Nowcasting Firms' Operating Activities from Satellite Data on Thermal Infrared Radiation

Yuan Xue, Bohui Zhang, Xiaofeng Zhao

(JFQA,2025 Forthcming)

石宛青

（武汉大学金融系）

2025 年 10 月 26 日

raw materials → finished product

Satellite Data on TIR → **Firms' Operating Activities**

- sales growth
- cost of goods sold
- capital expenditures
- profit margins

Difficult:
TIR--factory--company match

- stock returns

Question

- Can satellite data on TIR predict firm's operating activities?
  - Is TIR responsive to firms' real operating activities?
  - Can TIR predict firms' operating performance?
  - Can TIR predict firms' stock return?

Why interesting?

- **Industrial production** directly drives firm performance; is foundation for economic growth, employment; attract attention from policymakers, investors.
- Existing indicators have limitations: :
  - Low timeliness: financial reports provide infrequent "after-the-fact" snapshots.
  - Managerial distortion （Chen et al. ,2020）
  - Most alternative data studies focus on the consumer side (e.g., transactions, foot traffic, social media) capture the "selling stage" rather than "product-stage". (Zhu 2019; Blankespoor et al. 2022)
- Real-time, objective, product-stage signal: firm production consumes energy → generates **thermal signals** detectable by satellites.

Contribution

- contributes to literature on measure of firms' operating activities
  - prior:
    - finance typically focus on selling activities (Huang,2018);
    - infrequent, aggregated disclosures prone to manipulation (Chen et al. ,2020).
  - extend:introducing a direct, real-time,operate-stage measure——TIR.
- contributes to literature on satellite data in economics and finance
  - prior:
    - use remote sensing to track macro trends(Geddes et al.,2016)
    - visible firm-level cues like parking lot traffic (Katona et al.,2025)
  - extend: captures invisible thermal infrared emissions at the factory level

Hypothesis

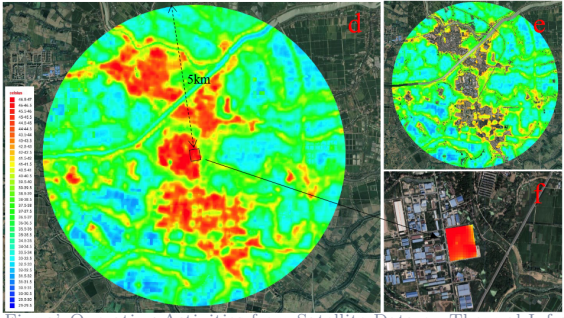
- H1: Corporate TIR is positively related to firms' future operating performance, controlling for current stock performance.
- H2: Corporate TIR is positively related to firms' future stock returns, controlling for current stock performance.

Design-data

- TIR: NASA’ s Landsat 8 and 9 satellites， 2013.2， 8 days， 30m
- sample:all manufacturing firms listed on China(SH,SZ),2014Q2-2022Q4
- Measuring corporate TIR
  1. Identify the factory
     - Registered addresses of listed companies and their subsidiaries
     - Use Google Maps to locate and identify types: (i) factory; (ii) office building; (iii) mixed-use (factory + office). Keep types 1 and 3.
     - Mark the factory area outlines (4 corner points A, B, C, D, and the center point)

Design-data

- Measuring corporate TIR
  1. Identify the factory
  2. Compute factory TIR
     - subtract the natural TIR from the observed TIR
     - $AR_{f,t} = FR_{f,t} - BR_{f,t}$
     - adjusted TIR(AR),Observed factory TIR (FR).bare lands (BR.devoid of human inhabitants and production activities)



Design-data

- Measuring corporate TIR
  1. Identify the factory
  2. Compute factory TIR
  3. Construct corporate TIR
     - $AR_{i,q} = \sum_{f=1}^{F} W_f \cdot AR_{f,q}$
     - W_f: factory f's initial investment/firm's total investment across all factories (IW) or is equal to 1/F (EW)
     - $DAR_{i,q} = \frac{AR_{i,q} - AR_{i,q-4}}{|AR_{i,q-4}|}$
- Firm performance
  - future operating:sales growth($SG_{i,q}$),cost of goods sold ($COGS_{i,q}$),capital expenditures ($Capx_{i,q}$),firms' profit margins($OperatingMargin_{i,q}$)
  - stock performance($Ret_{i,q}$)
- control variables
  - current stock return
  - Firm Control:$Size_{i,q}$, $Leverage_{i,q}$, $Loss_{i,q}$, $BM_{i,q}$, $Tangibility_{i,q}$, $Plants_{i,q}$
  - Region Control:$Temp_{i,q}$, $Humid_{i,q}$, $Preci_{i,q}$, $Sunshine_{i,q}$, $GDPGrowth_{i,q}$, $GDP/Cap_{i,q}$

Design-Summary statistics

- final sample:61,346 observations, involving 2,959 listed firms and 28,236 unique factories

Panel A: The factory-level analysis

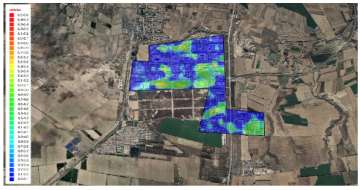
Variable	Unit	N	Mean	STD	P25	P50	P75
1	2	3	5	6	7	8	9
Outcome/TIR variables:							
$AR_{f,q}$	Kelvin	119,904	3.23	3.15	0.90	2.77	5.13
$DAR_{f,q}$	decimal	95,110	0.35	2.42	-0.30	0.01	0.43
Treatment variable:							
$COVID19_{f,q}$	decimal	119,904	1.04	1.88	0.00	0.00	1.39
Control variables:							
$Ret_{f,q}$	%	119,904	7.43	23.22	-8.23	2.31	17.73
$Size_{f,q}$	decimal	119,904	23.06	1.18	22.17	22.85	23.77
$Leverage_{f,q}$	decimal	119,904	0.45	0.17	0.33	0.46	0.58
$Loss_{f,q}$	dummy	119,904	0.14	0.35	0.00	0.00	0.00
$BM_{f,q}$	decimal	119,904	0.72	0.51	0.39	0.61	0.91
$Tangibility_{f,q}$	decimal	119,904	0.23	0.12	0.14	0.22	0.31
$Plants_{f,q}$	integer	119,904	40.38	52.32	12.00	22.00	45.00
$Temperature_{f,q}$	℃	119,904	16.05	8.47	9.44	18.45	22.07
$Humidity_{f,q}$	%	119,904	71.60	11.01	66.06	75.50	78.94
$Precipitation_{f,q}$	mm	119,904	3.21	2.49	1.09	2.64	4.97
$Sunshine_{f,q}$	hours	119,904	5.31	1.78	4.09	5.05	6.51
$GDPGrowth_{f,q}$	%	119,904	6.38	8.03	2.79	5.92	11.44
$GDP/Capita_{f,q}$	ten thousand yuan	119,904	9.91	4.24	6.78	9.35	13.50

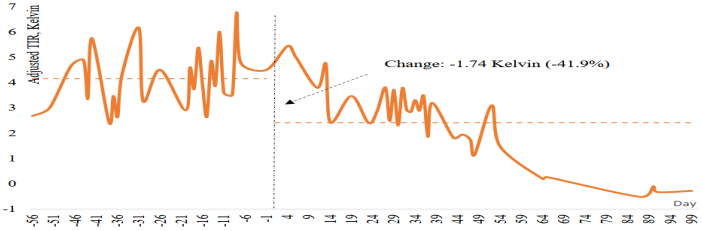
Result-Q1

Panel C: Adjusted TIR in the park area before and after the shutdown

Before shutdown

After shutdown





Result-Q1

Dependent variable	$AR_{f,q}$		$DAR_{f,q}$	
	1	2	3	4
COVID19$_{f,q}$	**-0.078****	**-0.086*****	**-0.054*****	**-0.057****
	(0.03)	**(0.02)**	**(0.01)**	**(0.02)**
$Ret_{f,q}$		0.001		0.001
		(0.00)		(0.00)
$Size_{f,q}$		-0.023		-0.041
		(0.03)		(0.06)
$Leverage_{f,q}$		-0.087		0.244
		(0.27)		(0.29)
$Loss_{f,q}$		-0.025		-0.098**
		(0.02)		(0.03)
$BM_{f,q}$		-0.007		-0.027
		(0.06)		(0.05)
$Tangibility_{f,q}$		-0.391**		0.803*
		(0.13)		(0.39)
$Plants_{f,q}$		0.001		0.001
		(0.00)		(0.00)
$Temperature_{f,q}$		0.001		0.011

Result-Q2

Dependent variable	$SG_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
DAR$_{i,q}$	**0.292****	**0.314*****	**0.272****	**0.281****
	(0.12)	**(0.11)**	**(0.11)**	**(0.10)**
$Ret_{i,q}$		0.143***		0.143***
		(0.03)		(0.03)
$Size_{i,q}$		11.636***		11.631***
		(1.72)		(1.72)
$Leverage_{i,q}$		32.001***		31.992***
		(5.97)		(5.97)
$Loss_{i,q}$		-11.825***		-11.825***
		(1.09)		(1.09)
$BM_{i,q}$		9.055***		9.041***
		(2.42)		(2.42)
$Tangibility_{i,q}$		-17.362*		-17.353*
		(8.68)		(8.68)
$Plants_{i,q}$		-0.118		-0.118
		(0.08)		(0.08)
$Temperature_{i,q}$		-0.185		-0.185
		(0.13)		(0.13)

Result-Q2

Panel A. Costs of goods sold

Dependent variable	$COGS_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
***DAR*$_{i,q}$**	**0.200***	**0.218****	**0.209****	**0.213****
	(0.10)	**(0.09)**	**(0.10)**	**(0.09)**
Control	No	Yes	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year-quarter fixed effects	Yes	Yes	Yes	Yes
Observations	61,337	61,337	61,337	61,337
R-squared	0.190	0.207	0.190	0.207

Panel B. Capital expenditures

Dependent variable	$Capx_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
***DAR*$_{i,q}$**	**0.005****	**0.005****	**0.005****	**0.005***
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**
Control	No	Yes	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year-quarter fixed effects	Yes	Yes	Yes	Yes
Observations	59,666	59,666	59,666	59,666

Result-Q3

Panel A. Raw returns

Dependent variable	$Ret_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
$DAR_{i,q}$	**0.131****	**0.111****	**0.128****	**0.101****
	(0.05)	**(0.04)**	**(0.05)**	**(0.04)**
$Ret_{i,q}$		-0.049***		-0.049***
		(0.02)		(0.02)
$Size_{i,q}$		-1.420		-1.421
		(1.16)		(1.16)
$Leverage_{i,q}$		2.392*		2.391*
		(1.19)		(1.19)
$Loss_{i,q}$		-3.843***		-3.840***
		(0.52)		(0.52)
$BM_{i,q}$		1.374**		1.377**
		(0.53)		(0.53)
$Tangibility_{i,q}$		1.035		1.014
		(2.25)		(2.26)
$Plants_{i,q}$		0.008		0.008
		(0.01)		(0.01)
$Temperature_{i,q}$		-0.009		-0.010
		(0.05)		(0.05)

Result-Q3

Panel A. Equally weighted TIR

	Excess	FF3	Carhart4	FF5
Portfolio	1	2	3	4
Low *DAR*	1.963	1.082	1.014	1.093
2	2.028	1.206	1.150	1.193
3	2.170	1.369	1.266	1.325
4	2.272	1.446	1.368	1.406
High *DAR*	2.366	1.476	1.383	1.548
High – Low	**0.403****	**0.394****	**0.369***	**0.455****
	(0.19)	**(0.19)**	**(0.19)**	**(0.19)**

Panel B. Investment-weighted TIR

	Excess	FF3	Carhart4	FF5
Portfolio	1	2	3	4
Low *DAR*	1.928	1.067	0.999	1.075
2	1.995	1.184	1.138	1.148
3	2.250	1.440	1.353	1.425
4	2.295	1.455	1.359	1.426
High *DAR*	2.356	1.462	1.371	1.522
High – Low	**0.427****	**0.395****	**0.372***	**0.447****
	(0.20)	**(0.20)**	**(0.20)**	**(0.20)**

Result-Additional analysis

1. Do sophisticated investors use TIR in trading?No
   - DAR——short sell,DAR——intuitional ownership,DAR——foreign invest
2. Do TIR-sale growth relation influenced by firms' energy efficiency? Yes
   - DAR×energy efficient industry——sale growth,DAR×TEP——sale growth,DAR×SOE——sale growth
3. Do investors incorporate TIR information before earnings announcements? No
   - DAR——CAR
4. Is TIR' s predictive power linked to on-site information access difficulty?Yes
   - DAR×site visit——CAR, DAR×high speed rail——CAR
5. Is TIR' s predictive power linked to firm information transparency?Yes
   - DAR×earnings management——CAR

Thanks!

Question & idea?

Idea

- 进一步?
  - TIR 预测企业信用风险、供应链风险
- 卫星数据的金融应用?
  - TIR 识别财务造假
  - TIR 作为能源消耗变量，结合产能，替代 CO2 等构造企业绿色指标
  - 多源遥感融合：TIR 只反映热能消耗，未反映生态状态。TIR 结合与 NDVI（植被指数）等是否能同时刻画 “产出强度 + 环境影响”? 探索其对收益、碳排、环境政策冲击的反应。
- 预测企业生产经营的其他另类数据?
  - 环境传感器与空气质量数据
  - 交通物流数据

Appendix-Summary statistics

Panel B: The firm-level analysis

Variable 1	Unit 2	N 3	Mean 5	STD 6	P25 7	P50 8	P75 9
Outcome variables:							
$SG_{i,q+1}$	%	61,346	18.75	53.43	-7.22	9.82	30.98
$COGS_{i,q+1}$	%	61,337	18.21	47.18	-5.73	10.18	30.26
$Employment_{i,y}$	%	17,702	7.38	30.13	-4.56	2.07	12.02
$OperatingMargin_{i,q+1}$	%	61,346	5.51	26.43	1.53	6.99	14.24
$Ret_{i,q+1}$	%	60,639	4.00	24.01	-11.30	-0.33	14.59
$ARet_{i,q+1}$	%	60,639	-3.07	17.42	-13.64	-4.82	5.79
$CAR(-1, 1)_{i, q+1}$	%	45,162	-0.24	4.96	-3.13	-0.41	2.38
$DSHO_{i,q}$	decimal	19,822	-0.05	2.46	-0.23	-0.00	0.19
$DIO_{i,q}$	%	61,346	-0.60	6.97	-3.65	-0.55	1.86
TIR variables:							
$DARe_{i,q}$	decimal	61,346	0.32	1.85	-0.21	0.03	0.34
$DARw_{i,q}$	decimal	61,346	0.32	1.87	-0.21	0.03	0.35
$DAReL8_{i,q}$	decimal	61,175	0.31	1.89	-0.22	0.02	0.35
$DARwL8_{i,q}$	decimal	61,175	0.32	1.89	-0.22	0.02	0.35
$DAReT1_{i,q}$	decimal	61,232	0.30	1.76	-0.20	0.03	0.34
$DARwT1_{i,q}$	decimal	61,232	0.31	1.81	-0.20	0.03	0.34
$DAReS_{i,q}$	decimal	56,957	0.35	1.99	-0.21	0.03	0.36
$DARwS_{i,q}$	decimal	56,957	0.36	2.09	-0.21	0.03	0.36
$DAReH_{i,q}$	decimal	55,282	0.35	2.72	-0.31	0.02	0.46
$DAReO_{i,q}$	decimal	51,231	0.37	3.30	-0.34	0.01	0.51

Appendix-Result-Q2-employment,margin

Panel C. Employment

Dependent variable	*Employment*$_{i,y}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
***DAR*$_{i,q}$**	**1.292****	**1.222****	**1.095****	**1.037****
	(0.50)	**(0.45)**	**(0.47)**	**(0.43)**
Control	No	Yes	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	17,702	17,702	17,702	17,702
R-squared	0.215	0.253	0.214	0.253

Panel D. Operating margin

Dependent variable	*OperatingMargin*$_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
***DAR*$_{i,q}$**	**0.053**	**0.053***	**0.063***	**0.061****
	(0.03)	**(0.03)**	**(0.03)**	**(0.03)**
Control	No	Yes	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes

Appendix-Result-Q3-Abnormal returns

- minus the returns of the 5 × 5 market value and book-to-market (Size/BM) matched portfolio

Panel B. Abnormal returns

Dependent variable	$ARet_{i,q+1}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
$DAR_{i,q}$	**0.098****	**0.111*****	**0.101****	**0.110*****
	(0.05)	**(0.04)**	**(0.04)**	**(0.03)**
$Ret_{i,q}$		-0.057***		-0.057***
		(0.01)		(0.01)
$Size_{i,q}$		0.075		0.074
		(0.29)		(0.29)
$Leverage_{i,q}$		2.780***		2.778***
		(0.85)		(0.85)
$Loss_{i,q}$		-3.989***		-3.986***
		(0.54)		(0.54)
$BM_{i,q}$		-0.740		-0.739
		(1.62)		(1.62)
$Tangibility_{i,q}$		1.906		1.885
		(1.84)		(1.84)
$Plants_{i,q}$		0.019*		0.019*
		(0.01)		(0.01)

Appendix-Result-TIR and sophisticated investors

- firm’ s net short position change in quarter q ($DSHO_{i,q}$)

Panel A. Short-selling activities				
Dependent variable	$DSHO_{i,q}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
$DAR_{i,q}$	**-0.006**	**-0.007**	**-0.012**	**-0.013**
	(0.01)	**(0.01)**	**(0.01)**	**(0.01)**
$Ret_{i,q}$		0.004**		0.004**
		(0.00)		(0.00)
$Size_{i,q}$		-0.043		-0.043
		(0.09)		(0.09)
$Leverage_{i,q}$		-0.100		-0.097
		(0.26)		(0.26)
$Loss_{i,q}$		0.030		0.029
		(0.06)		(0.06)
$BM_{i,q}$		-0.078		-0.078
		(0.08)		(0.08)
$Tangibility_{i,q}$		0.250		0.249
		(0.58)		(0.58)
$Plants_{i,q}$		-0.004***		-0.004***
		(0.00)		(0.00)
$Temperature_{i,q}$		0.002		0.002
		(0.01)		(0.01)

Appendix-Result-TIR and sophisticated investors

- firm’ s intuitional ownership change in quarter q ($DIO_{i,q}$),

Panel B. Institutional ownership

Dependent variable	$DIO_{i,q}$			
TIR variable	Equally weighted TIR $DAR_{i,q} = DARe_{i,q}$		Investment-weighted TIR $DAR_{i,q} = DARw_{i,q}$	
	1	2	3	4
$DAR_{i,q}$	**0.028**	**0.032***	**0.027**	**0.029**
	(0.02)	**(0.02)**	**(0.02)**	**(0.02)**
$Ret_{i,q}$		0.039***		0.039***
		(0.00)		(0.00)
$Size_{i,q}$		2.089***		2.089***
		(0.21)		(0.21)
$Leverage_{i,q}$		0.437		0.436
		(0.69)		(0.69)
$Loss_{i,q}$		-0.387***		-0.387***
		(0.10)		(0.10)
$BM_{i,q}$		1.757***		1.756***
		(0.33)		(0.33)
$Tangibility_{i,q}$		0.794		0.795
		(1.09)		(1.09)
$Plants_{i,q}$		-0.009		-0.009
		(0.01)		(0.01)
$Temperature_{i,q}$		0.001		0.001
		(0.01)		(0.01)

Appendix-Result-The effect of energy efficiency and productivity

Dependent variable	$SG_{i,q+1}$					
	1	2	3	4	5	6
$\boldsymbol{DARw_{i,q} \times Energy_{i,q}}$	**1.104***	**1.035***				
	(0.60)	**(0.59)**				
$Energy_{i,q}$	1.541	1.126				
	(2.41)	(2.41)				
$\boldsymbol{DARw_{i,q} \times TFP_{i,q}}$			**1.120****	**0.975***		
			(0.52)	**(0.49)**		
$TFP_{i,q}$			10.278***	9.022***		
			(1.39)	(1.37)		
$\boldsymbol{DARw_{i,q} \times SOE_{i,q}}$					**-0.479***	**-0.497***
					(0.26)	**(0.26)**
$SOE_{i,q}$					-10.938***	-8.202***
					(2.66)	(2.81)
$DARw_{i,q}$	0.157	0.173	0.179	0.202*	0.410***	0.424***
	(0.11)	(0.11)	(0.11)	(0.11)	(0.14)	(0.14)
Control	No	Yes	No	Yes	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-quarter fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	61,346	61,346	60,220	60,220	61,346	61,346
R-squared	0.185	0.202	0.189	0.206	0.185	0.203