Techies, Trade, and Skill-Biased Productivity

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What are the drivers of productivity growth?

- How do new technologies diffuse in the economy?
- What are the consequences for labor demand?

- Novel idea: use firm level employment of **techies** as indicator for firm-level investment in productivity enhancing.
  - **creators and/or mediators of technology diffusion** at the firm level.
  - distinguish R&D techies (general) versus ICT techies.
  - an alternative to problematic R&D expenditures and patents data that allows more forensic approach.

- Also study the role of global engagement: exporting and importing.

Techies: ICT and R&D functions

	Technical Managers & Engineers	
383a	R&D	Engineers and R&D managers, electricity and electronics
384a	R&D	Mechanical engineers and R&D managers
385a	R&D	Materials and chemical engineers and R&D managers
386a	R&D	Engineers and R&D managers, intermediate goods
388a	ICT	Information technology engineers and managers
388b	ICT	Information technology support engineers and managers
388c	ICT	Information technology project managers
388e	ICT	Telecommunications engineers and specialists
	Technicians	
473b	R&D	R&D technicians, electrical and electronic equipment
474b	R&D	R&D technicians, mechanical and metalworking equipment
475a	R&D	R&D technicians, processing industries
478a	ICT	R&D technicians, information technology
478b	ICT	Computer production and operation technicians
478c	ICT	Computer installation and maintenance technicians
478d	ICT	Telecommunications and computer network technicians

What we do

1. Estimate **Hicks-neutral** productivity + **biased** factor augmentation.
    - all firms in French private sector, excl agric, primary sectors, finance.
    - to do this, develop modest methodological contribution.
2. Associate these to R&D, ICT, exporting and importing.
    - First paper to jointly evaluate all these channels on 1.
3. Evaluate quantitative importance for labor demand and relative demand for skilled labor.

- We find: firms with more techies, and/or that import, see
    - Faster productivity growth, through SBTC .
    - $\Longrightarrow$ large effects on relative demand for skill, but level of demand for unskilled increases too.
    - $\Longrightarrow$ large effects on aggregate relative demand for skill.
- Suggests importance of engineers—not necessarily inventors—for productivity growth at the firm level.

Techies as creators and mediators of technology

- Brynjolfsson-Hitt (2003), Tambe-Hitt (2012), Tambe-Hitt (2014).
  - IT and IT workers associated with higher firm output ($\neq$ productivity).
- Harrigan-Reshef-Toubal (2016).
  - Techies increasingly prevalent in France: 8% in 1994, 14% in 2013.
  - Help explain firm employment growth and job polarization.
- Barth-Davis-Freeman-Wang (2017).
  - Most techies do not perform R&D in US manuf. establishments.
    - Also true in our French firms data; we focus on ICT vs. R&D.
  - Techies positively associated with output level and growth.
- Kelly-Mokyr-Ó Gráda ('12, '14), Ben Zeev-Mokyr-van der Beek ('17)
  - Argue that British advantage in labor "*possessing the technical skill or competence to implement the technology of the Industrial Revolution*".
  - Apprentices, not inventors—but conduits of diffusion.
- Maloney and Valencia-Caicedo (2017)
  - Engineer intensity in Americas, U.S. counties around 1880 helps predicting income today.

Related ideas

- **SBTC, directed TC, routinization, race with/against machine.**
  - Katz-Murphy (1992), Berman-Bound-Griliches (1994), Reshef (2013).
  - Kennedy (1964), Acemoglu (1998, 2003), Thoenig-Verdier (2003).
  - ALM ('03), Goos-Manning ('07), Acemoglu-Autor ('11), Autor-Dorn ('13), Michaels et al. ('14), Goos et al. ('14), Barany-Siegel ('16).
  - Gregory-Salomons-Zierahn (2016), Graetz-Michaels (2016), Acemoglu-Restrepo (2016), Autor-Salomons (2017).
- **Importing, offshoring and productivity.**
  - Feenstra-Hanson ('99), Grossman-Rossi-Hansberg ('08), Reijnders-Timmer-Ye ('16), Amiti-Konings ('07), Bas-Strauss-Kahn ('14,'15), Bas-Berthou ('17).
- **Export-productivity complementarities + skill bias.**
  - Bernard-Jensen (1999), Lileeva-Trefler (2010), Bustos (2011).
  - Yeaple (2005), Bustos (2011wp), Bas (2012), Vannoorenberghe (2011), Harrigan-Reshef (2015), Burstein-Vogel (2016).

Stylized Model

If Techies Are So Great, Why Don't All Firms Employ Them?

Techies as a fixed (but not sunk) investment cost

- Firm takes demand, costs, initial log productivity ω_{ft-1} as given.
- Chooses optimal techie employment T_{ft-1} to maximize profits.
- Techies T_f necessary for creating/adopting better technology:

$$\omega_{ft} = \omega_{ft-1} + \max\left\{\beta \ln\left(\frac{T_{ft-1}}{\gamma_f}\right) \ , \ 0\right\} \ , \quad \beta > 0$$

  - β common to all firms (which we estimate below).
  - γ_f varies across firms.
  - Cost of employing techies>0 :

$$C\left(T_{ft-1}\right) = rT_{ft-1} + \kappa_f$$

- Heterogeneity in γ_f, κ_f can rationalize heterogeneity in
  - extensive margin of techie employment ($T_{ft-1} > 0$?);
  - intensive margin of techie employment (how many?);
  - despite $\beta > 0$ (techies are useful).
  - (common feature with trade models with heterogenous firms).

Implications

- $T^*_{ft-1} = 0$ more likely when fixed costs κ_f high, efficiency $1/\gamma_f$ low.
  - $T^*_{ft-1} = 0$ possible even if $\kappa_f = 0$.
- If $T^*_{ft-1} > 0$, then more techies
  - when they are more efficient ($\partial T^*_{ft-1}/\partial\gamma_f < 0$)
  - in more productive firms ($\partial T^*_{ft-1}/\partial\omega_{ft-1} > 0$).
- $T^*_{ft-1} > 0$ more likely and greater techie intensity predicted when demand, initial productivity are higher.
  - And this is what we find.../

VARIABLES	I(techies>0)	Techie wage bill share for techies>0
log Revenue	0.131***	0.003***
	(0.003)	(0.001)
Exporter dummy	0.548***	0.004**
	(0.013)	(0.002)
Importer dummy	0.591***	-0.002
	(0.012)	(0.002)
Skilled wage bill share	0.525***	0.134***
	(0.049)	(0.013)
Observations	612769	69,175
R-squared	0.522	0.434

- Techies more likely in larger, skill intensive firms, facing larger mkts.
- Conditional on >0 (11% of firms), larger and more skill intensive firms are more techie-intensive.

Econometric Framework

Normalized production function: extension of GLZ (2016)

- Diamond, McFadden & Rodriguez (1978) "impossibility theorem": biased TC not identifiable without structure (e.g., long linear t trend).
- Normalization overcomes this problem (León-Ledesma *et al.* 2010):

$$\frac{Q_{ft}}{\overline{Q}} = e^{\omega_{ft}^{H}} \left[\alpha_L \left(\frac{L_{ft}}{\overline{L}}\right)^{\gamma} + \alpha_S \left(\frac{e^{\omega_{ft}^{S}} S_{ft}}{\overline{S}}\right)^{\gamma} + \alpha_K \left(\frac{K_{ft}}{\overline{K}}\right)^{\gamma} + \alpha_M \left(\frac{M_{ft}}{\overline{M}}\right)^{\gamma} \right]^{1/\gamma}$$

  - $\overline{X}$ = geometric mean of X
  - $\overline{\omega}^{H} = \overline{\omega}^{S} = 0$.
- Why/how? Normalization pins down α's (see below).

Identification assumptions

$$\frac{Q_{ft}}{\overline{Q}} = e^{\omega^H_{ft}} \left[\alpha_L (\frac{L_{ft}}{\overline{L}})^\gamma + \alpha_S (\frac{e^{\omega^S_{ft}} S_{ft}}{\overline{S}})^\gamma + \alpha_K (\frac{K_{ft}}{\overline{K}})^\gamma + \alpha_M (\frac{M_{ft}}{\overline{M}})^\gamma \right]^{1/\gamma}$$

- ω^H_{ft} and ω^S_{ft} **known to firm when choosing inputs**.
  - Implication: they directly appear in FONCs.
- Techies only affect ω^H_{ft} and ω^S_{ft} with a lag, like investment.
- **Techies excluded from** L, S.
  - econometric tests: plausible.
  - violation does not bias second step (controlled markov).

Demand and revenue

- Demand:

$$P_{ft} = A_t \left(\frac{Q_{ft}}{\overline{Q}} \right)^{-1/\eta}$$

  - $\eta > 1$ elasticity of demand—**jointly estimated** with production function parameters.
  - A_t common to all firms in industry.

- Revenue:

$$R_{ft} = e^{u_{ft} + \frac{\eta+1}{\eta}\omega_{ft}} A_t \left(\frac{Q_{ft}}{\overline{Q}} \right)^{\frac{\eta+1}{\eta}}$$

  - u_{ft} revenue shifter, $E\left(u_{ft}\right) = 0$.
  - Absorbs measurement error, unanticipated productivity shocks.
  - **UN-known to firm when choosing inputs.**

Using FONCs to eliminate unobsrvables

- Materials quantities or prices rarely observed. GLZ manipulate static FONCs to substitute M, using observable expenditures E^M:

$$\frac{M_{ft}}{\overline{M}} = \left(\frac{\alpha_L}{\alpha_M} \frac{E^M_{ft}}{E^L_{ft}} \right)^{1/\gamma} \frac{L_{ft}}{\overline{L}}$$

- Skilled labor input in efficiency units $e^{\omega^S_{ft}} S_{ft}$ also unobserved. Our **modest methodological contribution** is to substitute $e^{\omega^S_{ft}} S_{ft}$ with:

$$\frac{e^{\omega^S_{ft}} S_{ft}}{1 \cdot \overline{S}} = \left(\frac{\alpha_L}{\alpha_S} \frac{E^S_{ft}}{E^L_{ft}} \right)^{1/\gamma} \frac{L_{ft}}{\overline{L}}$$

- Taking geometric means of the above, we get

$$\alpha_L \overline{E}^M = \alpha_M \overline{E}^L \quad , \quad \alpha_L \overline{E}^S = \alpha_S \overline{E}^L$$

Estimating equation

$$\ln R_{ft} = \ln \frac{\eta}{\eta+1} + \ln \left[E_{ft}^{M} + E_{ft}^{S} + E_{ft}^{L} + E_{ft}^{L} \frac{\alpha_K}{\alpha_L} \left(\frac{K_{ft}/\overline{K}}{L_{ft}/\overline{L}} \right)^{\gamma} \right] + u_{ft}$$

- u_{ft} orthogonal, unexpected revenue shock.
- Estimate by Weighted-NLLS, under constraints $\gamma < 1$ and $\frac{\alpha_K}{\alpha_L} > 0$.
- Solve for α's using estimate of $\frac{\alpha_K}{\alpha_L}$ and (normalization + CRS):

$$\begin{aligned} \alpha_L \overline{E}^M &= \alpha_M \overline{E}^L \\ \alpha_L \overline{E}^S &= \alpha_S \overline{E}^L \\ \alpha_L + \alpha_S + \alpha_M + \alpha_K &= 1 \end{aligned}$$

- Separately for each industry, SEs clustered by firm.
- Using estimated parameters and data, back out ω_{ft}^{H} and ω_{ft}^{S}.

Productivity and labor demand: Hicks neutral

$$
\begin{aligned}
\frac{dS}{S} &= (\eta - 1)\,\mathbf{d\boldsymbol{\omega}_H} + \left[(\sigma - 1) + (\eta - \sigma)\,\lambda_S\right] d\omega_S \\
\frac{dL}{L} &= (\eta - 1)\,\mathbf{d\boldsymbol{\omega}_H} + \left[\qquad\qquad\quad (\eta - \sigma)\,\lambda_S\right] d\omega_S
\end{aligned}
$$

- Elasticity of both S and L w.r.t. Hicks-neutral ω_H : $\eta - 1$.
  - labor-saving effect has elasticity -1,
  - demand effect through lower costs has elasticity η.

Productivity and labor demand: skill augmenting

$$\begin{aligned}\frac{dS}{S} &= (\eta - 1)\, d\omega_H + [(\sigma - 1) + (\eta - \sigma)\, \lambda_S]\, \mathbf{d\omega_S} \\ \frac{dL}{L} &= (\eta - 1)\, d\omega_H + [\qquad\qquad (\eta - \sigma)\, \lambda_S]\, \mathbf{d\omega_S}\end{aligned}$$

- Elasticity of S w.r.t. skill augmentation ω_S : $(\sigma - 1) + (\eta - \sigma)\, \lambda_S$.
  - demand effect via η.
  - substitution effect via σ.
  - $\lambda_S =$ cost share of S.
- Elasticity of L w.r.t. skill augmentation ω_S : $(\eta - \sigma)\, \lambda_S$.
  - **if $\eta > \sigma$, skill-augmenting productivity raises demand for L.**
- if $\sigma > 1$, skill-augmenting productivity raises S/L (SBTC).

Controlled Markov process for productivity

$$
\begin{aligned}
\omega_{ft}^{H} &= \beta_1^H \mathbf{T}_{ft-1} + \beta_2^H 1_{\{\mathbf{Exp}_{ft-1}>0\}} + \beta_3^H 1_{\{\mathbf{Imp}_{ft-1}>0\}} \\
&\quad + \pi_H^H \omega_{ft-1}^H + \pi_S^H \omega_{ft-1}^S + \text{ controls } + \xi_{ft}^H \\
\omega_{ft}^{S} &= \beta_1^S \mathbf{T}_{ft-1} + \beta_2^S 1_{\{\mathbf{Exp}_{ft-1}>0\}} + \beta_3^S 1_{\{\mathbf{Imp}_{ft-1}>0\}} \\
&\quad + \pi_H^S \omega_{ft-1}^H + \pi_S^S \omega_{ft-1}^S + \text{ controls } + \xi_{ft}^S
\end{aligned}
$$

- $\xi_{ft}^i \sim$ noise.
- Controls: firm age$_{ft-1}$, ln R_{ft-1}, industry$\times$year FEs.
- WLS, bootstrapped SEs clustered by firm (ωs are estimated).
- DL/DJ (2013) insight: lagged productivity controls for selection, implies βs are causal effects—for treated firms.

Data and Results

Administrative data on French private sector firms

- DADS: labor inputs by detailed occupation (PCS).
  - S = owners and top management, highly skilled professionals, non-ICT and non-R&D engineers.
  - L = middle managers, white collar, office workers, non-ICT and non-R&D technicians, retail, wholesale, blue collar, personal services, drivers, etc.
  - T = ICT and R&D technicians, engineers and managers.
- FARE: balance sheet data on revenue, materials expenditures, capital stock (Atkinson and Mairesse 1978).
- French customs: imports, exports.
- All merged via firm level *SIREN* identifier (excellent match).
- Sample: 2009–2013, 16 industries (2-digit NACE).

Production function estimates

Industry	αL	αS	αM	αK	σ	η	Obs.	Firms	t-stat for Ho: σ=1
Food, beverage, tobacco	0.19	0.05	0.57	0.19	2.86	-5.09	26407	6516	9.53
Textiles, wearing apparel	0.30	0.11	0.55	0.05	2.24	-2.95	9732	2337	2.66
Wood, paper products	0.29	0.10	0.43	0.18	1.16	-3.48	19892	4808	2.93
Chemical products	0.14	0.07	0.55	0.24	1.32	-4.73	5748	1292	4.37
Rubber and plastic	0.23	0.07	0.57	0.13	2.92	-3.44	15960	3702	5.48
Basic metal and fabricated metal	0.25	0.07	0.31	0.37	1.48	-5.87	34074	7960	9.11
Computer, electronic	0.19	0.12	0.46	0.23	1.54	-2.99	5462	1267	4.15
Electrical equipment	0.18	0.08	0.53	0.21	1.38	-5.07	4597	1063	4.26
Machinery and equipment	0.19	0.09	0.49	0.24	1.40	-4.85	11475	2605	4.32
Other manufacturing	0.25	0.10	0.35	0.30	1.33	-4.08	27648	6722	8.77
Construction	0.28	0.10	0.38	0.25	1.24	-2.87	159641	41175	8.11
Wholesale	0.09	0.05	0.76	0.09	1.48	-7.97	176180	42846	3.68
Retail	0.09	0.04	0.76	0.11	1.77	-11.99	210097	52078	7.62
Transportation and storage	0.30	0.05	0.08	0.57	1.36	-4.23	27683	6899	7.37
Accommodation and food services	0.30	0.09	0.27	0.34	1.67	-6.73	95571	25817	8.65
Administrative and support activities	0.43	0.13	0.09	0.35	2.52	-5.61	28674	7557	13.60
wgtd. avg.	0.19	0.07	0.53	0.20	1.62	-7.01			

- Reasonable estimates, all extremely statistically significant.
- $\sigma < |\eta|$: racing with (not against) the machine?

2nd stage baseline estimates

Techies and trade effects on Productivity, Pooled (αS=0.07; σ=1.62)

	Hicks Neutral	Skill augmenting	Output effect of skill augmenting, αS*ΔωS	Relative skill demand effect, (σ-1)*ΔωS
Techies	0.042	0.700***	0.049	0.434
- scaled effect	0.001	0.017***	0.001	0.010
Exports>0	-0.011	0.033	0.002	0.020
Imports>0	0.026**	0.066***	0.005	0.041

Notes: Bootstrapped standards errors clustered by firms. Sample: 612769 obs. on 205472 firms during 2009-2013. Specifications include other covariates and industry x year FE. Asterisks indicate statistical significance, * = 0.10, ** = 0.05, *** = 0.01.

- Significant techie effect on ω^S (SBTC).
- Significant import effects on ω^H and ω^S.

Implied cross-section labor demand effects

- Use 2nd stage coefficients, average 1st stage elasticities σ_i, η_i.
- Comparing a firm at 75^{th} percentile of techies to one with none:
  - 60% higher employment of skilled labor S.
  - 15% higher employment of unskilled labor L.
  - 40% higher skill intensity S/L.
- Comparing firms that import to those who do not:
  - 115% higher employment of skilled labor.
  - 25% higher employment of unskilled labor.
  - 70% higher skill intensity.
- Demand for both unskilled and skilled increases.

Implied techie-induced aggregate changes

- In the data $\Delta \frac{S}{S+L} = 1.86\%$ (14.14 in 2009, 16 in 2013).
- Combine 2[nd] stage coefficients, 1[st] stage elasticities σ_i, η_i, actual expenditures on techies and importing across firms.
- Implied aggregate demand shift on $\Delta \frac{S}{S+L}$ in 2009–2013:
  - Techies : **1.12%**.
  - Importing : **1.6%**
  - Takes into account changes in firm sizes and skill intensities.
- Large effects: not taking into account equilibrium constraints.
- Reassuring: reasonable magnitudes, in ballpark of observed changes.

ICT versus R&D techies

Techies and trade effects on Productivity, Pooled (αS=0.07; σ=1.62)

	Hicks Neutral	Skill augmenting	Output effect of skill augmenting, αS*ΔωS	Relative skill demand effect, (σ-1)*ΔωS
ICT	0.086	0.908***	0.064	0.563
R&D	-0.012	0.450*	0.032	0.279
- scaled effect ICT	0.001	0.012	0.001	0.007
- scaled effect R&D	-0.0002	0.009	0.001	0.006
Exports>0	-0.011	0.033*	0.002	0.020
Imports>0	0.025**	0.066***	0.005	0.041

Notes: Bootstrapped standards errors clustered by firms. Sample: 612769 obs. on 205472 firms during 2009-2013. Specifications include other covariates and industry x year FE. Asterisks indicate statistical significance, * = 0.10, ** = 0.05, *** = 0.01.

- R&D associated with SBTC—ICT twice more on the margin.
- Cannot reject $H_0 : \beta^S_{\text{ICT}} = \beta^S_{\text{R\&D}}$, and scaled effects similar.

Engineers versus technicians

Techies and trade effects on Productivity, Pooled ($\alpha S=0.07$; $\sigma=1.62$)

	Hicks Neutral	Skill augmenting	Output effect of skill augmenting, $\alpha S*\Delta\omega S$	Relative skill demand effect, $(\sigma-1)*\Delta\omega S$
Engineers	-0.008	1.015***	0.071	0.629
Technicians	0.188	-0.233	-0.016	-0.144
- scaled effect engineers	-0.0001	0.017	0.001	0.011
- scaled effect technicians	-0.0001	-0.002	0.000	-0.001
Exports>0	-0.011	0.034*	0.002	0.021
Imports>0	0.025**	0.068***	0.005	0.042

Notes: Bootstrapped standards errors clustered by firms. Sample: 612769 obs. on 205472 firms during 2009-2013. Specifications include other covariates and industry x year FE. Asterisks indicate statistical significance, * = 0.10, ** = 0.05, *** = 0.01.

- Engineers (not technicians) account for techie effect on SBTC.
- Scaled effect of engineers similar to total effect of techies.

Effects of imports via intermediate inputs, by source

Techies and trade effects on productivity, Pooled

	Hicks neutral	Skill augmenting
A. Intermediate inputs		
Techies	0.042	0.700***
Exports>0	-0.011	0.030
Imports>0	0.034	0.023
Imports of intermediates>0	-0.009	0.052**
B. By source countries		
Techies	0.040	0.685***
Exports>0	-0.008	0.018
Imports (High Income) >0	0.017	0.040***
Imports (Other Countries) >0	-0.001	0.054***

Notes: Bootstrapped standards errors clustered by firms. Sample: 612769 obs. on 205472 firms during 2009-2013. Specifications include other covariates and industry x year FE. Asterisks indicate statistical significance, * = 0.10, ** = 0.05, *** = 0.01.

- Import effect on ω^H driven by high income countries.
- Import effect on ω^S driven by intermediate inputs.

Contributions, findings, takeaways

- First paper to jointly evaluate effect of R&D, ICT, exporting and importing channels on firm level productivity.
  - Methodology: extend GLZ to 4 factors, with SBTC.
  - Novel source of firm level variation: **techies**.
- What we found:
  - Large techie effect on productivity via SBTC.
  - Large import effect on productivity via Hicks-neutral and SBTC.
  - Large relative demand shifts: within firms, aggregate.
  - Elasticities of demand $>>$ elasticities of substitution: implies SBTC need not reduce employment of less skilled workers (possibility for racing with the machine, not against it).
- Techies important, either for innovation or technology adoption.
- Implication for education policy?