) misallocation framework.
- The model is extended to include **energy** alongside capital and labour.
- Distortions operate at the **province–sector** level rather than the firm level.
- These distortions reflect differences in policy, prices, infrastructure, 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

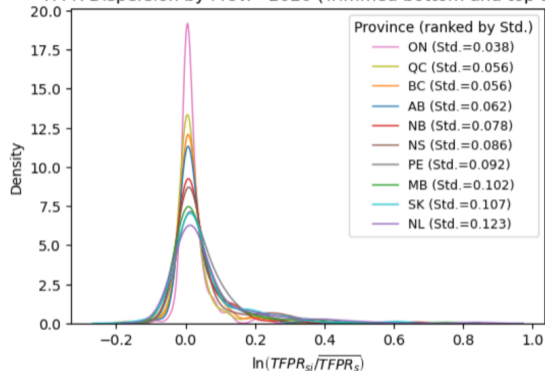


Total Productivity (TFPR) Dispersion by Province

TFPR Dispersion by Prov. - 2014 (Trimmed bottom and top 1%)



TFPR Dispersion by Prov. - 2020 (Trimmed bottom and top 1%)



- 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.

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

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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 :

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

→ 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:

$$\pi_{si} = P_{si} Y_{si} - (1 + \tau_{Ksi}) r K - (1 + \tau_{Lsi}) w L - (1 + \tau_{Esi}) p_E E$$

- Distortions (τ s) enter as wedges in input prices.
→ 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:

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

- 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.

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

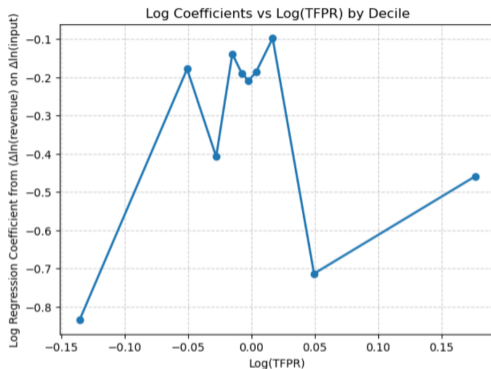


Figure: Log Coefficients vs Log(TFPR) by Decile

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.