Input substitution for sustainable industrialisation: Evidence from India

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Motivation

Economic policy instruments for decarbonisation

- **Taxing** the carbon content of **fossil fuels** (coal, oil and gas) at the **social cost of carbon** is economically **efficient** (*in absence of other distortions*).
- However, carbon taxes alone may compromise economic growth by disincentivising production.
- Endogenous growth theory - the **source of economic growth** is **innovation**.
- Acemoglu et al. (2014) argue that **research subsidies**, especially for the "clean" sector, **along with carbon taxes** are essential for long-run sustainable growth.

Roadmap

- Motivation: To promote sustainable industrialisation in India, while increasing manufacturing-sector employment. Can labour-augmenting technical change lead to substitution from fossil fuels towards labour?
- Conceptual Framework: Deriving the elasticity of substitution
- Objective: Estimate the **elasticity of substitution** between **labour and energy** (electricity and coal) in the Indian manufacturing sector, using industry- and firm-level data
- Data and Preliminary Results
- Outlook: Instrumental Variable (IV) estimation of elasticities

The role of directed technical change

Endogenous growth theory

- Following the Schumpeterian growth paradigm, Acemoglu (2002) and others explain the dynamic process of innovation
- Technological progress can be directed towards specific factors of production, in contrast to Hicks-neutral technical change

$$Y = (\omega_K K^\rho + \omega_L L^\rho)^{\frac{1}{\rho}}$$

- Acemoglu (2002) explains that two key factors determine the direction of technical change:
  - **Price effect** - Scientists/entrepreneurs will innovate towards more profitable technologies (those with higher prices)
  - **Market size effect** - Innovation will be directed towards the more abundant factors of production, i.e. factors with a larger market
- Overall direction of technical change will depend on these two effects

Insights from economic history

Why the Industrial Revolution was British

- Robert Allen (2011, 2006) highlights the role of relative prices in stimulating technical change and industrialisation
- Allen (2006) claims the **low relative price of coal to the wage rate for labour** created appropriate conditions for energy- and capital-intensive innovation
- Inventors developed **machines that economised on labour**, instead relying on cheap coal and raw materials, to raise profits (Kelly et al. 2022; Broadberry and Gupta, 2009)
- Malanima (2020) finds a strong **positive correlation between living standards and energy consumption** in Europe and the United States since the Great Divide of 1820

Sources: *The Economic History Review, Journal of Political Economy*

Possibilities for sustainable industrialisation

Sustainable industrialisation in the 21st century

- Emerging economies such as India face dual challenges of providing **large-scale employment** and **decarbonising the economy**
- Two potential opportunities for sustainable industrialisation:
  - **Increase the share of renewable energy** in electricity generation and industrial production
  - Enable **labour-augmenting technical change** such that **firms** increasingly use **technologies that complement labour** and derive energy from clean sources in industrial production
    - Potential mechanism: Expansion of renewable energy and market integration can **reduce energy prices** (Gonzales et al. 2022; NBER WP), raising firm productivity $\Rightarrow$ **Firms expand production** and **hire more labour** (Singer, 2023, LSE WP; Abeberese, 2017)

Conceptual Framework

Elasticity of Substitution between labour and energy

Consider a CES production function with capital, labour and energy as inputs:

$$Q = A[K^\rho + \omega_L L^\rho + \omega_E E^\rho]^{\frac{1}{\rho}} \tag{1}$$

where $\sigma = \frac{1}{1-\rho}$ is the elasticity of substitution.

ω_L and ω_E are L-augmenting and E-augmenting technical changes, respectively. A is a Hicks-neutral productivity shock.

The profit maximisation problem leads to the first-order condition:

$$\frac{L}{E} = \left(\frac{p_E}{p_L}\right)^\sigma \left(\frac{\omega_E}{\omega_L}\right)^{1-\sigma} \tag{2}$$

where σ is the Morishima elasticity of substitution (Morishima 1967; Russell 2020)

Data Sources

- Annual Survey of Industries, 2008-09 to 2018-19
- Construct panel for input quantities at the level of NIC-5 digit industry (*611 sectors*) by state × region (rural/urban) × year
- Electricity prices[1] and wage rates are averages at the NIC-3 digit level (*71 sectors*) × state × region × year
- Coal prices are averages by state, region (rural/urban) and year (Harrison et al. 2015, NBER WP)

[1] Price data under revision based on tariff schedules for industry

Empirical Strategy

Estimating the elasticity of substitution (σ):

$$ln\left(\frac{L}{E}\right)_{isrt} = \alpha_{isr} + \gamma_t + \sigma ln\left(\frac{p_E}{p_L}\right)_{msrt} + \epsilon_{isrt} \quad (3)$$

where α_{isr} is the industry $\times$ state $\times$ region (rural/urban) fixed effect, and γ_t is the year fixed effect.

i - NIC 5-digit industry

m - NIC 3-digit industry

Descriptive Statistics

Table 1: Summary Statistics for NIC-5 digit industry, by state & region, 2018-19

Variable	*N*	*N* (Value > 0)	Mean	Std. Dev.	p99
Employment	10,553	10,401	864	4,362	11,796
Avg. Wage rate (*Rs. per manday*)	10,521	10,521	433	162	1,016
Qty. Electricity (kWh)	10,553	10,544	2.5×10^7	2.0×10^8	3.9×10^8
Avg. Electricity price (*Rs. per kWh*)	10,552	10,552	7.1	1.4	10
Qty. Coal (tonne)	10,553	1,471	12,980	364,776	164,699
Avg. Coal price (*Rs. per tonne*)	10,274	10,274	8,667	3,610	28,460

Results

Elasticity of substitution between labour and electricity

log(Qty. ratio - Labour to Electricity)	(1)	(2)	(3)	(4)
log(Price ratio - Electricity to Labour)	0.429***	0.467***	0.507***	0.336***
	(0.012)	(0.015)	(0.013)	(0.017)
Urban Area		0.223***	0.0927***	
		(0.009)	(0.007)	
N	107,709	107,709	107,709	107,709
R^2	0.017	0.068	0.426	0.017
Year Dummies	Yes	Yes	Yes	No
State Dummies	No	Yes	Yes	No
Rural/Urban Dummies	No	Yes	Yes	No
NIC-5 digit Dummies	No	No	Yes	No
Year FE	No	No	No	Yes
State × Rural/Urban × NIC-5 digit FE	No	No	No	Yes

Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Constant term suppressed.

Elasticity of substitution between labour and coal

log(Qty. ratio - Labour to Coal)	(1)	(2)	(3)	(4)
log(Price ratio - Coal to Labour)	1.134***	0.758***	0.449***	0.454***
	(0.058)	(0.078)	(0.069)	(0.072)
Urban Area		0.732***	0.311***	
		(0.042)	(0.036)	
N	15,488	15,488	15,488	15,488
R^2	0.026	0.076	0.447	0.01
Year Dummies	Yes	Yes	Yes	No
State Dummies	No	Yes	Yes	No
Rural/Urban Dummies	No	Yes	Yes	No
NIC-5 digit Dummies	No	No	Yes	No
Year FE	No	No	No	Yes
State $\times$ Rural/Urban $\times$ NIC-5 digit FE	No	No	No	Yes

Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Constant term suppressed.

Elasticity of Substitution by industry

- Hetergeneity across industries: σ computed by NIC-2 digit sector
  - All sectors have an elasticity of substitution between labour and electricity, $\sigma < 1 \Rightarrow$ **Labour and Electricity are gross complements** across the manufacturing sector (*similar findings in Bretschger and Jo, 2021, for France*)
- Elasticity of substitution between labour and coal: < 1 on average, but heterogeneous across sectors
  - $\sigma > 1$ for manufactures of: tobacco, apparel & leather, metal products, computers, electronics, electrical equipment, motor vehicles and other transport equipment.
- Firm-level panel data would enable estimation of elasticities across the firm size distribution $\Rightarrow$
  - Do more productive firms have greater substitution possibilities and capacities to adapt? (Bretschger and Jo, 2021)

Elasticity of Substitution: Labour and coal by NIC-2 digit sectors

NIC-2 digit industry	σ
Manufacture of food products	0.817***
	(0.056)
Manufacture of beverages	0.524***
	(0.066)
Manufacture of tobacco products	1.435***
	(0.066)
Manufacture of textiles	0.793***
	(0.057)
Manufacture of wearing apparel	1.552***
	(0.092)
Manufacture of leather and related products	1.278***
	(0.066)
Manufacture of wood and products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.723***
	(0.068)
Manufacture of paper and paper products	0.130*
	(0.057)
Printing and reproduction of recorded media	1.559***
	(0.250)
Manufacture of coke and refined petroleum products	0.893***
	(0.102)
Manufacture of chemicals and chemical products	0.473***
	(0.062)
Manufacture of pharmaceuticals, medicinal chemical and botanical products	0.945***
	(0.068)

NIC-2 digit industry	σ
Manufacture of rubber and plastics products	0.881***
	(0.060)
Manufacture of other non-metallic mineral products	0.305***
	(0.056)
Manufacture of basic metals	0.619***
	(0.055)
Manufacture of fabricated metal products, except machinery and equipment	1.200***
	(0.059)
Manufacture of computer, electronic and optical products	1.471***
	(0.155)
Manufacture of electrical equipment	1.365***
	(0.082)
Manufacture of machinery and equipment n.e.c.	1.194***
	(0.058)
Manufacture of motor vehicles, trailers and semi-trailers	1.978***
	(0.090)
Manufacture of other transport equipment	1.633***
	(0.087)
Manufacture of furniture	0.993***
	(0.155)
Other manufacturing	1.625***
	(0.115)
Repair and installation of machinery and equipment	1.209***
	(0.140)
N	15,488
R^2	0.234

Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Constant term suppressed. Year dummy variables included.

Outlook

Using instrumental variables to estimate σ

- Panel/time-series data: Using **lagged values of relative prices as instruments** may mitigate the contemporaneous correlation between relative prices and factor-augmenting technical change

- Using a shift-share instrument to capture industry-specific price shocks
    - **Abeberese (2017**, *ReStat*) estimates the reduced form effect of electricity prices on firm performance in Indian manufacturing using ASI data
    - **Bartik-style instrument** for electricity prices: national coal prices for power plants interacted with the state's share of thermal power in electricity generation
    - Results show negative effects of electricity prices on firm performance (output & productivity) and a reduction in machine intensity

Shift-share IV for coal and electricity prices: Validation

- Problem with national coal prices as "exogenous shock/shift": **insufficient industry-level shocks** $\rightarrow$ required for identification à la Borusyak et al. (2022, ReStud)
- Alternative: **identification from shares** à la Goldsmith-Pinkham et al. (2020, AER) $\rightarrow$ difficult to prove exogeneity of shares even in pre-period.
- IV for coal prices: exploiting exogenous **national increases in clean energy cess** on coal (Rs. 50/tonne in 2010 to Rs. 400/tonne in 2016) $\rightarrow$ national coal prices interacted with **share of expenditure on coal in total expenditure** at industry-level in pre-period (2007-08)
- Firm-level **panel data needed** for improved estimation (ASI - not available after 2012; Prowess - proprietary data)
- Explore mechanisms: changes in **capital intensity** due to shifts in coal prices (limited data in ASI)

Thank you for your attention.

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