Econometrics of Complementarities

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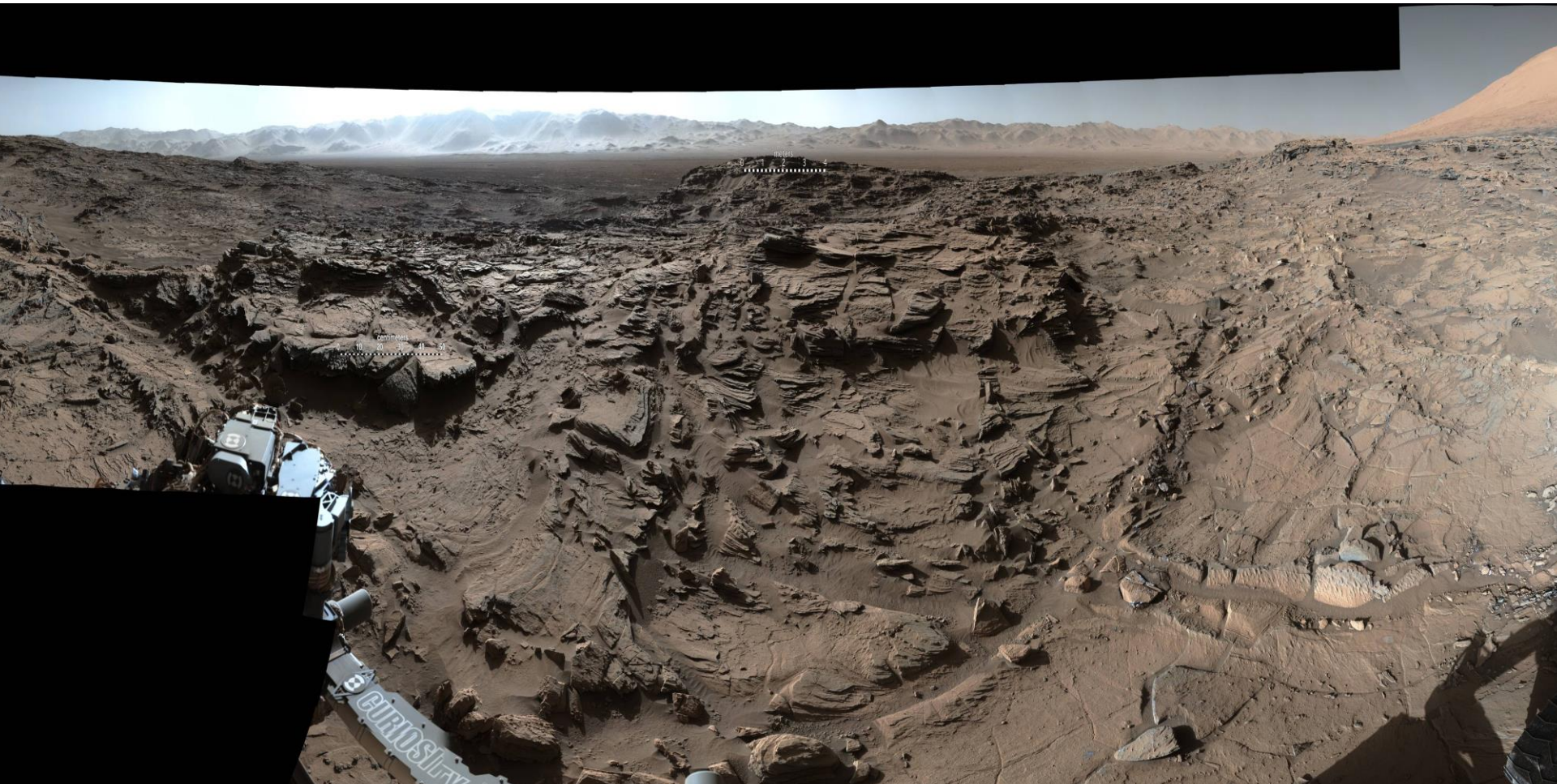

INTRODUCTION

- **Synergies** “interaction of two or more agents or forces so that their combined effect is greater than the sum of their individual efforts”
- Complementarity is this applied to a decision-making context.
- Example: Consider decisions whether to -
  1. Adopt strategy that requires implement frequent changes in technology
  2. Invest in flexibly trained workforce
  3. Give workers more discretion
     - Complementarity between pairs of these decisions
     - We would expect them to cluster together
- Say a firm has all 3. Should the organization now adopt another one (e.g. job protections)? “Matrix of Change”

SOME ECONOMETRICS OF ORGANIZATIONAL COMPLEMENTARITIES

- **Production theory.** Standard economic theory of the firm considers substitutability & complementarity between factors of production. Examples:
  - Labor and capital
  - Skilled and unskilled labour
  - Skilled labour and capital ("capital-skill complementarity")
- **Consumer demand**
  - Early work on demand attempts to estimate these (e.g. Stone, 1958)
  - Fundamental to anti-trust issues in IO (e.g. mergers)
- Basic theory can be extended to many other **choice** variables of firms (Milgrom & Roberts, 1990; Levinthal, 1997; "**Rugged landscapes**"); clustering of practices
  - Organizational/Managerial choices (e.g. decentralization; incentive pay; technology adoption; flexible training, etc.)
  - Local rather than global optima (multiple equilibria)

A DEFINITION OF COMPLEMENTARITY

- See Brynjolfsson & Milgrom (2013)
- Consider two organizational practices X_1 and X_2
- Let:
  - Δ_1 = increase in profits that would result from changing X_1 alone
  - Δ_2 = increase in profits that would result from changing X_2 alone
  - Δ_B = increase in profits from doing X_1 & X_2 together
- Note that these can all be positive or negative
- Then the changes are weakly complementary if $\Delta_B \geq \Delta_1 + \Delta_2$
- In neoclassical theory of the firm, capital and labor inputs to production are complements if the increase in output from raising both together exceeds the sum from increasing either separately

COMMON EXAMPLES

- **Types of Human Resource strategies**
  - Incentive pay (group and individual)
  - Team work
  - Hiring and firing
  - Promotions and appraisals
- **Organization and new technology**
  - Information and Communication Technologies (ICT)
  - Decentralization
  - Number of layers
- But important that this links with more standard literature e.g. Technologies and skills (“skill biased technical change”)
  - Increase in wage inequality (e.g. Machin & Van Reenen, 1998; Goldin & Katz, 2008; Acemoglu & Autor, 2011)

WHY IS IT HARD TO CHANGE ORGANIZATIONAL PRACTICES?

- **Co-ordination across different agents difficult**
  - Practices, assets, strategies controlled by different actors. Need Action Plan; incentive alignment
- **Many organizational practices implicitly rather than explicitly defined**
  - Culture, rules of thumb, routines, heuristics
- **Synchronizing changes in time**
  - Building new reputation & investing in a plant take a long time. Other actions more immediate
- **Some Implications**
  - Change is lumpy
  - Start-ups find organizational change easier than incumbents
  - Imitation hard (which are the successful sub-group of practices?).

WHAT MAKES ORG PRACTICES DIFFERENT FROM STANDARD FACTORS OF PRODUCTION?

- Hard to adjust? But all factors have some costs of adjustment
- Practices are not continuous but discrete? Lumpy capital decisions (e.g. building a factory; Minimum Efficient Scale). Difference in degree rather than in kind
- Practices hard to observe? Measuring any capital stock difficult (e.g. PIM)
- Absence of a market for "organization", so difficult to observe "market price" (e.g. a lot about opportunity cost of managerial time). True, although management consultancy industry may give indication
- Externalities – e.g. learning. Similar to R&D

Upshot is that it's necessary to consider basic production theory first

Recall Ichniowski, Shaw and Prennushi (1997)

- **Results:**
  - Clustering of “high performance” practices – lines which adopted one practice tended to adopt many others
  - Introducing clusters of these high-performance management practices associated with improved performance (adopting one or two doesn’t matter: need to adopt large number)

- Argues for complementarity of HR practices

IDENTIFYING COMPLEMENTARITIES I: CORRELATION OF PRACTICES

- **Correlation of practices**
  - Consider profit function $\Pi(X_1, X_2, Z)$ where are 2 suspected complementarity practices

$$\frac{\partial^2 \Pi}{\partial X_1 \partial X_2} > 0$$

- Then X_1 will be increasing in X_2 so we would expect the two practices to co-vary together: $cov(X_1, X_2) > 0$
- **Problem:** a correlated shock causes both X_1 and X_2 to increase together even if they are not complements (Athey and Stern, 1998)
  - e.g. A positive demand shock means that a firms may spend more on new technologies & more skilled workers
- **Solution**? instruments for X_2 in determination of X_1 equation

IDENTIFYING COMPLEMENTARITIES: ORGANIZATIONAL DEMAND EQUATION

- In classical case, costs are the instruments
  - Regress X_1 on price of X_2
  - In demand functions, demand for a good a function of its own price & the prices of other goods. The sign of the coefficient on the price of other goods indicates whether it is a substitute or complement; e.g. Hausman et al (1994)
- Problem is that prices of different organization practices usually **unobserved**. Not traded on a market.
- More difficult to think of what could exogenously shift organizational practices separately

IDENTIFYING COMPLEMENTARITIES II: PERFORMANCE REGRESSIONS

- Regress performance (PERF) on interactions of organizational practices (ORG)

$$PERF_{it} = \alpha(\mathrm{X}_{1,it} * \mathrm{X}_{2,it}) + \beta_1 \mathrm{X}_{1,it} + \beta_2 \mathrm{X}_{2,it} + \eta_i + u_{it}$$

- "Complementarity" if α>0 (Ichniowski et al, 1997)
- Better than just correlation of X_1 and X_2 because *PERF* is at least a different variable than the ORG choice measures
- But still have problem if u_{it} correlated with X_1 & X_2 (in fact now need two instruments: one each for X_1 & X_2)
- Also, there is a question of whether this is just picking up a single latent index

IDENTIFYING COMPLEMENTARITIES II: PERFORMANCE REGRESSIONS & LATENT INDEX

- Consider the structural model

$$PERF = \gamma \, \mathrm{X}^{*} + u$$

- Where X* is an unobserved latent variable
- We observe two noisy signals of this latent variable

$$X_1 = \mathrm{X}^{*} + v_1; X_2 = \mathrm{X}^{*} + v_2;$$

- Where the v's are orthogonal i.i.d. errors (noise terms)
- Example: Bloom & Van Reenen (2007) has X* as managerial quality & uses 18 signals of this
- Since X_1*X_2 is a strong signal of X* we may estimate significant interactions (α>0) even though NO complementarities

$$PERF_{it} = \alpha(\mathrm{X}_1 * \mathrm{X}_2)_{it} + \beta_1 \, \mathrm{X}_{1,it} + \beta_2 \, \mathrm{X}_{2,it} + \eta_i + u_{it}$$

IDENTIFYING COMPLEMENTARITIES II: PERFORMANCE REGRESSIONS

- Possible to test these alternative models
- Latent variable model implies that attenuation bias falls in a systematic way as more proxies are added. This is not the same implication for complementarity model

CONSIDER THE EXAMPLE OF COMPLEMENTARITY BETWEEN HUMAN CAPITAL AND DECENTRALIZATION

- Relatively easy case because only one ORG practice (decentralization) & 2 standard factors of production (skilled & unskilled workers. Can generalize
- **Organization equation**
  - Decentralization increases with greater supply of skills, e.g. do higher relative wages (prices of skilled vs. unskilled labor) inhibit decentralization?
- **Skill demand equation**
  - Does decentralization increase demand for skilled workers? Regress cost share of skills on decentralization
- **Production or cost function**
  - Positive interactions between skills and decentralization in the production function
- Caroli & Van Reenen (2001, QJE) & Bresnahan et al (2002, QJE) find evidence in favor of all 3 predictions

STANDARD APPROACH TO COMPLEMENTARITIES: EXAMPLE OF A 3 FACTOR MODEL

• A firm's production (Q) function depends on 2 types of labor skills (*H* = high, *L* = low) and organizational capital (e.g. Decentralization) denoted "*ORG*"

• Competitive market price for 3 factors
  - W^L factor price of low-skilled labor (unskilled wage)
  - W^H, factor price of high-skilled labor (skilled wage)
  - W^{ORG} , factor price of organizational capital

• Easy to include additional factors, just labelling

$$Q = AF(H, L, ORG)$$

EMPIRICAL MODEL: FACTOR DEMAND EQUATION

Dual of the production function is (long-run) cost function, C(.)

If we observed cost of organization W^{ORG}

$$C(W^H, W^L, W^{ORG})$$

3 Factor demand equations (for Translog cost function using Shepherd's Lemma). One redundant (Bond & Van Reenen, 2007)

$$SHARE^H = \phi_{HH} \ln(W^H / W^L) + \phi_{OH} \ln(W^{ORG} / W^L) + \alpha_{HY} \ln(Q)$$

$$SHARE^{ORG} = \phi_{HO} \ln(W^H / W^L) + \phi_{OO} \ln(W^{ORG} / W^L) + \alpha_{OY} \ln(Q)$$

$SHARE^H$ = Share of high skilled labor in total costs

$$SHARE^H = \frac{W^H H}{W^H H + W^L L + W^{ORG} ORG}$$

EMPIRICAL MODEL: FACTOR DEMAND EQUATION

Skilled labor demand equation

$$SHARE^{H} = \phi_{HH} \ln(W^{H} / W^{L}) + \phi_{OH} \ln(W^{ORG} / W^{L}) + \alpha_{HY} \ln Q$$

Organizational capital demand

$$SHARE^{O} = \phi_{HO} \ln(W^{H} / W^{L}) + \phi_{OO} \ln(W^{ORG} / W^{L}) + \alpha_{OY} \ln Q$$

Note: could impose further theoretical restrictions such as

Homogeneity: $\alpha_{HY} = \alpha_{OY} = 0$ (Q drops out)

Symmetry: $\alpha_{HH} = \alpha_{OO}$ & $\alpha_{OH} = \alpha_{HO}$

EMPIRICAL MODEL: FACTOR DEMAND EQUATION

Skilled labor demand equation

$$SHARE^{H} = \phi_{HH} \ln(W^{H} / W^{L}) + \phi_{OH} \ln(W^{ORG} / W^{L}) + \alpha_{HY} \ln Q$$

Organizational capital demand

$$SHARE^{O} = \phi_{HO} \ln(W^{H} / W^{L}) + \phi_{OO} \ln(W^{ORG} / W^{L}) + \alpha_{OY} \ln Q$$

Standard theory predicts: $\phi_{HH} < 0$ and $\phi_{OO} < 0$: *Relative factor demand falls in own factor price*

EMPIRICAL MODEL: FACTOR DEMAND EQUATION

Skilled labor demand equation

$$SHARE^{H} = \phi_{HH} \ln(W^{H} / W^{L}) + \phi_{OH} \ln(W^{ORG} / W^{L}) + \alpha_{HY} \ln Q$$

Organizational capital demand

$$SHARE^{O} = \phi_{HO} \ln(W^{H} / W^{L}) + \phi_{OO} \ln(W^{ORG} / W^{L}) + \alpha_{OY} \ln Q$$

If **complementarity**: $\phi_{OH} < 0$ and $\phi_{HO} < 0$ *Demand for a factor falls if price of complementary factor rises*

If **substitutability**: $\phi_{OH} > 0$ and $\phi_{HO} > 0$ *Demand for a factor rises if price of substitutable factor rises*

PRECISE CONDITIONS (SEE BOND & VAN REENEN, 2007, HANDBOOK OF ECONOMETRICS)

$$SHARE^{O} = \phi_{HO} \ln(W^{H} / W^{L}) + \phi_{OO} \ln(W^{ORG} / W^{L}) + \alpha_{OY} \ln Q$$

Cross partial elasticity of ORG factor demand with respect to the skilled wage is:

$$\frac{\partial \ln ORG}{\partial \ln W^{H}} = \eta_{HO} = \frac{S_S \phi_{HO} + S_0}{S_0} = S_S \sigma_{HO}$$

Where Hicks-Allen partial elasticity of complementarity is:

$$\sigma_{HO} = \frac{\phi_{HO} + S_0 S_S}{S_0 S_S}$$

SOME ISSUES

- Many standard problems such as finding suitable instruments for prices
  - Need supply shocks that vary across time and firm
- For ORG particularly challenging as unclear what the "price" of organizational change is. What is the analog of wage rate or cost of capital?
  - Consider short-run variable cost function

SHORT-RUN FACTOR DEMAND EQUATION

Assume ORG is fixed in short-run (quasi-fixed) short-run variable cost function, CV(.)

$$CV(W^H, W^L; ORG, Q)$$

2 groups, *S, Wages, W*
H = highly educated
L = low educated

ORG = organization

Again, by Shephard's Lemma share of high skilled labor in total labor costs is:

$$SHARE^H = \phi_H \ln(W^H / W^L) + \alpha_O \ln(ORG) + \alpha_{YS} \ln(Q)$$

If coefficient positive indicates complementarity:
Higher ORG implies higher share of skilled workers

SOME ISSUES

- Still unclear how to measure “quantity” of org capital. We usually have qualitative indicators
  - Although more recent progress on measurement
  - And “intangible capital” literature may give some clues
- And really still need instruments for ORG

APPLICATION

- Caroli & Van Reenen (2001, QJE) on “skill biased organizational change”

- British & French establishment level data on organizational practices (roughly, decentralization)
  - UK more vague
  - French delayering

CAROLI AND VAN REENEN (2001) – IMPACT OF ORG CHANGE ON SKILL DEMAND

TABLE II

CHANGES IN WAGE BILL SHARES IN BRITAIN: EFFECTS OF ORGANIZATIONAL AND TECHNOLOGICAL CHANGE

	1984–1990 Change in wage bill share of:					
Mean of dependent variable	−.012	−.001	−.014	−.005	−.005	.037
	Unskilled manuals	Semi-skilled manuals	Skilled manuals	Clerical workers	Supervisors & foremen	Managers & technical staff
A. Basic controls						
OC	−0.047	−0.001	0.014	0.025	0.015	−0.005
	(0.018)	(0.018)	(0.016)	(0.019)	(0.008)	(0.021)
B. Basic controls and technology						
OC	−0.049	0.001	0.022	0.025	0.013	−0.012
	(0.018)	(0.019)	(0.016)	(0.019)	(0.008)	(0.021)
TECH	0.032	−0.021	−0.060	−0.056	−0.003	0.108
	(0.038)	(0.040)	(0.035)	(0.040)	(0.017)	(0.044)
ΔIND_TECH	−0.028	−0.006	−0.076	0.050	0.056	0.004
	(0.050)	(0.052)	(0.045)	(0.053)	(0.023)	(0.058)
ΔCOMP	−0.023	0.004	−0.009	−0.019	0.010	0.037
	(0.014)	(0.014)	(0.012)	(0.014)	(0.006)	(0.016)

OC = organizational change (e.g. Decentralization)

Notes: 378 plants, controls for unions, financial performance, Ownership, JCC, size, weighted OLS

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Organizational change has large negative association With the least skilled workers

IMPACT OF ORG CHANGE ON SKILL DEMAND. UK

TABLE II

CHANGES IN WAGE BILL SHARES IN BRITAIN: EFFECTS OF ORGANIZATIONAL AND TECHNOLOGICAL CHANGE

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	(0.050)	(0.052)	(0.045)	(0.053)	(0.023)	(0.058)
ΔCOMP	−0.023	0.004	−0.009	−0.019	0.010	0.037
	(0.014)	(0.014)	(0.012)	(0.014)	(0.006)	(0.016)

Technological change (e.g. Computerization) has large positive association with the most skilled workers

ORG CHANGE REDUCES THE DEMAND FOR LEAST SKILLED WORKERS (FRANCE)

TABLE IV

CHANGES IN WAGE BILL SHARES IN FRANCE: EFFECTS OF ORGANIZATIONAL CHANGE (DELAYERING) AND TECHNICAL CHANGE

	1992–1996 Change in wage bill share of:				
Mean of dependent variable	−.026	0	−.008	.022	.012
	Unskilled manuals	Skilled manuals	Clerical workers	Middle Managers & Technicians	Senior managers
A. Basic controls					
OC	−0.015	0.017	−0.002	0.003	−0.003
	(0.007)	(0.009)	(0.004)	(0.005)	(0.004)
B. Basic controls +					

EMPIRICAL MODEL: ORGANIZATIONAL DEMAND EQUATION

Representative firm in an industry's cost function, CV(.)

$$CV(W^H, W^L; ORG, Q)$$

Differentiate with respect to ORG (organizational practice)

$$\ln(ORG) \approx \phi_H \ln(W^H / W^L) + \lambda \ln(Q)$$

If coefficient negative indicates complementarity:
When skills more expensive less likely to decentralize

HIGHER RELATIVE WAGES OF SKILLED WORKERS REDUCES LIKELIHOOD OF ORGANIZATIONAL CHANGE

TABLE V

DETERMINANTS OF ORGANIZATIONAL CHANGE IN BRITAIN AND FRANCE

	Britain		France	
Mean of dependent variable	.432	.432	.524	.524
	(1)	(2)	(3)	(4)
	OC	*OC*	*OC*	*OC*
Regional relative wage	−0.893	−0.683	−1.122	−1.165
(high-low education)	(0.285)	(0.210)	(0.629)	(0.602)
TECH > 0		0.165		
		(0.021)		
TECH				0.190
				(0.081)
Log (Employment size)	0.095	0.076	0.042	0.038
	(0.016)	(0.017)	(0.022)	(0.023)
Demand rise	0.089	0.077	−0.047	−0.047
	(0.032)	(0.033)	(0.051)	(0.051)

Source: Caroli & Van Reenen (2001, QJE)

BLUNDELL, GREEN & JIN (2017)

employees.[18] We focus on employees' responses to three questions:

"How much influence do you have about the following?"

1) "The range of tasks you do in your job",

2) "the pace at which you work"

3) "how you do your work".

The responses for each question range from 1 "A lot" to 4 "None". These questions are included in the cross-sectional WERS surveys for 1998, 2004, and 2011. Rather than use these questions separately we implement a principal components analysis to compute an index of the ability of workers to influence their own work. We define the index as 4 minus the first principal

DEPENDENT VARIABLE IS DECENTRALIZATION

TABLE 4—REGRESSIONS OF EMPLOYEE INFLUENCE INDEX

	(1)	(2)	(3)	(4)	(5)	(6)
Current % of BAs	0.573***	0.535**	0.600**	0.642***	1.306**	1.205***
	[0.123]	[0.272]	[0.238]	[0.134]	[0.585]	[0.251]
wave04	0.186***	0.188***	0.185***	0.177***	0.153***	0.152***
	[0.0237]	[0.0261]	[0.0255]	[0.0287]	[0.0353]	[0.0310]
wave11	0.293***	0.298***	0.291***	0.261***	0.185**	0.196***
	[0.0277]	[0.0401]	[0.0335]	[0.0322]	[0.0727]	[0.0415]
% of BAs in 1995-6		0.0626				
		[0.406]				
Current % of HS?			0.0395			
			[0.292]			
Constant	0.398***	0.396***	0.369*	1.073**	0.648***	0.654***
	[0.0241]	[0.0292]	[0.215]	[0.434]	[0.224]	[0.185]
further controls*	no	no	no	yes	yes	yes
instruments	na	na	na	na	cohort structure	4 IVs
Observations	670	670	670	670	670	580
R-squared	0.295	0.295	0.295	0.388	0.365	0.381

Note: All regressions are at the TTWA level, weighetd by employment in the area.
*Further controls include the current proportions of workplaces in the area by industry, by bands of workplace size, and by bands of organization size.
Source: Authors' analysis of the UK Workplace Employment Relations Survey.

COLLEGE (B.A.) SUPPLY IN THE LOCAL AREA (TTWA)

BACK TO THE PRIMITIVES - PRODUCTION FUNCTION ESTIMATION.

- More general translog includes higher order terms

$$\ln Q = \alpha_H \ln H + \alpha_L \ln L + \alpha_O \ln ORG$$

$$+\alpha_{HO}(\ln H * \ln ORG) + \alpha_{LO}(\ln L * \ln ORG)$$

$$+\alpha_{HL}(\ln H * \ln L) + \alpha_{OHL}(\ln ORG * \ln H * \ln L)$$

$$+\alpha_{HH}(\ln H)^2 + \alpha_{LL}(\ln L)^2 + \alpha_{CC}(\ln ORG)^2$$

BACK TO THE PRIMITIVES - PRODUCTION FUNCTION ESTIMATION.

- Caroli & Van Reenen (2001) use panel data

$$\Delta \ln Q = \alpha_H \Delta \ln H + \alpha_L \Delta \ln L + \alpha_O \Delta \ln ORG$$
$$+\alpha_{HO} \Delta(\ln H * \ln ORG) + \alpha_{LO} \Delta(\ln L * \ln ORG)$$
$$+....$$

PRODUCTION FUNCTION ESTIMATION: LOWER IMPACT OF ORG CHANGE (OC) WHEN MORE UNSKILLED WORKERS

TABLE VII

FIRM-LEVEL PRODUCTION FUNCTIONS FOR FRANCE 1992–1996

Change in Value added 1992–1996 (annualized mean = .01)						
					$OC = 1$	$OC = 0$
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Capital)	0.226	0.227	0.233	0.232	0.237	0.227
	(0.080)	(0.080)	(0.081)	(0.082)	(0.140)	(0.094)
ln(Labor)	0.879	0.875	0.888	0.889	0.807	0.817
	(0.097)	(0.096)	(0.100)	(0.100)	(0.155)	(0.130)
Lagged variables						
OC	0.017	0.037	0.034	0.022		
	(0.012)	(0.016)	(0.017)	(0.030)		
OC *% Unskilled		−0.114	−0.125	−0.115		
		(0.057)	(0.059)	(0.062)		
% Unskilled	−0.031	0.030	0.101	0.097	−0.118	0.026
	(0.029)	(0.043)	(0.051)	(0.052)	(0.054)	(0.038)

Source: Caroli & Van Reenen (2001, QJE)

BRESNAHAN, BRYNJOLFSSON AND HITT (2002, QJE)

- US Compustat Data – publicly listed US firms
- Harte-Hanks data with estimate of value of IT capital stock
- Cross sectional information on firm ORG (teamwork, decentralization, etc.) and skills
- ORG, Skills and IT all positively associated
- ORG*IT significant interactions in production function
  - Don’t include firm fixed effects though (unlike Caroli & Van Reenen)

OTHER EXAMPLES OF COMPLEMENTARITY :

- Garicano and Heaton (2010, JoLE)
  - Police and Compstat; IT and ORG complements
- Bloom, Sadun and Van Reenen (2013, AER)
  - Higher return to IT in the US; IT & HR management complements
- Trucking papers
  - Blader, Gartenberg & Pratt (2019), Relational Contracts
  - Hubbard (2000); Baker & Hubbard (2003, 2004)

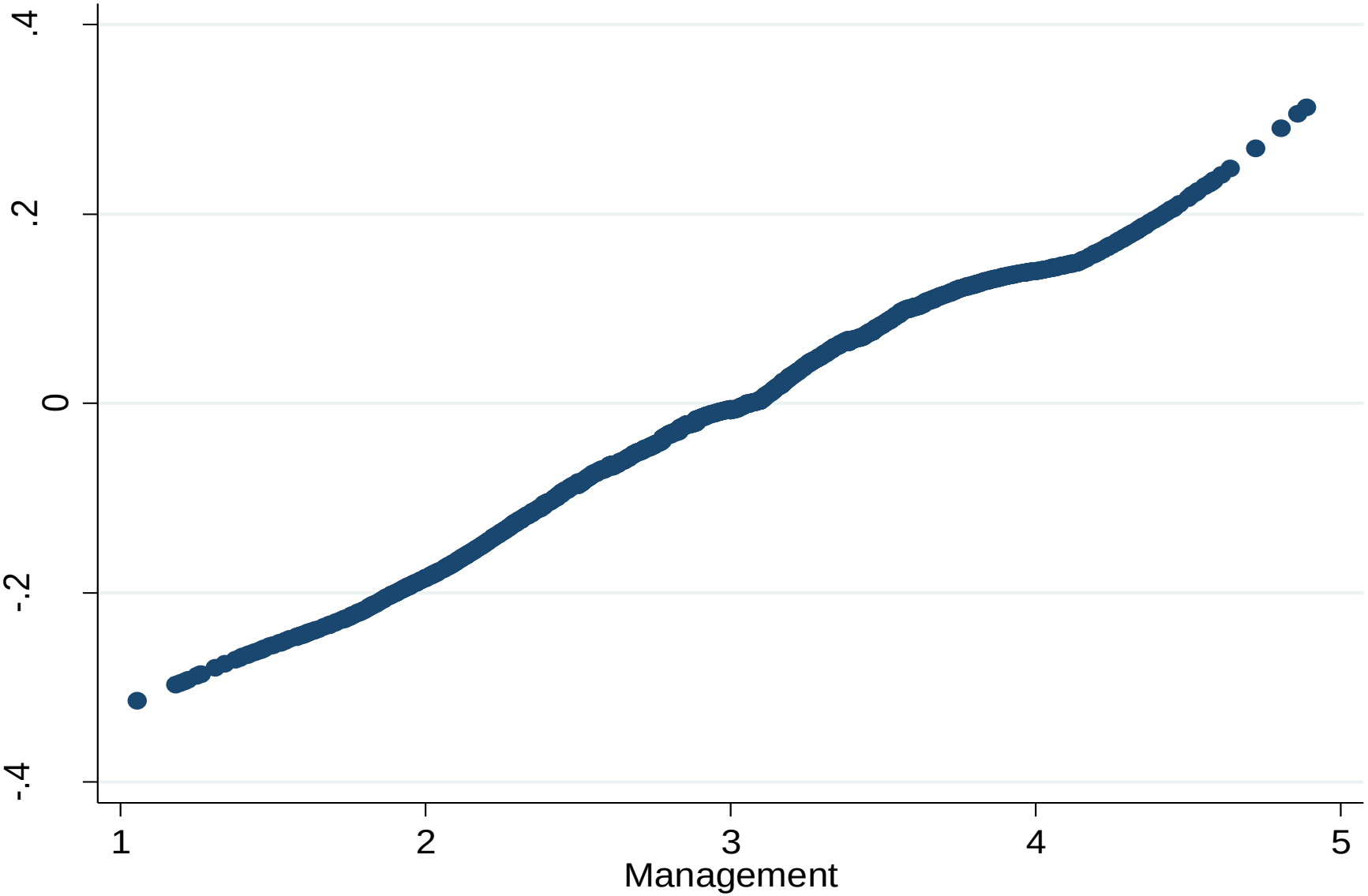
OTHER WAYS TO ESTIMATE COMPLEMENTARITY

- **Meagher and Strachan (2016)**
  - Milgrom-Roberts suggests non-linearity in relationship between PERF and ORG. Should expect convexity in relationship between performance and practices. Little effect from low intensity (few practices) but big effect at some threshold of high intensity
  - MS argue that this can be seen in Bloom & Van Reenen (2007) management data. Uses sophisticated Bayesian techniques to pick this up

- Really a variant of the interaction approach

- Not so clear in most recent raw data (see over)

Figure A3: Firm TFP is increasing in management



Notes: This plots the lowess predicted valued of TFP against management (bandwidth=0.5). TFP calculated as residual of regression of ln(sales) on ln(capital) and ln(labor) plus a full set of 3 digit industry, country and year dummies controls. N = 10,900. **Source:** Bloom, Sadun & Van Reenen (2016)

CONCLUSIONS

- Complementarities endemic in organizational theory
- But hard to identify convincingly
- Simple framework shows that tight relationship between standard theory of substitutability/complementarity in consumer and production theory and in management
  - Covariance of practices
  - “Demand” for practices
  - “Demand” for complementary factors
  - Estimation of cost/production function
- Much evidence for complementarity, especially for ICT