The Light and the Heat
Productivity Co-benefits of Energy-saving Technology

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Motivation: climate change and mitigation

- The IPCC estimates that end-century warming will exceed 1.5°C (IPCC, 2013)
  - Impacts disproportionately located in developing countries (Mendelsohn et al., 2006)
- Great interest in identifying
  - impact of temperature on economic outcomes (Deschenes & Greenstone 2007, 2011; Guiteras 2009; Burgess et al. 2013; Hsiang et al. 2013; Barreca, Clay, Deschenes, Greenstone, & Shapiro 2014, Sudarshan & Tiwari 2014)
  - effective mitigation strategies – not easy to convince individual/firms to adopt, given wedge between public and private returns (Bollen et al. 2009; Knittel & Sandler 2011; Deschenes et al. 2013)

Motivation: energy efficiency and India

- India fourth-largest energy consumer globally (International Energy Agency)
- Indian industry second largest consumer of primary commercial energy (Bhattacharya and Cropper, 2010)
- Lighting represents almost 20% of global electricity consumption (International Energy Agency)
- Energy efficiency projected to potentially close the gap between projected energy demand and supply (Bureau of Energy Efficiency)
    - But very difficult to get firms to adopt "green" technologies (Knittel & Sandler, 2011)

Research questions

- **What are the impacts of temperature on the workplace outcomes of factory workers?**
- **Can mitigation strategies have private "co-benefits" that promote adoption?**

Our case: ready-made garments

1. Garment sector has high absorption capacity for influx of unskilled workers (particularly young women) (Heath & Mobarak 2014)
    - Partner firm alone employs 90,000 workers (80% female), growing at 10% p.a.
2. Several frictions hinder potential of this industry and its workers:
    - Absenteeism high and retention low
    - Labor productivity low (average efficiency in our sample is 53%)
3. **What role does the work environment play in productivity and attendance? What can firms do to mitigate the generated inefficiencies?**

Overview

1. Estimate temperature-productivity gradient using line-level, daily production data for 29 garment factories and mean daily temperatures in Bangalore, India
2. Estimate extent to which introduction of LED lighting mitigates negative effects of temperature on productivity
3. Using actual firm costing data, generate cost-benefit calculations for LED lighting adoption with / without estimated productivity gains

Data

Timeline: May 2010-September 2013

Workplace outcomes

- 29 factory units: 446 production lines over 941 days
- Daily line-level data on efficiency (produced/target q), budgeted efficiency
- Daily worker-level data on attendance

Temperature and Humidity

- Daily temperature: National Climatic Data Center (NCDC) at the National Oceanic and Atmospheric Administration (NOAA)
- Monthly Relative Humidity: NOAAs National Data Center (NNDC)

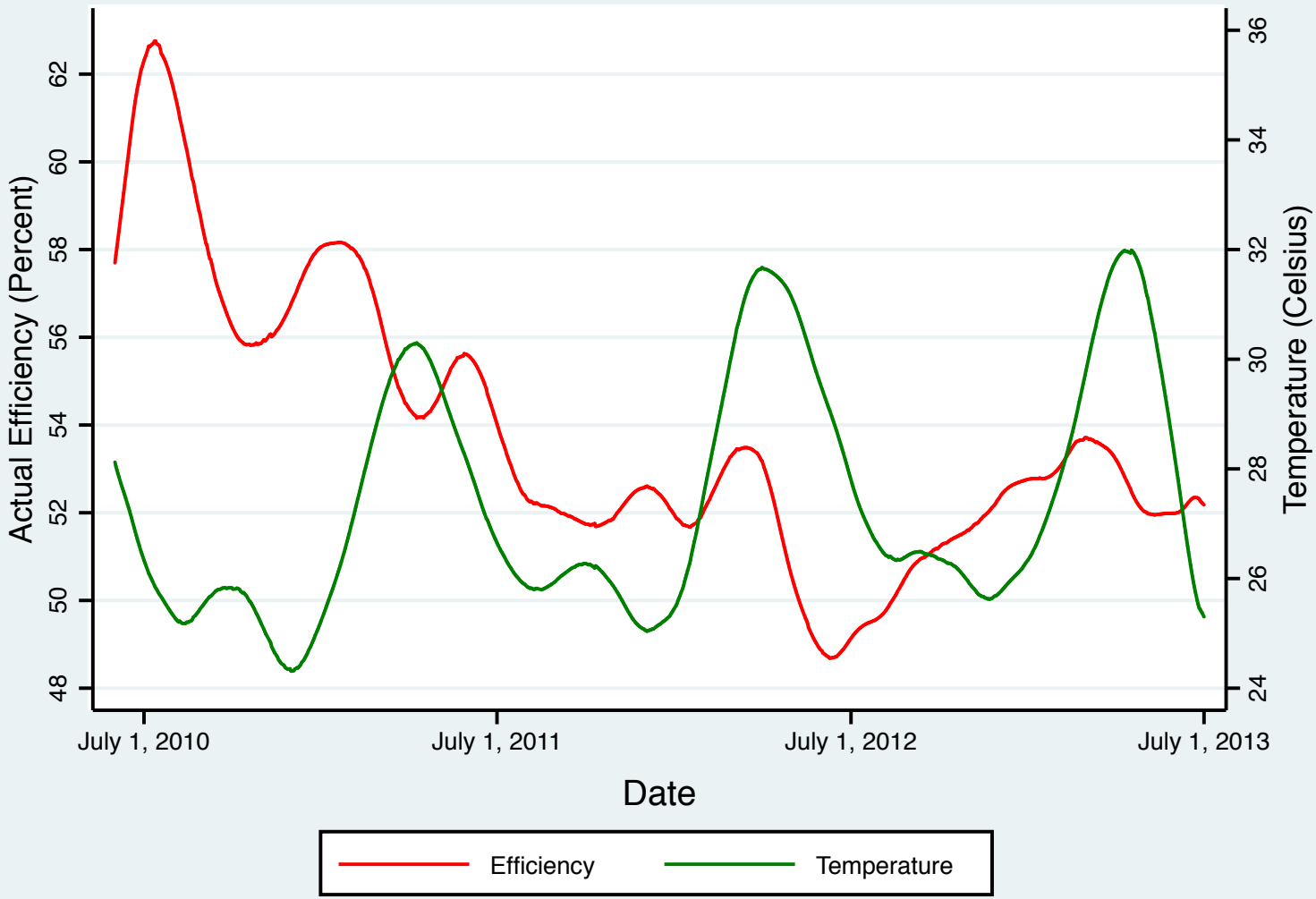
LED Rollout: 25 garment factories

- Month and year of replacement of florescent lighting with LEDs

Summary Statistics

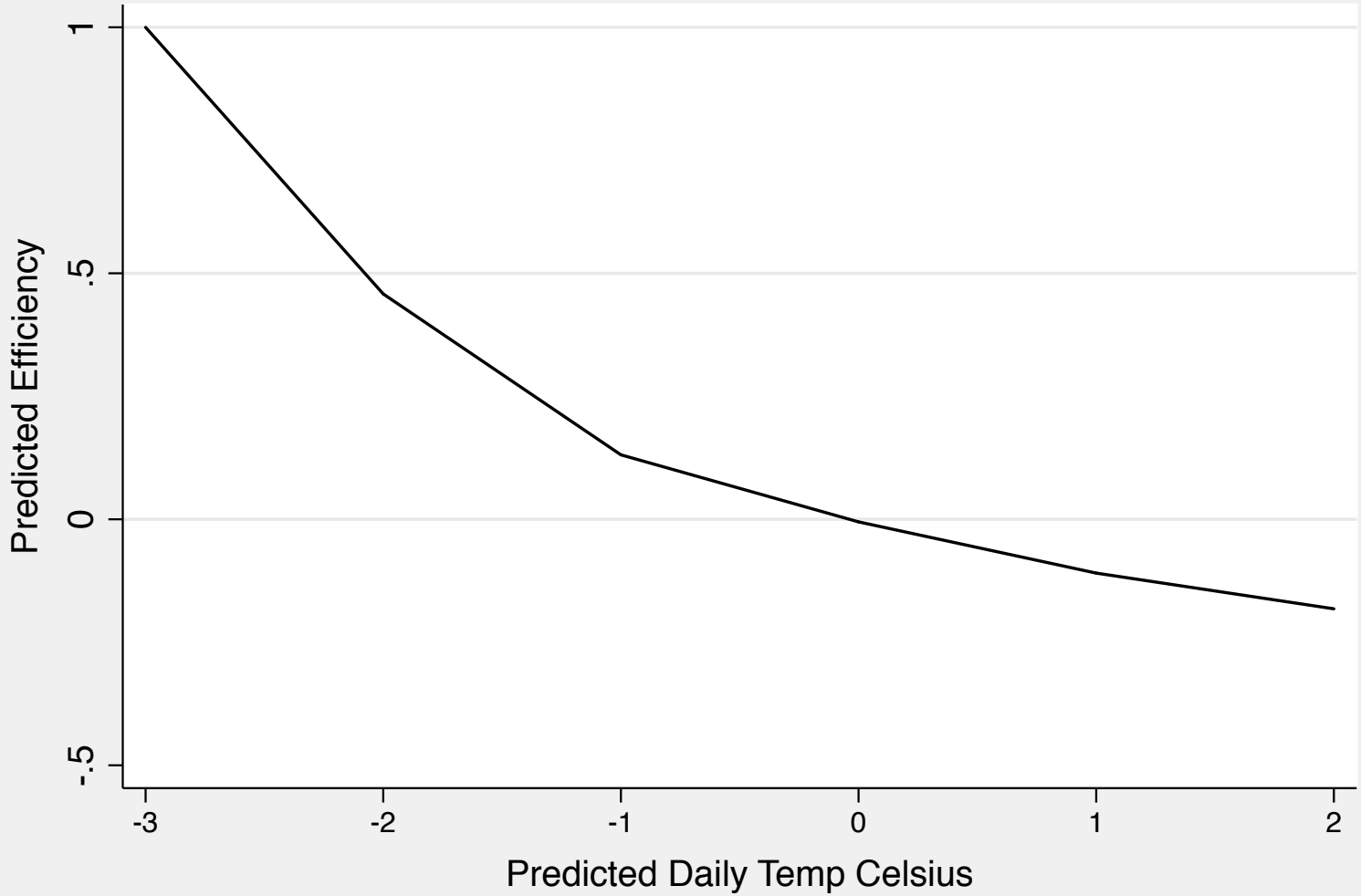
	Whole Sample		*Without LED*		*With LED*	
Number of line-day observations	214,968		71,969		142,999	
Number of lines	446					
Number of days	941					
Number of units	29					
	Mean	SD	Mean	SD	Mean	SD
Weather						
Temperature (degree Celsius)	27.599	2.786	27.441	2.730	27.679	2.811
Relative Humidity (%)	67.418	11.159	68.423	11.380	66.913	11.012
Wet Bulb Globe Temperature (degree Celsius)	24.348	1.921	24.289	1.903	24.377	1.929
Heat Index (degree Celsius)	29.669	4.026	29.502	4.039	29.752	4.016
Production						
Actual Efficiency	53.411	21.452	52.054	21.411	54.095	21.440
Budgeted Efficiency	61.929	11.364	63.325	10.490	61.226	11.717

Temperature and Efficiency Time Series



Notes: Efficiency is produced quantity divided by targeted quantity. Date trimmed before June 1, 2010 due to limited production data.

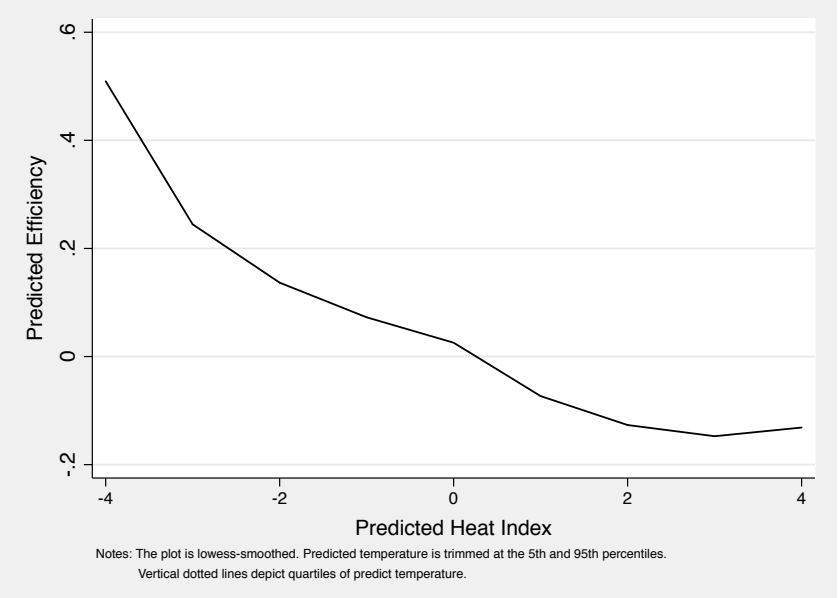
Temperature - Efficiency Gradient



Notes: The plot is lowess-smoothed. Predicted temperature is trimmed at the 5th and 95th percentiles.
Vertical dotted lines depict quartiles of predict temperature.

Temperature-Efficiency Gradient

Heat Index



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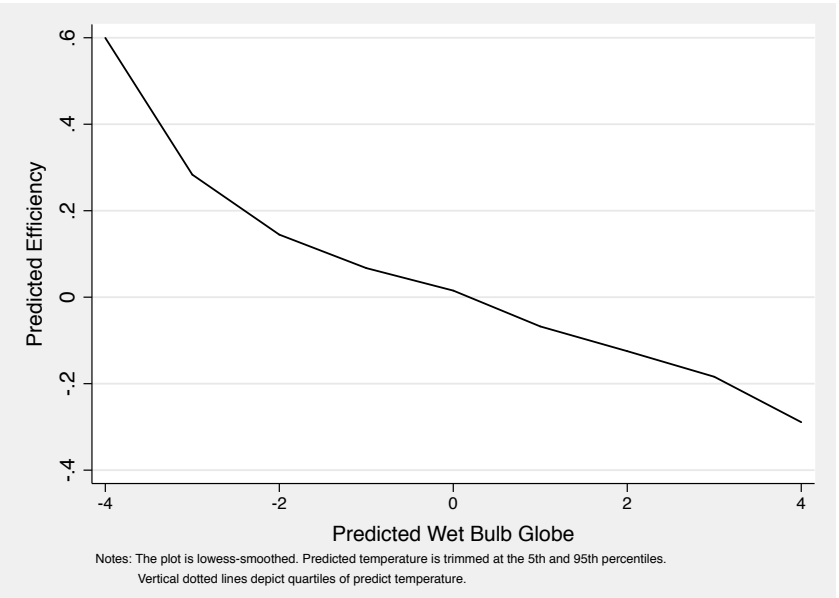
Wet Bulb Globe



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Empirical Specification: Effects of Temperature

$$E_{ludmy} = \alpha_0 + \beta T_{dmy} + \phi B_{ludmy} + \alpha_l + \gamma_{uy} + \eta_m + \delta_d + \varepsilon_{ludmy}$$

– line l, unit u, day d, month m, year y –

E = efficiency
B = budgeted efficiency
T= daily temperature in degrees Celsius
α_l = line fixed effects
γ_{uy} = unit x year fixed effects
η_m = month fixed effects
δ_d = day of week fixed effects

Temperature - Efficiency Gradient Before LED

	Actual Efficiency (Actual Production / Targeted Production)			
Temperature	-0.232**	-0.211**		
	(0.0963)	(0.0970)		
Heat Index			-0.161***	
			(0.0587)	
Wet Bulb Globe Temperature				-0.263**
				(0.109)
Relative Humidity		0.0980		
		(0.0887)		
Fixed Effects	Month, Day of Week, Factory x Year, Production Line			
Observations	71,969	71,969	71,969	71,969
R-squared	0.228	0.229	0.228	0.229

Efficiency on Temperature Lags Before LED

	Actual Efficiency (Actual Production / Targeted Production)			
Temperature	-0.155	-0.147		
	(0.0984)	(0.0994)		
Temperature (1 Week Lag)	-0.340**	-0.312**		
	(0.149)	(0.154)		
Heat Index			-0.103*	
			(0.0593)	
Heat Index (1 Week Lag)			-0.260***	
			(0.0883)	
Wet Bulb Globe Temperature				-0.177
				(0.111)
Wet Bulb Globe Temperature (1 Week Lag)				-0.462***
				(0.178)
Relative Humidity		0.0980		
		(0.0887)		
Fixed Effects	Month, Day of Week, Factory x Year, Production Line			
Observations	71,969	71,970	71,969	71,970
R-squared	0.229	0.230	0.229	0.230

Attendance on Temperature Lags Before LED

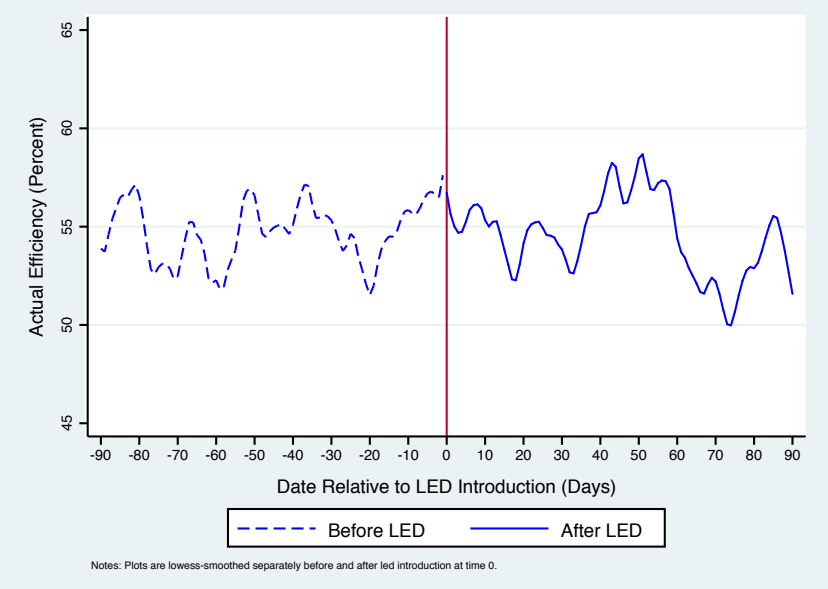
	Attendance			
	1(Present for Full Work Day)			
Temperature	0.00130	0.00112		
	(0.00112)	(0.00114)		
Temperature (1 Week Lag)	-0.00556***	-0.00599***		
	(0.00203)	(0.00196)		
Heat Index			0.000896	
			(0.000631)	
Heat Index (1 Week Lag)			-0.00194*	
			(0.00105)	
Wet Bulb Globe Temperature				0.00124
				(0.00128)
Wet Bulb Globe Temperature (1 Week Lag)				-0.00560**
				(0.00221)
Relative Humidity		-0.00195**		
		(0.000877)		
Fixed Effects		Month, Day of Week, Factory x Year		
Observations	7,630,496	7,630,496	7,630,496	7,630,496
R-squared	0.005	0.005	0.005	0.005

LED Rollout

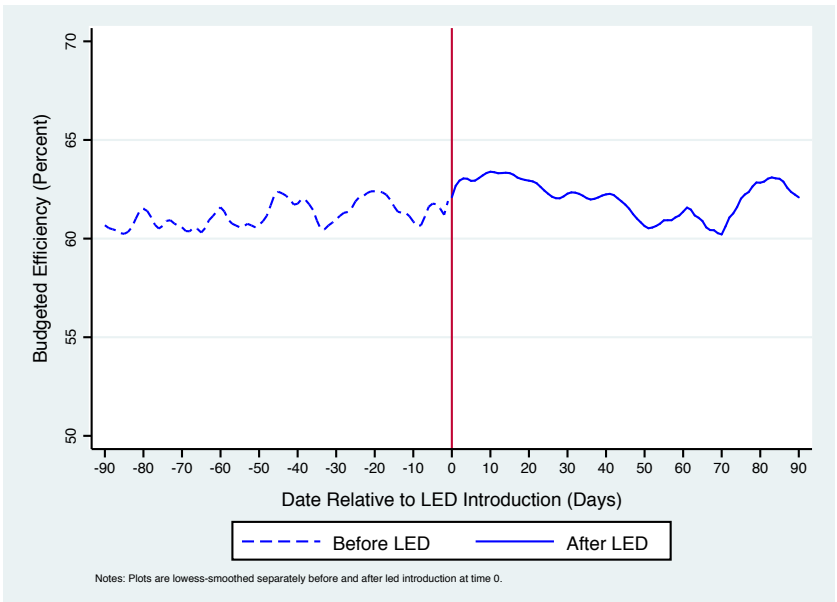
- LEDs rolled out across 25 of 29 factories from Oct 2009 to Feb 2013
- Buyer pressure + intra-firm "green" initiatives
- On average, each unit replaced about 1000 7W florescent bulbs with same number of 1W LEDs

Before and After LED

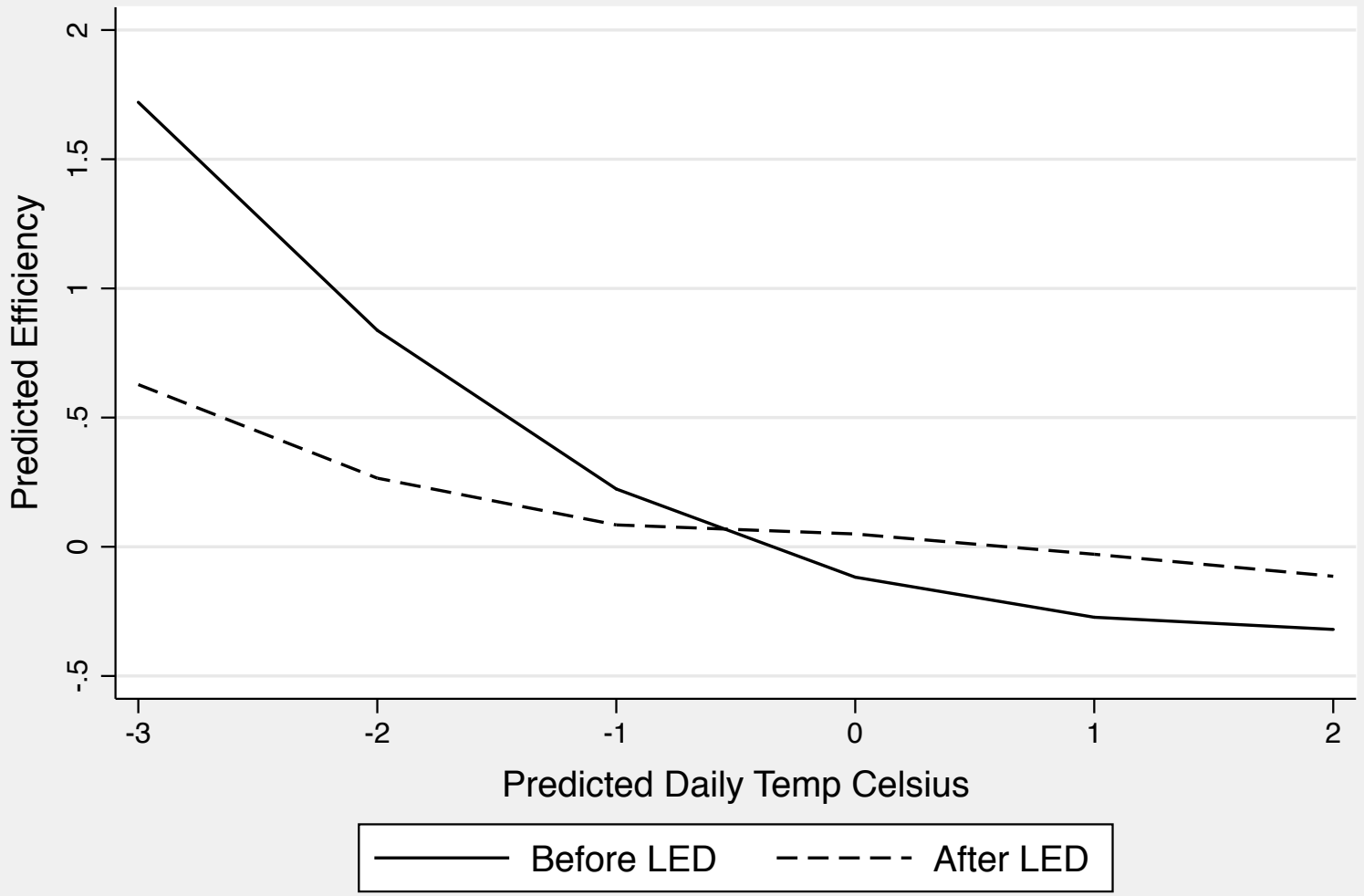
Actual Efficiency



Budgeted Efficiency



Mitigative Impact of LED



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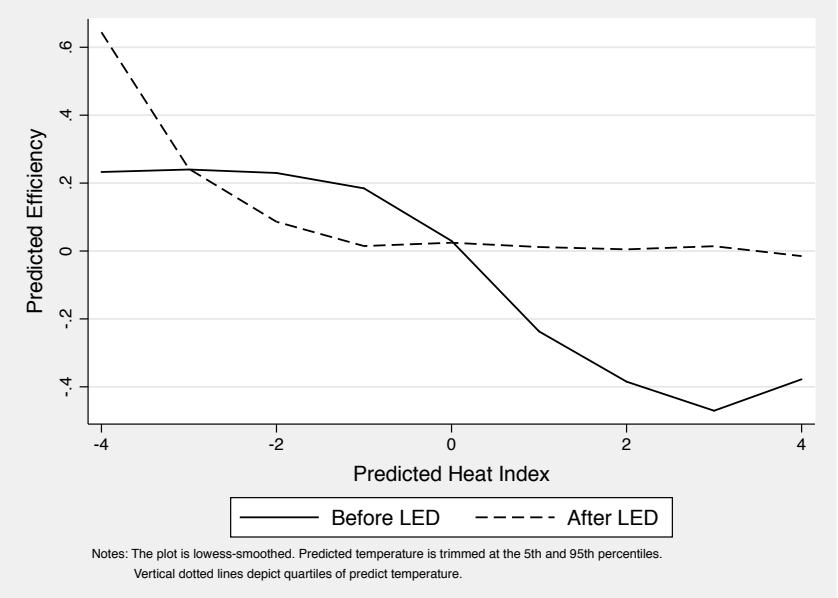
Mitigative Impact of LED

Heat Index



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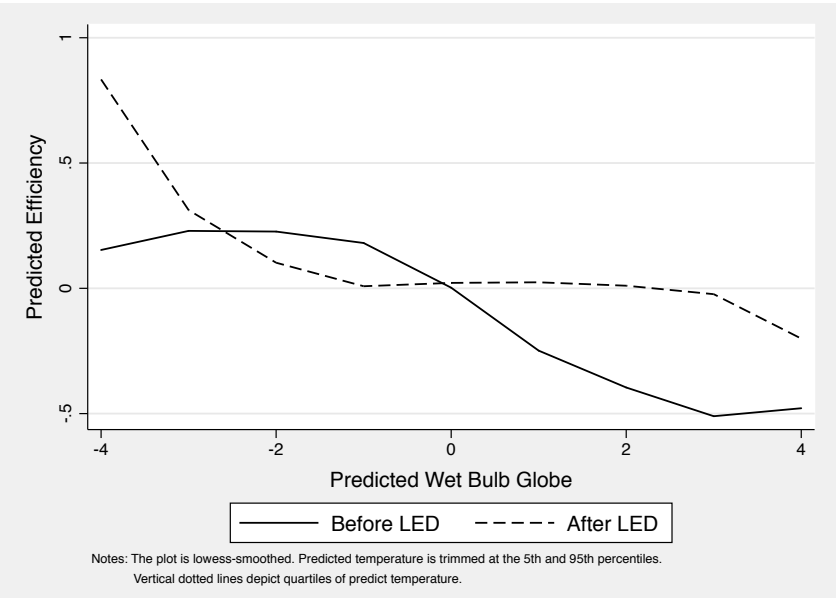
Wet Bulb Globe



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Mitigative Impact of LED

	Actual Efficiency (Actual Production / Targeted Production)			
Temperature x LED	0.237**	0.244**		
	(0.102)	(0.102)		
Heat Index X LED			0.150**	
			(0.0608)	
Wet Bulb Globe Temperature x LED				0.415***
				(0.123)
Temperature	-0.314***	-0.300***		
	(0.0899)	(0.0903)		
Heat Index			-0.199***	
			(0.0535)	
Wet Bulb Globe Temperature				-0.446***
				(0.104)
LED	-5.917**	-6.117**	-3.870**	-9.493***
	(2.900)	(2.891)	(1.918)	(3.047)
Fixed Effects	Month, Day of Week, Factory x Year, Production Line			
Observations	214,968	214,968	214,968	214,968
R-squared	0.209	0.209	0.209	0.209
	-0.078	-0.056	-0.049	-0.031
Temperature Impacts Net of LED	(0.069)	(0.068)	(.045)	(0.082)

Cost-benefit Analyses

- At average heat index (30 C), LED introduction associated with efficiency gain of .6 pp
- Translated to profit per factory unit per day = 41 USD (13K USD per factory per year, or 4 percent)
- Cost of bulb replacement per factory = 6300 USD; energy savings = 3000 USD per factory per year
- Break-even using energy savings alone $>$ 2 yrs; break-even accounting for efficiency gains $<$ 6 mo

Conclusions

- Temperature has substantial impacts on industrial labor productivity in India
- Reducing this elasticity is good for both workers and firms
- We show that energy-saving LED lighting has an additional productivity benefit via temperature mitigation
- Accounting for this "hidden" return drastically changes the cost-benefit calculations of LED adoption (break-even in 5-6 months as opposed to 2 years)