

The Role of Energy Efficiency in Productivity: Evidence from Canada

(Job Market Paper)

Anil Gogebakan
University of Calgary
Ph.D. Candidate in Economics

October 17, 2025

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

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 & labor misallocation → 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

Share of Manufacturing Sector

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

Country	Manufacturing Share (% of GDP)
China (2023)	25.5
India (2023)	13.0
USA (2023)	10.3
Canada (2014–2020 avg.)	~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
→ fragmented markets.
- High variation in energy prices, infrastructure, and regulation.
- Limited interprovincial trade → persistent spatial misallocation.
- Rich provincial input–output data (2014–2020).
- 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

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

Contribution

- First **comprehensive** estimate of energy misallocation (sector \times province data).
- 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 → Extend to include **energy** alongside capital and labor.
- **Provinces/sectors** face distortions **instead of firms** → marginal revenue products differ at province-sector level.
- Compare observed allocation vs. efficient benchmark.
- Fully tractable and flexible model, HK(2009), allowing for clean decomposition of misallocation:
 - **Within-sector (across provinces)**
 - **Between-sector (within provinces).**

Economic Environment Assumed

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

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

- 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.

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 enter as wedges on input prices.
→ Marginal revenue products (MRP) are distorted.

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:

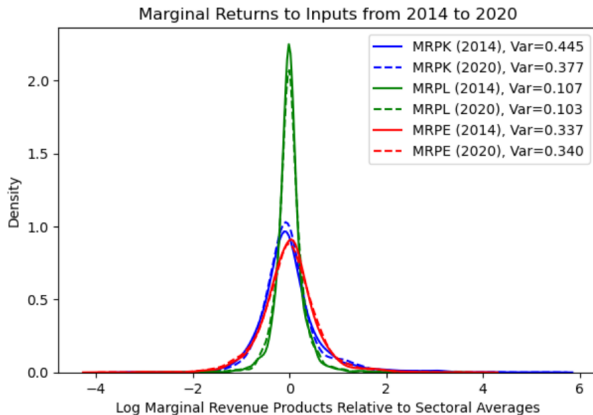
$$\underbrace{\ln(MRPK_{si})}_{\epsilon_{si}} - \underbrace{\ln(r)}_{\beta_0} - \underbrace{\ln\left(\frac{\sigma-1}{\sigma}\right)}_{\text{sector FE}} - \underbrace{\ln(\alpha_s)}_{\text{sector FE}} = \ln\left(\frac{P_{si} Y_{si}}{r K_{si}}\right)$$

- 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.

Dispersion of MRPs, 2014 vs. 2020



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

Relative TFPR Dispersion by Province

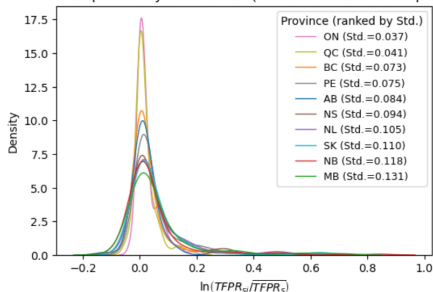
Recall that:

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

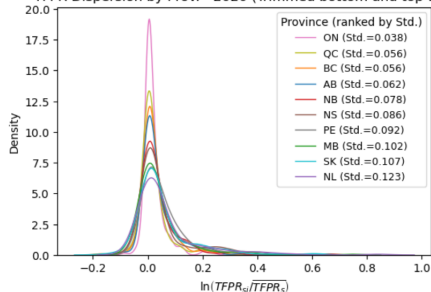
- TFPR = geometric average of MRPs under Cobb–Douglas.
- Measure dispersion relative to sectoral average.
- Higher dispersion \Rightarrow greater productivity loss.

TFPR Dispersion Insights

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

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. This suggests that measurement error is responsible for up to 3 % of the estimated productivity gap in main results, suggesting that measurement error is not driving the results. See Hsieh and Klenow (2009) for more details.

Measurement Error

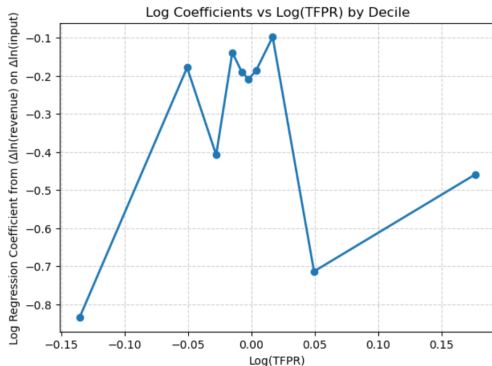


Figure: Log Coefficients vs Log(TFPR) by Decile

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. All years are pooled for estimation and plotting. All variables are measured relative to the sectoral mean, with sectors weighted by value-added shares. While measurement error appears to be more of a concern in the lowest and highest TFPR deciles, this is addressed in the main analysis by trimming the top and bottom 1% of the distribution, reducing concerns about measurement error by handling outliers in the data. See Bils et al. (2021) for further details.

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.

Thank You! 😊

Questions and comments are very welcome.

References I

- Albrecht, L. and Tombe, T. (2016). Internal trade, productivity and interconnected industries: A quantitative analysis. *Canadian Journal of Economics/Revue canadienne d'économique*, 49(1):237–263.
- Alvarez, J., Krznar, M. I., and Tombe, T. (2019). *Internal trade in Canada: case for liberalization*. International Monetary Fund.
- Bartelsman, E., Haltiwanger, J., and Scarpetta, S. (2013). Cross-country differences in productivity: The role of allocation and selection. *American economic review*, 103(1):305–334.
- Bils, M., Klenow, P. J., and Ruane, C. (2021). Misallocation or mismeasurement? *Journal of Monetary Economics*, 124:S39–S56.
- Carrillo, P., Donaldson, D., Pomeranz, D., and Singhal, M. (2023). Misallocation in firm production: A nonparametric analysis using procurement lotteries. Technical report, National Bureau of Economic Research.
- Chen, K. and Irarrazabal, A. (2015). The role of allocative efficiency in a decade of recovery. *Review of Economic Dynamics*, 18(3):523–550.
- Choi, B. (2020). Productivity and misallocation of energy resources: Evidence from korea's manufacturing sector. *Resource and Energy Economics*, 61:101184.
- Gopinath, G., Kalemli-Özcan, Ş., Karabarbounis, L., and Villegas-Sanchez, C. (2017). Capital allocation and productivity in south europe. *The Quarterly Journal of Economics*, 132(4):1915–1967.
- Hsieh, C.-T. and Klenow, P. J. (2009). Misallocation and manufacturing tfp in china and india. *The Quarterly journal of economics*, 124(4):1403–1448.
- Jones, C. I. (2011). Misallocation, economic growth, and input-output economics. Technical report, National bureau of economic research.
- Restuccia, D. (2019). Misallocation and aggregate productivity across time and space. *Canadian Journal of Economics/Revue canadienne d'économique*, 52(1):5–32.
- Restuccia, D. and Rogerson, R. (2008). Policy distortions and aggregate productivity with heterogeneous establishments. *Review of Economic dynamics*, 11(4):707–720.
- Restuccia, D. and Rogerson, R. (2017). The causes and costs of misallocation. *Journal of Economic Perspectives*, 31(3):151–174.
- Tombe, T. and Winter, J. (2015). Environmental policy and misallocation: The productivity effect of intensity standards. *Journal of Environmental Economics and Management*, 72:137–163.

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)

◀ Back

◀ Back