Matching Workers' Skills and Firms' Technologies: From Bundling to Unbundling

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Old World: Skills are Bundled

We study the **matching** of workers to firms when

- workers have multidimensional skills
- firms produce from the aggregation of their workers' skills and have heterogeneous production functions
- there are missing markets
  - Firms can only hire workers, i.e., purchase sets of skills
  - Workers cannot sell each of their skills separately

Old World: Research questions

Competitive equilibrium of the labor market

- A single friction: skill bundling

Research questions

- Sorting patterns induced by the matching btw firms and workers
- Heterogeneity of workers' types within firms
- How do wages depend on skills

New World: Unbundling of Skills

Technologies and/or institutional changes make it easier

- for workers, to sell their skills outside employment relationships
- and for firms, to outsource tasks and use contracted workers

Examples

Platforms and the gig economy, German Hartz reforms, Temp agencies, outsourcing

New World: Research questions

From bundling to unbundling

- Unbundling may entail costs for firms and/or workers
- As unbundling costs decrease, markets for skills gradually open
- Limiting case: Costless unbundling: separate markets for skills

Research questions

- How does unbundling change wages and matching?
- Winners and losers among firms and workers?

Preview of Results

Bundling of skills

- Existence of equilibrium and uniqueness of aggregate skill
- Aggregate sorting based on workers' comparative (rather than absolute) skill advantage
- Heterogeneity of workers' skills **within** firms can be in both dimensions
- Wage equation à la AKM

Unbundling

- Larger output in the economy
- Generalists better off, Specialists worse off
- Polarization: Specialized firms tend to specialize further
- Makes wages more linear in skills

Important Papers

Roy models, no firm heterogeneity within sectors

HS (1987), Edmond and Mongey (2020) (unbundling), Costinot and Vogel (2010) (unbundling regime with 1-dim workers/tasks sorting)

Assortative matching (no skill aggregation)

Lindenlaub (2017) [*n*-dim worker/job sorting], Eeckhout and Kircher (2018) [quality and quantity, 1-dim sorting in quality]

Multidimensional matching with transferable utility

- Continuous: Chiappori, McCann, and Pass (2017), Chiappori, McCann, and Pass (2020)
- Hedonic prices: Chiappori, McCann and Nesheim (2010), Ekeland (2005), (2010), Rosen (1974), Lancaster (1966)
- Screening / Optimal transport / Nonlinear pricing: Wilson (1993), Rochet and Choné (1998), Villani (2009), Galichon (2016)
- Weak Optimal Transport: Gozlan, Roberto, Samson, and Tetali (2017), Gozlan and Juillet (2020)

Road map

Introduction

Bundling

Unbundling

The Empirical Content of Bundling and Unbundling

Reduced-Form Evidence (Swedish Data)

Summary and Road ahead

Framework

- Workers are heterogeneous in skills $x \hookrightarrow H^w(dx)$ on $\mathbb{R}^k_+$
- Firms are heterogeneous in technologies $\phi \hookrightarrow H^f(d\phi)$ on $\mathbb{R}^k_+$
- Firm of type ϕ hires a positive measure of workers $N^d(dx;\phi)$
- Produces output with production function

$$F(T;\phi) = F(T_1,\ldots,T_k;\phi)$$

  - using aggregated employees' skills

$$T_j(\phi) = \int x_j N^d(dx;\phi)$$

- An example is the CES production function $\phi = (\alpha, z)$

$$F(T;z,\alpha) = z\ [\,(1-\alpha)T_1^\sigma + \alpha T_2^\sigma\,]^{\eta/\sigma}$$

Equilibrium on the labor market

An **assignment of workers to firms** $N^d(dx;\phi)$ clears the labor market iif

$$\int_{\phi} N^d(dx;\phi)H^f(d\phi) = H^w(dx)$$

A **matching** between workers and firms is characterized by the probability measure :

$$\pi(x,\phi) = N^d(x;\phi)H^f(\phi) \text{ on } \mathcal{X} \times \Phi$$

Primal problem

- Maximizing output in the economy over market-clearing assignments

$$\sup_{N^d | N^d H^f = H^w} \int F\left(\int x N^d(dx;\phi);\phi\right) H^f(d\phi) \tag{1}$$

Dual Problem

- Function $w(x)$: wage of worker with skill vector x
- Minimizing sum of total profits and total wages over wage schedules

Equilibrium

Market-clearing assignment decentralized by a wage schedule

Connection to optimal transport (OT)

- Weak OT (WOT): Nonlinearity in the kernel N^d
- Mass of $N^d(dx; \phi) =$ Size of firm ϕ is determined in equilibrium
- "Weak OT with unnormalized kernels" with Nathael Gozlan
- Prove primal and dual attainment, duality formula

Fundamental Theorems under bundling

- Existence of equilibrium
- Decentralized by a (convex and homogenous of degree one) *wage schedule*
- "Algorithms for WOT with an application to Econ", with FP Paty

Aggregate sorting

- Firm-aggregate skill $T(\phi)$ is unique (with $\phi = (\alpha, z)$)
- Aggregate sorting has intuitive properties (PAM)
- Using the CES production function example

$$F(T; z, \alpha) = z \left[(1-\alpha) T_1^{\sigma} + \alpha T_2^{\sigma} \right]^{\eta/\sigma}$$

  - Total quality of employees $|T|$ increases in z
  - Firms with higher α use more skill 2 relative to skill 1 (T_2/T_1 increases in α)
- The matching depends on the relative supply of "generalists" (endowed with both skills) and "specialists" (endowed with mostly one skill)

Matching if specialists are "relatively rare" (1/3)

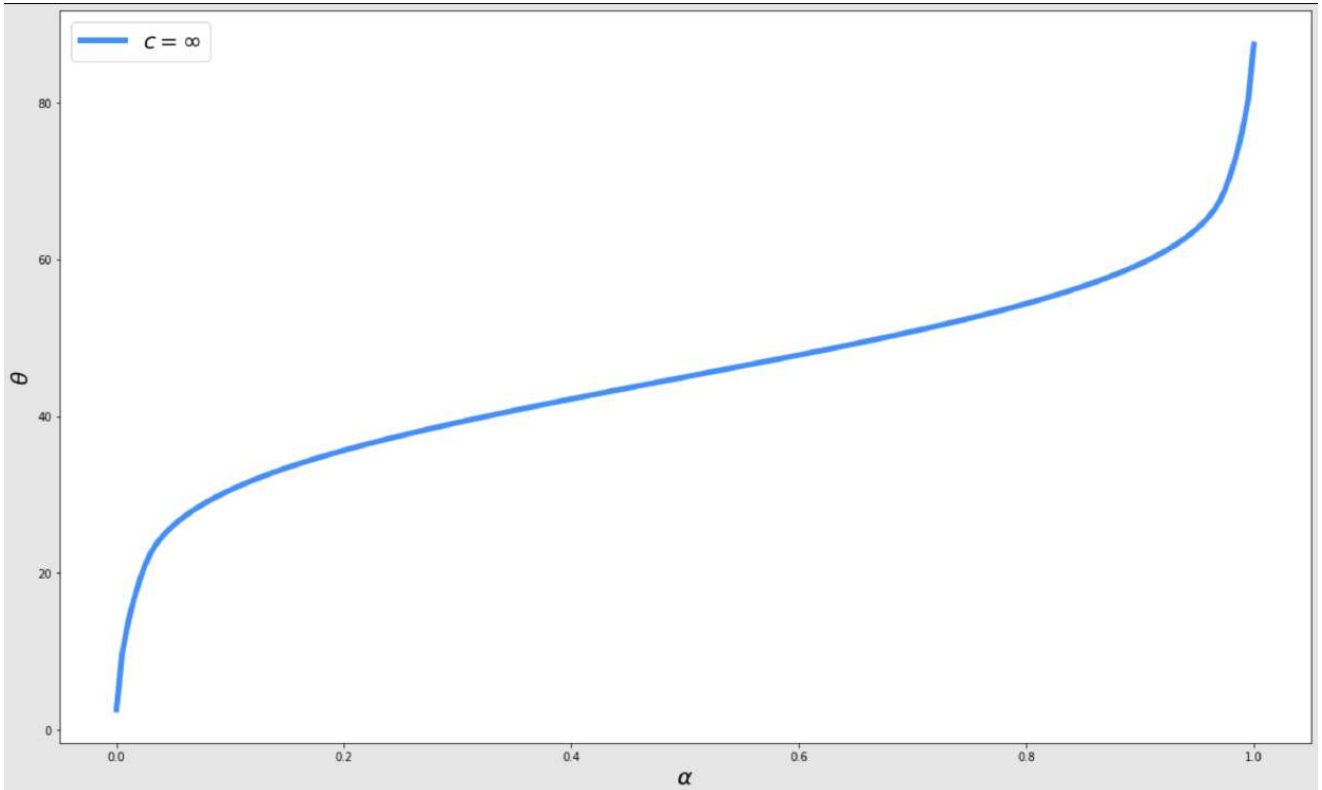

Figure 1: Horizontal axis: Firm's α; Vertical axis: workers' profile $\theta = x_2/x_1$ at equilibrium. All employees of a given firm α have same comparative advantage ($\theta = x_2/x_1$) (CES: $\sigma = 1$ and $\eta = .5$, α uniform, θ is $\beta(2, 2)$)

Within-firm heterogeneity in skills only about workers' qualities

Wage structure if specialists are "relatively rare" (2/3)

- AKM-style log-wage decomposition

$$\ln w(x) = \underbrace{\ln \lambda}_{\text{Worker effect}} + \underbrace{\ln w(\tilde{x}(\alpha, z))}_{\text{Firm effect due to matching}}$$

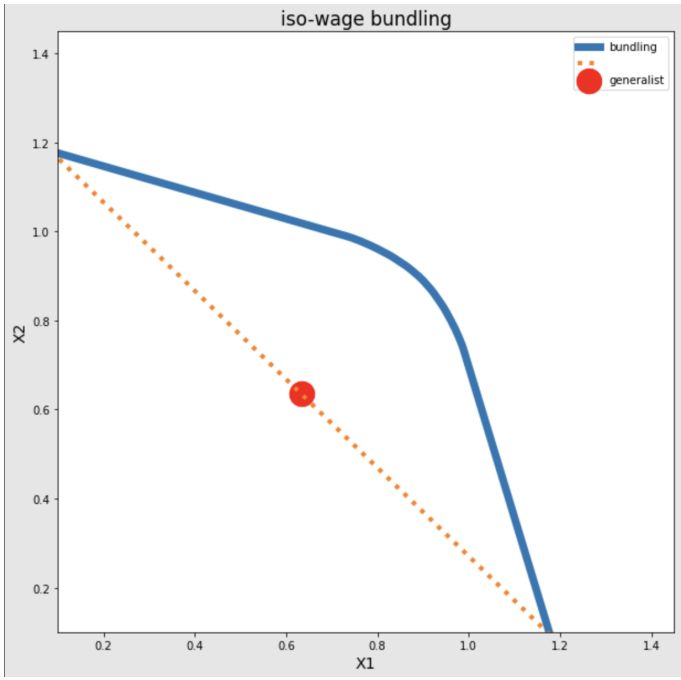

Figure 2: Generalists paid *strictly* less than equiv combination of specialists

Wage structure if specialists are “relatively rare” (3/3)

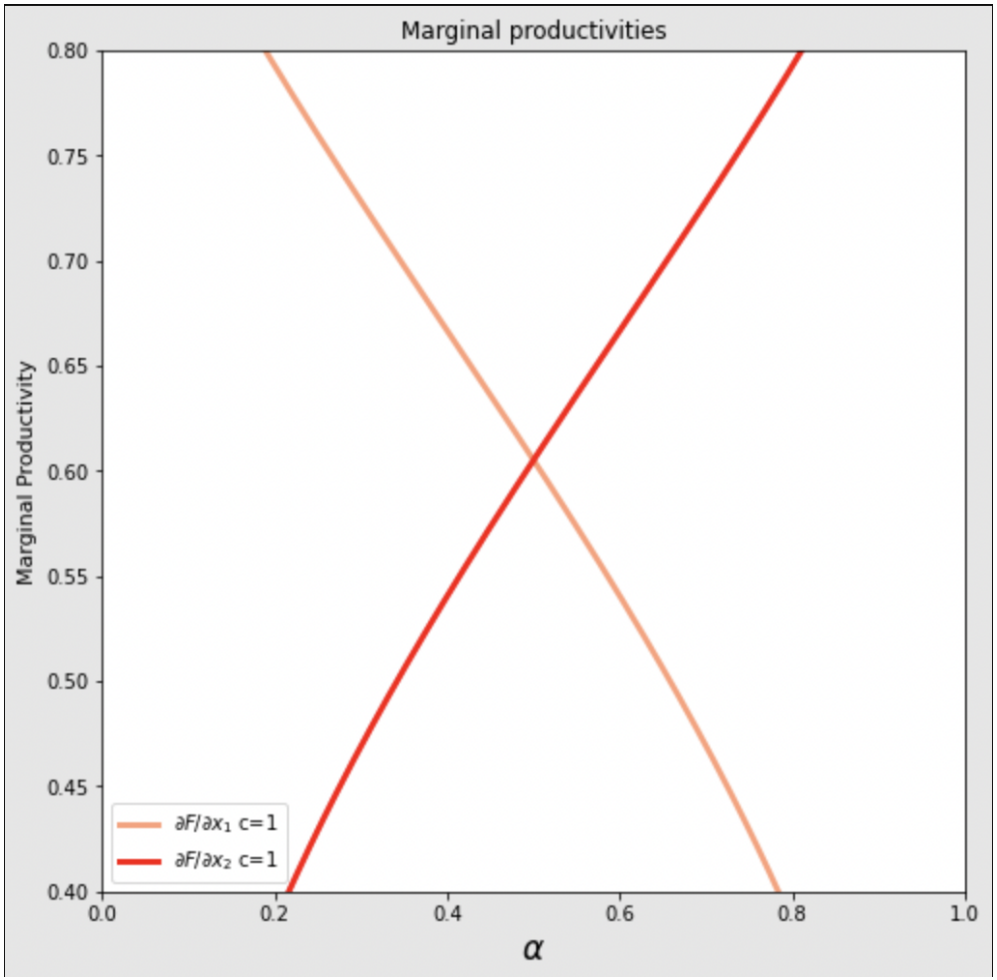

Figure 3: Law of one price does not apply: Implicit prices of skills vary across employing firms

If there are (locally) more specialists than generalists

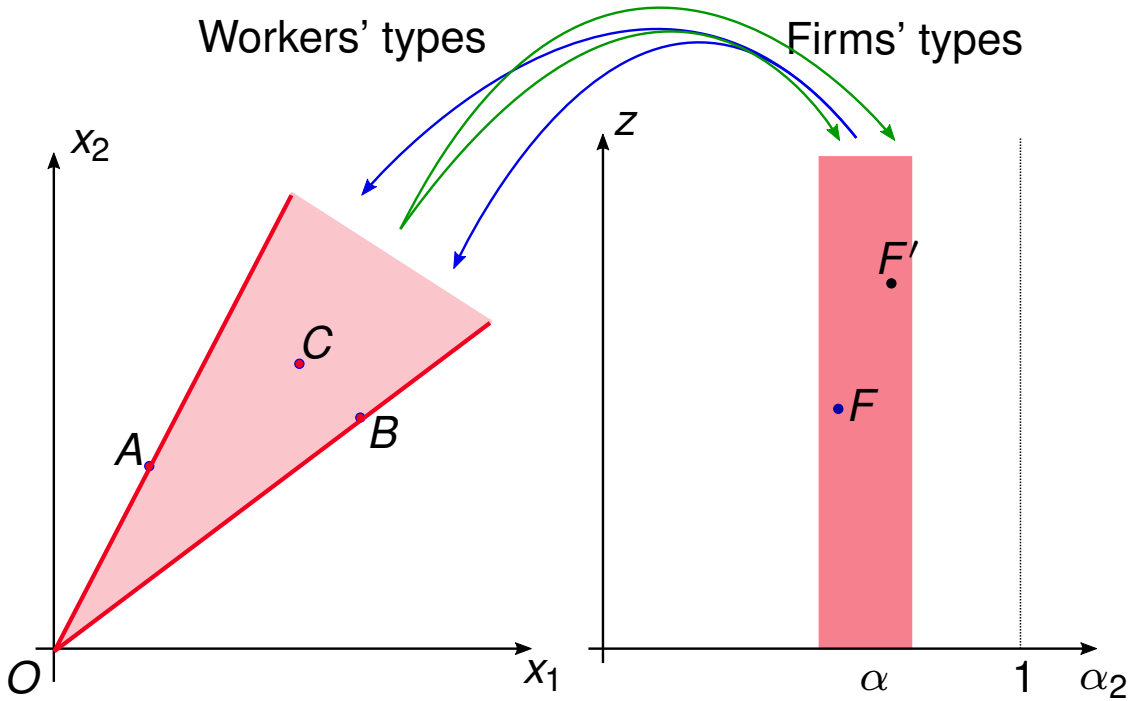

Figure 4: Employees within a given firm have different skill profiles x_2/x_1. Wage is linear in skills in the corresponding region

Costless Unbundling: Market for skills

- Prices for stand-alone skills
- Full efficiency

Some generalists better off, specialists worse off

- Specialists face more competition than under bundling
- Generalists are the most constrained by skill bundling, benefit most from unbundling
- Conversely for firms

Costless unbundling

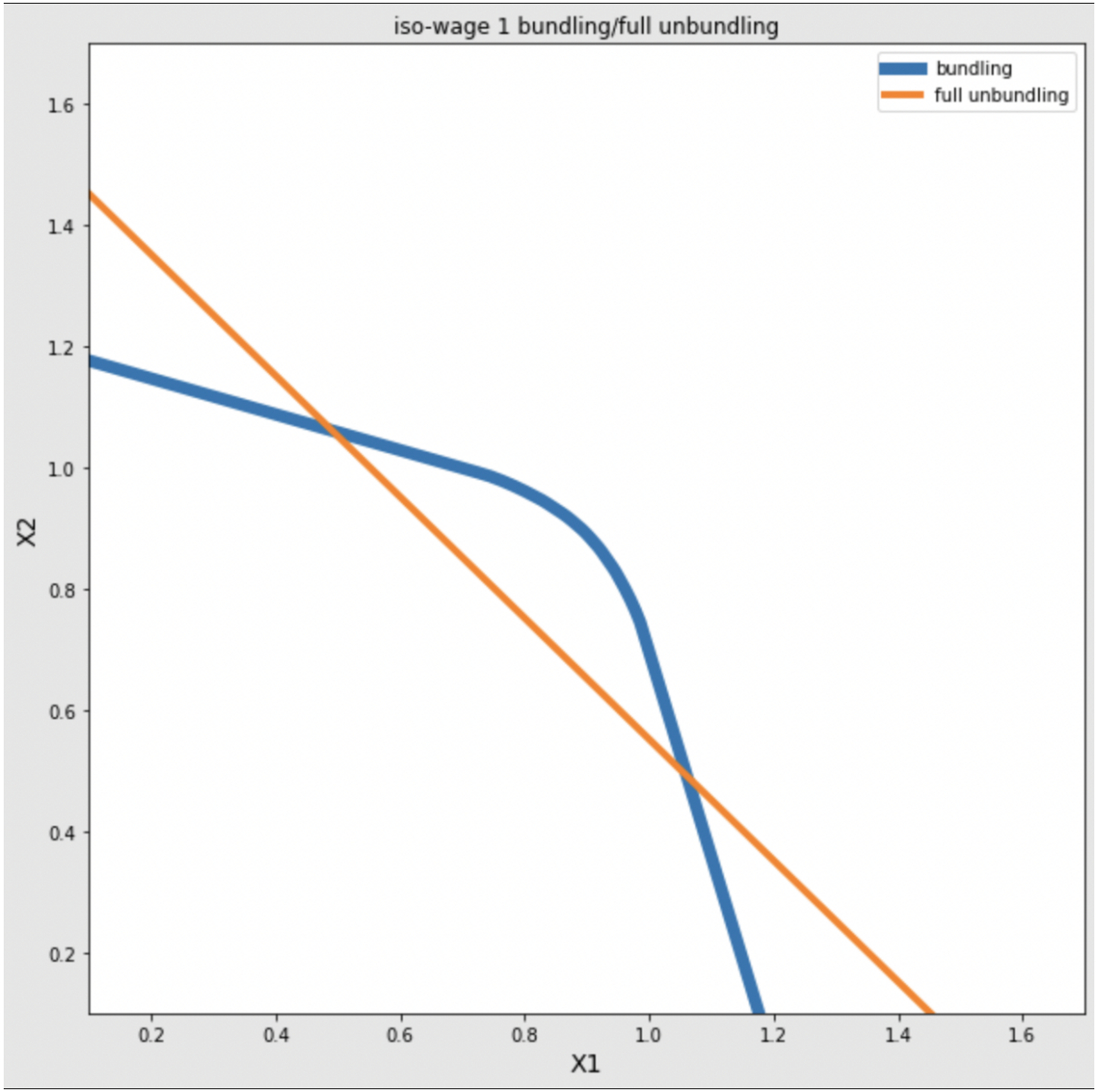

Figure 5: Law of one price now applies!

Costless unbundling

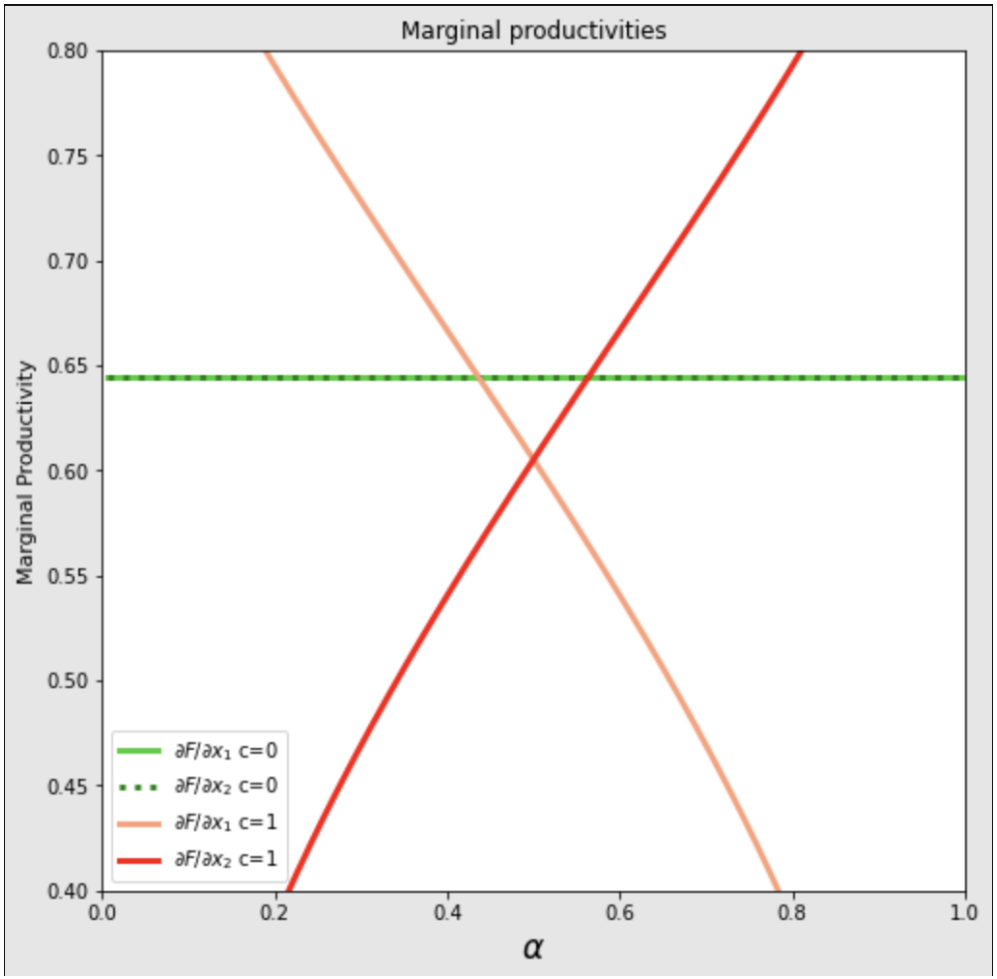

Figure 6: Implicit prices are constant

Costless unbundling: Polarization

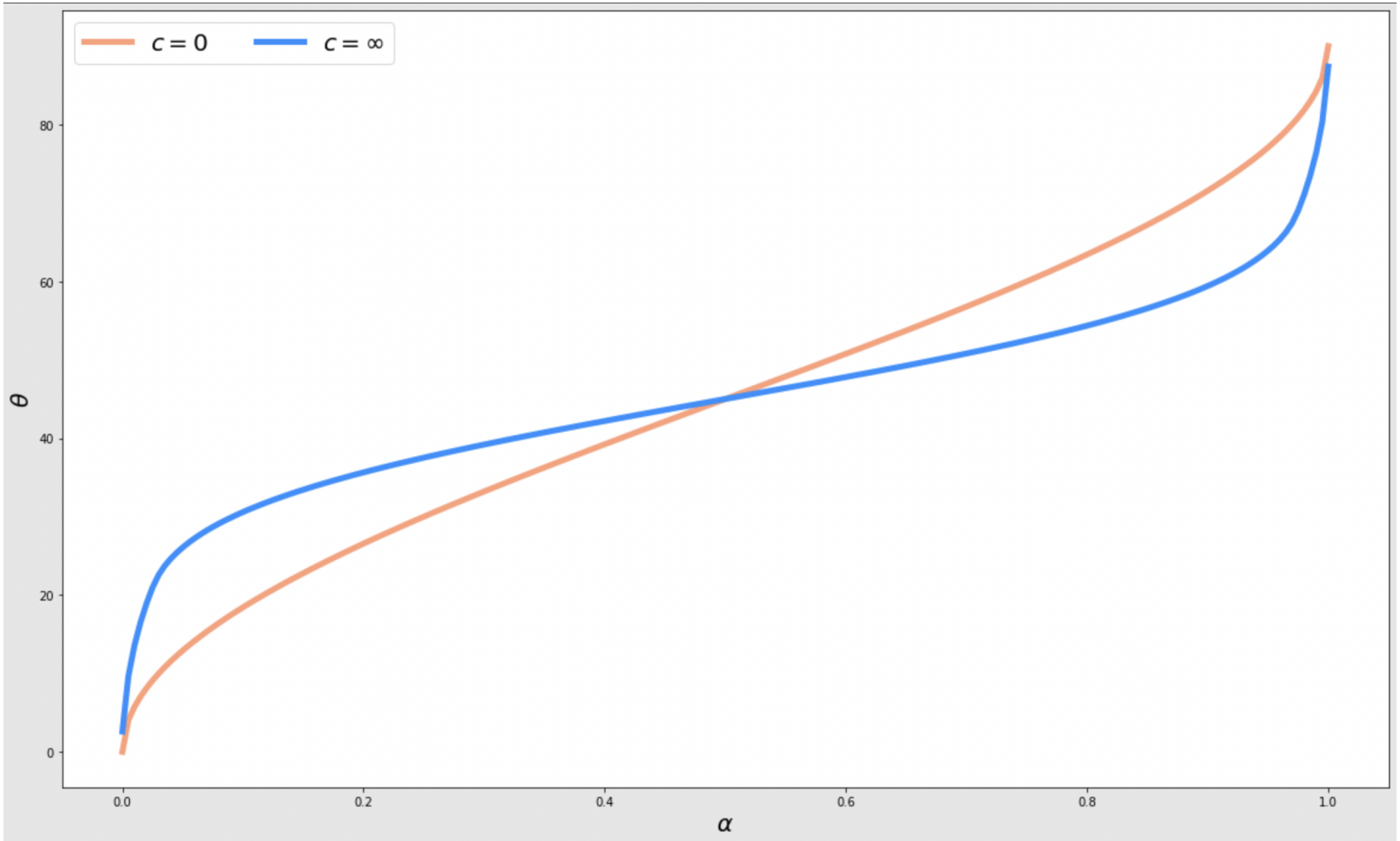

Figure 7: Skill profiles of labor force better aligned with firms' core skill under unbundling (Orange) than under bundling (Blue)

Costly Unbundling and Endogenous Labor Supply

Now unbundling entails a per-unit cost c

- Workers are allowed to sell part or all of their skills separately on markets (trade mechanism) ...
- ... At a cost incurred by workers and/or by firms (e.g., fees paid to platform)
- Creates a wedge between firm price and worker price

In a variant we allow workers to convert one skill into another

Costly unbundling: Sorting

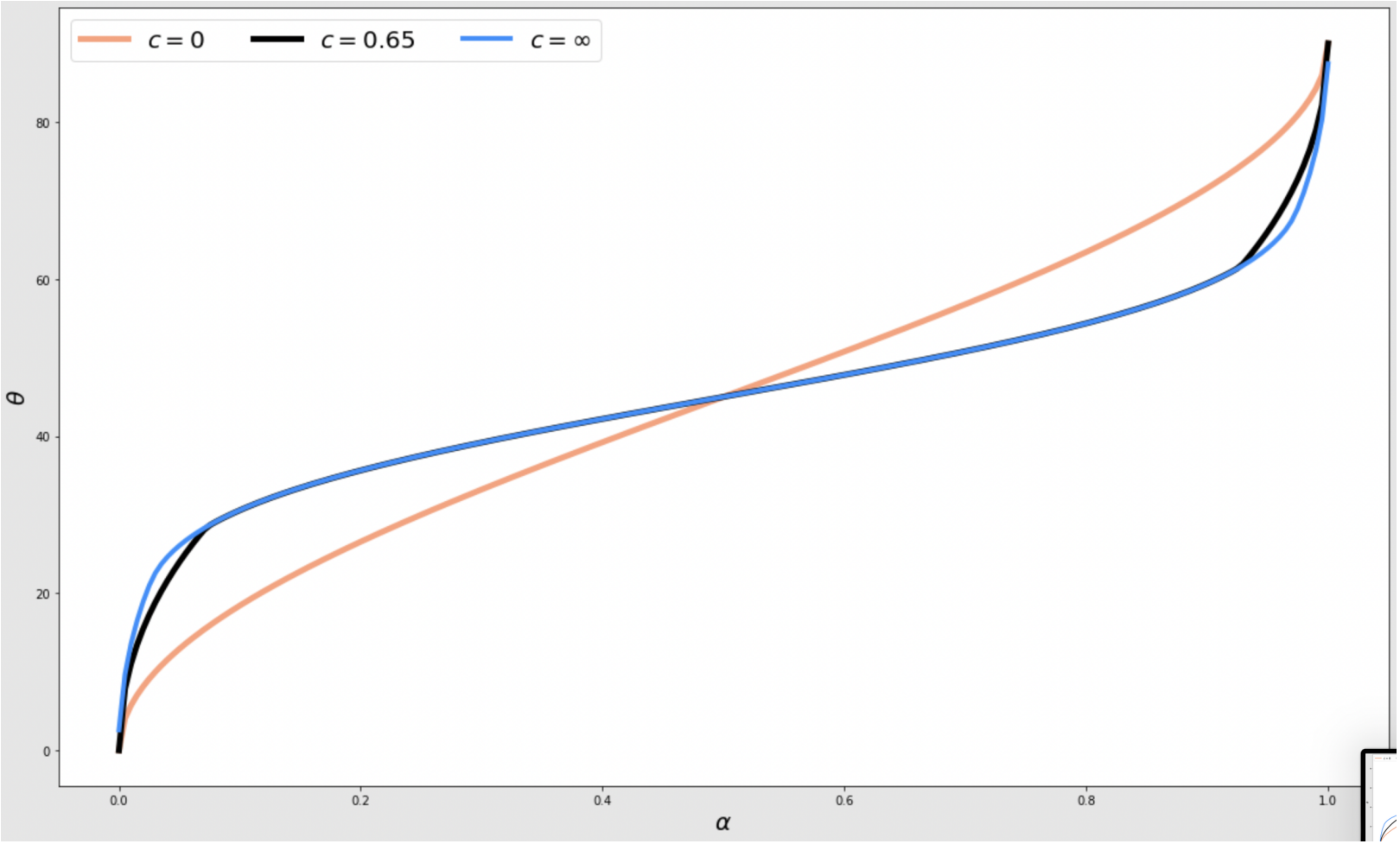

Figure 8: From Bundling (Blue) to Unbundling (Orange)

Costly unbundling: Sorting

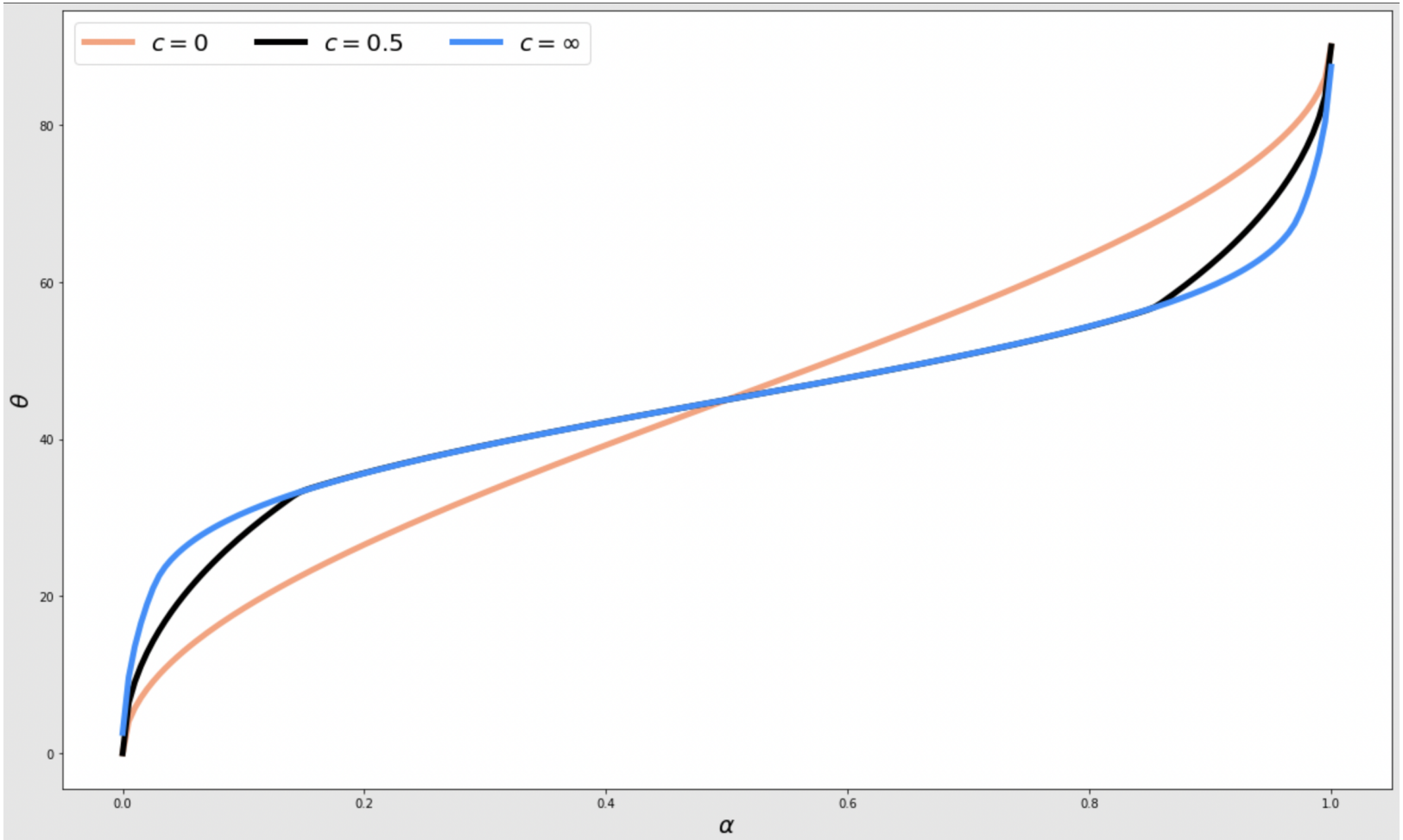

Figure 9: From Bundling (Blue) to Unbundling (Orange)

Costly unbundling: Sorting

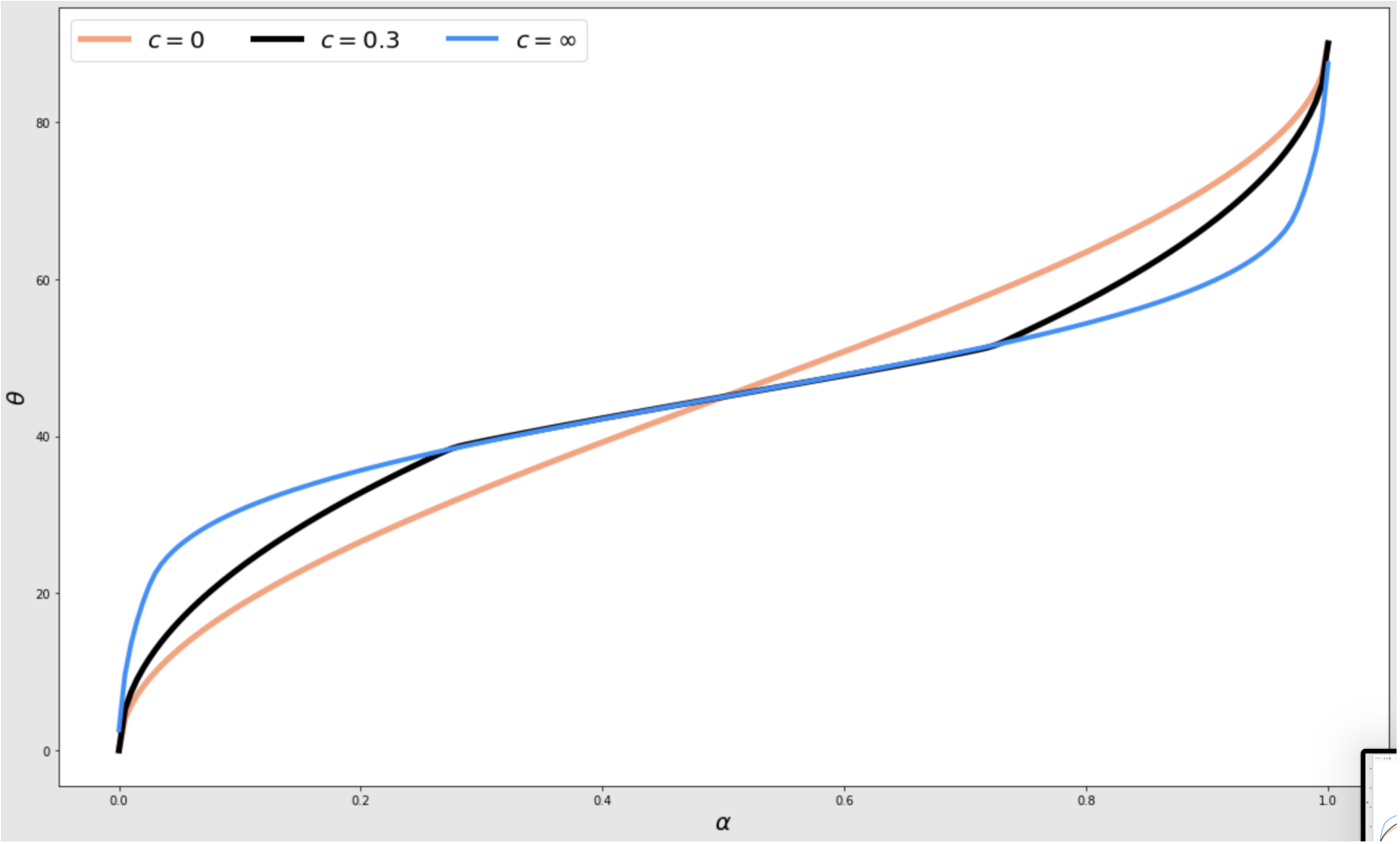

Figure 10: From Bundling (Blue) to Unbundling (Orange)

Costly unbundling: Sorting

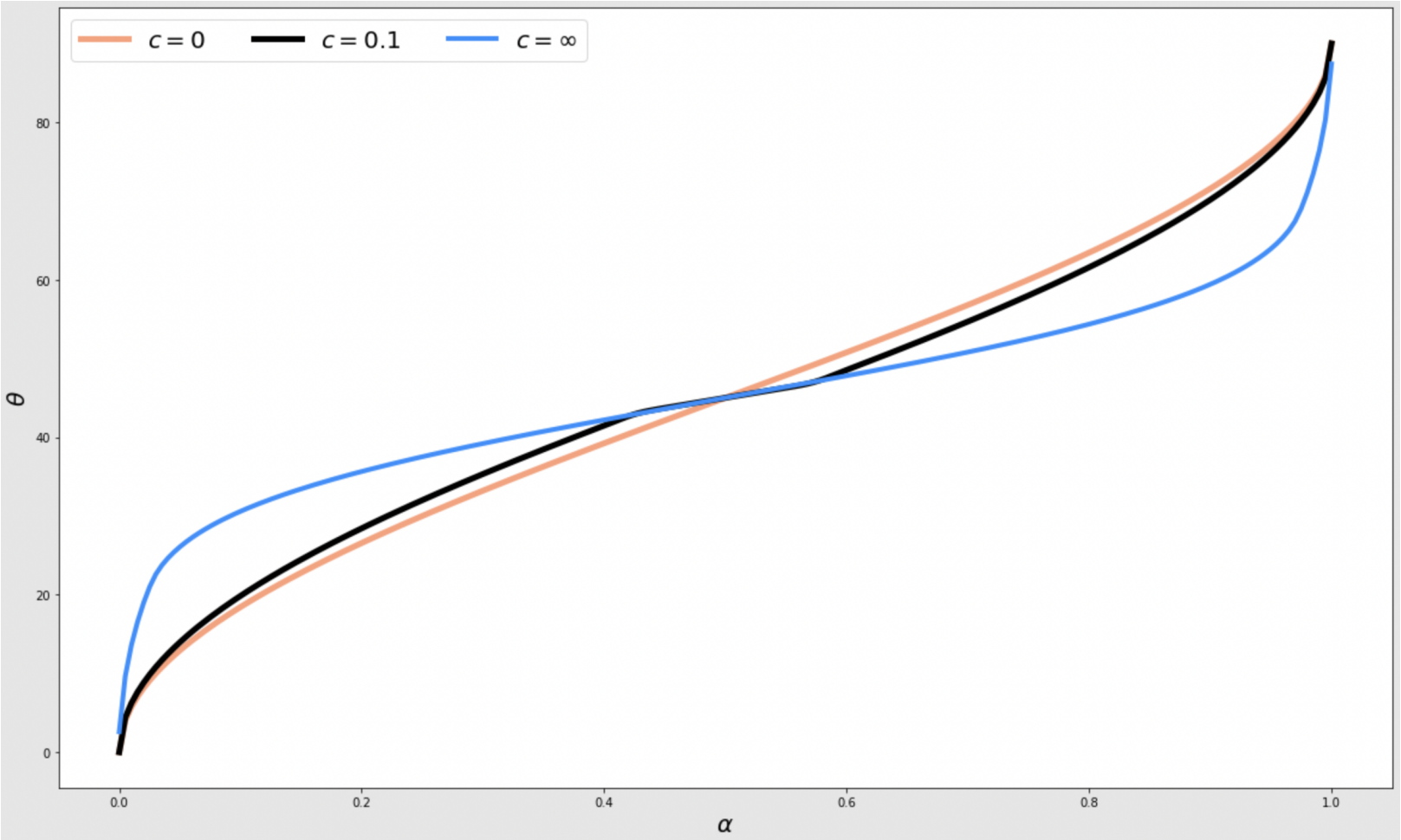

Figure 11: From Bundling (Blue) to Unbundling (Orange)

Costly unbundling: Sorting

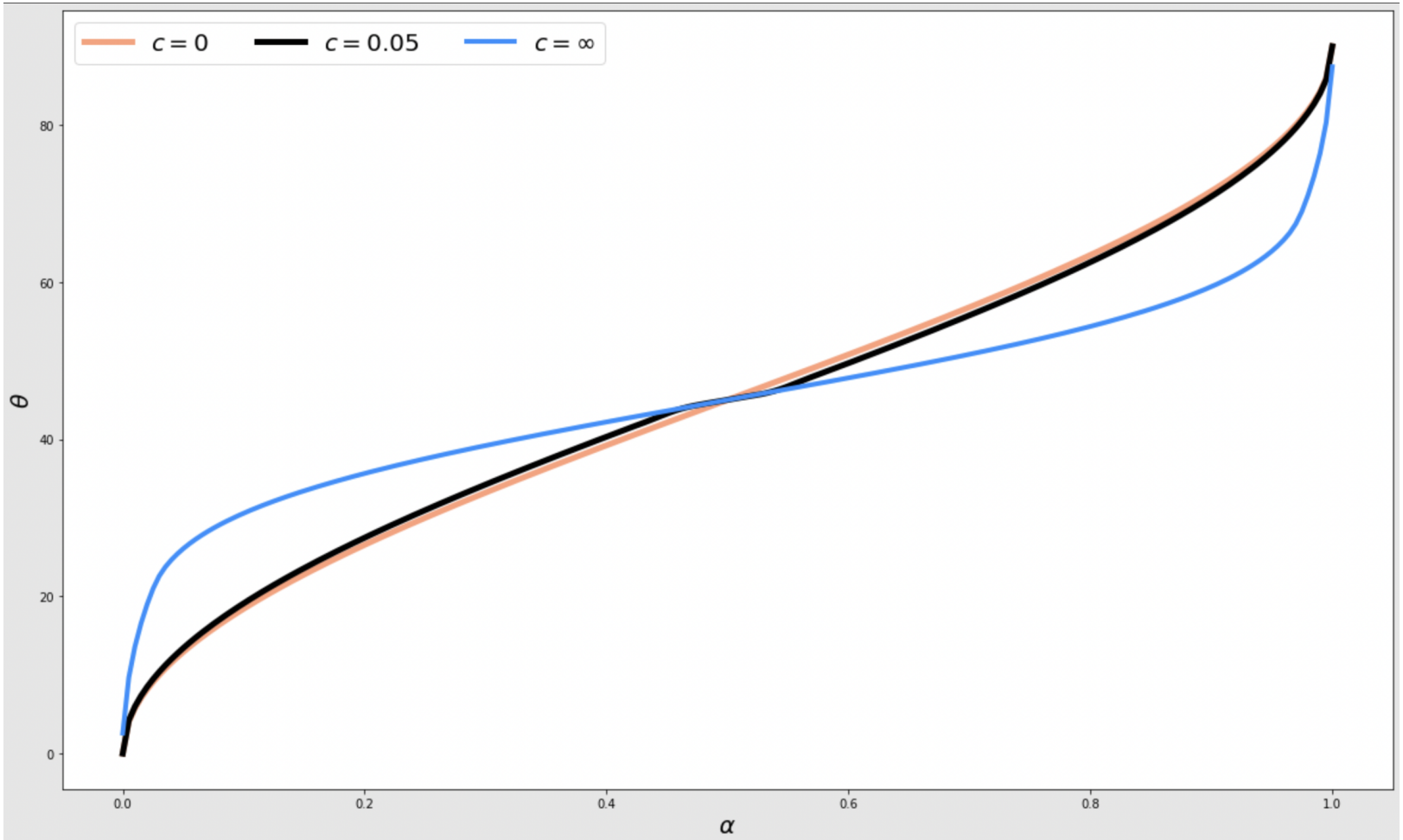

Figure 12: From Bundling (Blue) to Unbundling (Orange)

Costly unbundling

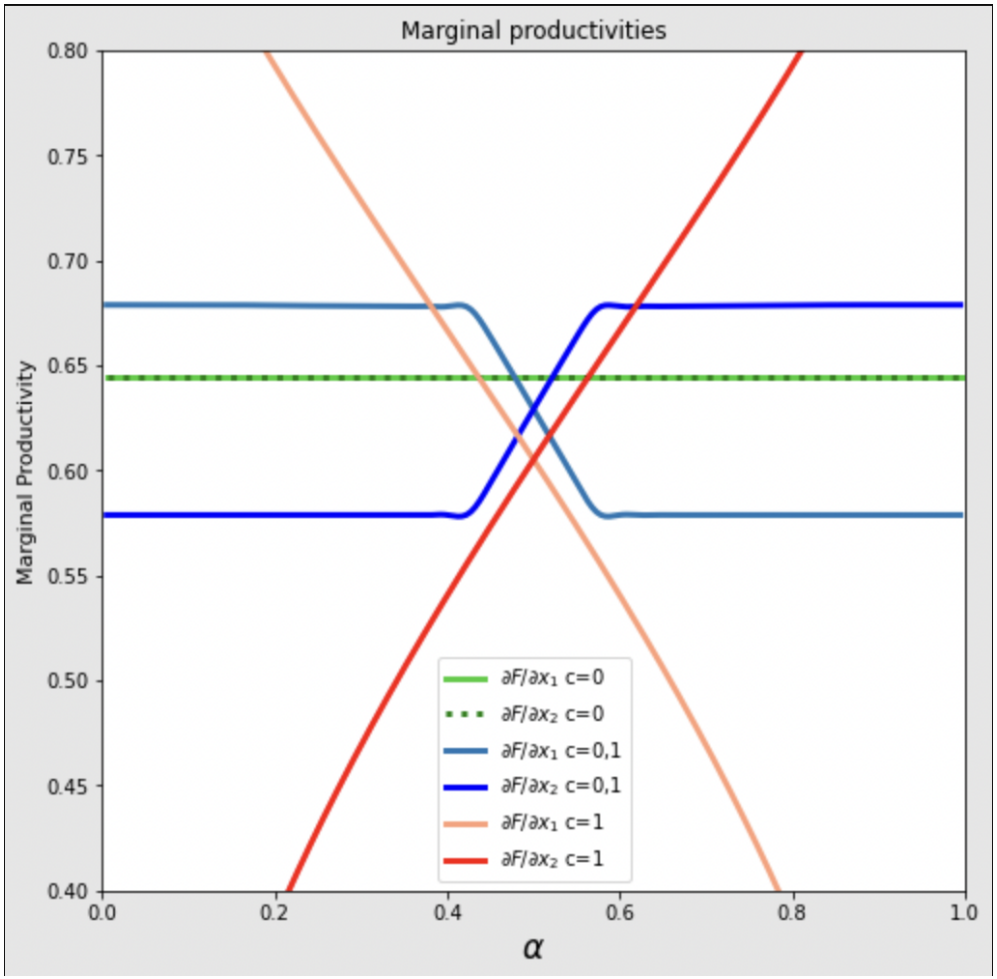

Figure 13: Implicit prices of skills for costly unbundling (in blue)

The Empirical Content of the Model

Bundling ...

- Give firms substance and within-firm heterogeneity
- Matching, skills, and technology
- In the old world, AKM was pervasive ...

... and Unbundling

- ... but with unbundling and markets' opening, firm-effects prevalence diminishes
- to the benefit of generalists whose "markdown" decreases

The Empirics of Labor Market Bundling and Unbundling

Joint with O.N. Skans

Data from Swedish military draft

- Males born 1952 to 1981
- Cognitive (C) and non-cognitive (N) skills on discrete 1-9 scale
- Define C-spec. $[C > N + 1]$, N-spec.$[N > C + 1]$, and Gen.
- Use coworker specializations to infer type of firm

We find

- Sorting of workers across establishments (within and across occupations): *C*-specialists work with *C*-specialists (same for *N*-specialists); effect most pronounced for high-quality workers
- Relationship between sorting and wages: Wages higher if you work with people of your own type
- Evolution 1997-2012: Polarization increases through time; wages of generalists increase over time

Table 1: Descriptive statistics

	(1) All	(2) Generalist	(3) C-Specialist	(4) N-Specialist	(5) Wage obs
Year	2004.8	2004.8	2004.9	2004.7	2005.1
Cohort	1965.8	1966.0	1965.4	1965.8	1965.1
Age	39.0	38.8	39.5	39.0	40.0
Worker skills:					
Cognitive (C=1-9)	5.252	5.190	6.914	3.643	5.366
Non-cognitive (N=1-9)	5.179	5.206	4.090	6.267	5.239
$C+N$ low (<9)	0.252	0.237	0.207	0.339	0.233
$C+N$ mid ($9-11$)	0.376	0.422	0.316	0.325	0.371
$C+N$ high (>11)	0.371	0.341	0.476	0.336	0.396
Establishment size	82.1	81.9	88.2	76.0	118.4
Generalist establishment	0.767	0.777	0.722	0.787	0.782
Cognitive establishment	0.136	0.125	0.209	0.087	0.141
Non-cognitive est.	0.097	0.098	0.069	0.126	0.077
Matched	0.504	0.777	0.209	0.126	0.507
Observed occupation	0.517	0.514	0.539	0.503	0.978
Observed wage	0.529	0.526	0.551	0.513	1.000
ln(Wage)	10.182	10.182	10.227	10.131	10.182
ln(Earnings)	10.102	10.104	10.138	10.059	10.157
N	12,627,401	6,964,632	2,744,810	2,917,959	6,682,011

Note: Descriptive statistics for the used data covering 1996-2013. Establishments are restricted to be size 6 (i.e. 5 coworkers) to 600. In columns (2) to (4) we split the sample and according to if the worker is a Generalist, defined as $abs(C-N)<2$ or a Specialist in C or N. Column (5) only uses workers for whom we have information on wages. Generalist establishments have a majority of employees as generalists, or an exactly equal share of specialists of the two types. Non-generalist establishments are classified according to the dominating type of specialists among employees. These classifications only use *co-workers*, i.e. not the subject himself. "Matched" workers are C-Specialists in Cognitive establishments (resp. N). Monthly earnings are recorded for all observations.

Table 2: Leave-out mean regressions on worker types

	(1) Actual sorting	(2) Random sorting	(3) Sorting on $C+N$	(4) Sorting on C/N
Panel A:				
Dependent variable: Being N-specialist				
Coworker share of N-specialists	0.224	0.009	0.283	0.987
	(0.006)	(0.007)	(0.006)	(0.000)
Coworker share of C-specialists	-0.263	0.004	0.124	-0.005
	(0.004)	(0.005)	(0.005)	(0.000)
Constant	0.229	0.215	0.127	0.004
	(0.002)	(0.002)	(0.002)	(0.000)
Panel B:				
Dependent variable: Generalist				
Co-worker share of N-specialists	-0.023	-0.010	-0.417	-0.980
	(0.008)	(0.008)	(0.008)	(0.000)
Co-worker share of C-specialists	-0.155	-0.003	-0.423	-0.974
	(0.007)	(0.008)	(0.008)	(0.000)
Constant	0.593	0.555	0.740	0.990
	(0.003)	(0.003)	(0.003)	(0.000)
Panel C:				
Dependent variable: Being C-specialist				
Co-worker share of N-specialists	-0.201	0.001	0.134	-0.008
	(0.004)	(0.005)	(0.005)	(0.000)
Co-worker share of C-specialists	0.418	-0.001	0.299	0.978
	(0.007)	(0.007)	(0.006)	(0.000)
Constant	0.178	0.230	0.132	0.007
	(0.002)	(0.002)	(0.002)	(0.000)
Observations (all panels)	731,946	731,946	731,946	731,946

Note: Dependent variable is own type, estimates are for the share of co-workers of different types. Reference is the share of generalists. Data are for 2005. At least 6 workers and at most 600 workers with measured skills are employed in each establishment. Three last columns show regression on simulated allocations across the actual establishment size distribution, see text for details. Standard errors are clustered at the establishment level.

Table 3: Leave-out mean regressions on two-dimensional worker types

Workers with High total ability : Dependent variable type	(1) High-ability N-Specialist	(2) High-ability Generalist	(3) High-ability C-Specialist
Estimates:			
Co-workers N-Specialists	0.075***	-0.055***	-0.105***
	(0.004)	(0.004)	(0.003)
Co-workers C-Specialists	-0.098***	-0.027***	0.223***
	(0.004)	(0.006)	(0.006)
(reference: Generalists)			
Co-workers High ability	0.075***	0.329***	0.184***
	(0.004)	(0.006)	(0.004)
(reference: Mid ability)			
Co-workers Low ability	-0.078***	-0.127***	-0.039***
	(0.003)	(0.004)	(0.003)
Constant	0.072***	0.117***	0.023***
	(0.002)	(0.002)	(0.002)
Observations	731,946	731,946	731,946

Notes: The results come from 9 different regressions (the full table is given in Skans, Choné, and Kramarz (2021)) where the worker types are dependent variables. Types are defined from the combination of indicators for C/N-Specialists vs generalist combined with indicators for total ability being low, mid or high. We report results from the 3 regressions for high total ability workers. Explanatory variables are co-worker averages of the C/N-specialists (generalists as the reference) and Low/High ability (mid ability as the reference). Data are for 2005. At least 6 workers and at most 600 workers with measured skills are employed in each establishment. Standard errors are clustered at the establishment level.
* ($p < 0.10$), ** ($p < 0.05$), *** ($p < 0.01$)

Table 4: Specialist co-workers increasingly predict same-type specialists

Panel A: Being a C-specialist (dep. var.)	(1) Base	(2) Control for Occupation	(3) Co-workers in Job
C-specialists interacted with time	0.008***	0.008***	0.006***
	(0.001)	(0.001)	(0.001)
N-specialists interacted with time	-0.003***	-0.002*	-0.003***
	(0.001)	(0.001)	(0.001)
C-specialists	0.415***	0.269***	0.455***
	(0.006)	(0.008)	(0.008)
N-specialists	-0.203***	-0.122***	-0.241***
	(0.004)	(0.007)	(0.006)
N	2,317,898	1,255,003	896,931
Panel B: Being a N-specialist (dep. var.)	(1) Base	(2) Control for Occupation	(3) Coworkers in Job
N-specialists interacted with time	0.004***	0.002*	0.003**
	(0.001)	(0.001)	(0.001)
C-specialists interacted with time	-0.003***	-0.004***	-0.002*
	(0.001)	(0.001)	(0.001)
N-specialists	0.227***	0.144***	0.264***
	(0.005)	(0.008)	(0.008)
C-specialists	-0.251***	-0.147***	-0.261***
	(0.004)	(0.006)	(0.005)
N	2,317,898	1,255,003	896,931

Notes: The dependent variable is a an indicator for being a C-specialist in panel A (N-specialist in Panel B). Subjects are 40 to 45 years old. Explanatory variables are the share of co-workers that are C/N-specialists interacted with time, normalized so that the main effects of co-workers reflect 2005. All specifications include year indicators. Col (2) also controls for occupation indicators at the 3-digit level (sample requires that occupations are observed). Column (3) measures co-workers in job (occupation*establishment) instead (sample requires at least 5 co-workers in job). Standard errors clustered at the establishment level. Data cover 1996-2013.
* ($p < 0.10$), ** ($p < 0.05$), *** ($p < 0.01$)

Table 5: Returns to specific skills are higher when co-workers are specialist in those skills

	(1) Base	(2) Control for Occupation	(3) Co-workers in Job
Panel A: Wages as a function of co-workers skills			
C-specialists in C-establishment	0.027***	0.009***	0.040***
	(0.003)	(0.002)	(0.003)
N-specialists in N-establishment	0.016***	0.005*	0.023***
	(0.004)	(0.003)	(0.004)
C-establishment	0.087***	0.020***	0.126***
	(0.004)	(0.003)	(0.005)
N	1,458,790	1,432,159	1,259,521
Panel B: Earnings as a function of co-workers skills			
C-specialists in C-establishment	0.036***	0.009***	0.044***
	(0.003)	(0.003)	(0.004)
N-specialists in N-establishment	0.023***	0.005*	0.026***
	(0.003)	(0.003)	(0.004)
C-establishment	0.081***	-0.002	0.108***
	(0.003)	(0.003)	(0.005)
N	2,945,409	1,432,159	1,259,521

Notes: The dependent variable is log of wages. Control variables are the indicators for each C-skill (1 to 9) and N-skill (1 to 9), indicators for being a C- or an N-specialist, as well as year indicators, an age polynomial and eight plant size indicators. Displayed estimates are for C-specialists in C-establishments (and conversely for N-specialists). Sample excludes establishments where the majority of workers are generalists. Specialization of establishment is based on the specialization among co-workers. Column (2) adds controls for occupations. Column (3) performs the analysis at the job (occupation times establishment) level instead. Panel A uses wages that only exist for a 50 percent sample. Panel B uses monthly earnings instead. Sample overlap when conditioning on observed occupations (col 2 and 3). Standard errors clustered at the establishment level. Data cover 1996-2013.

* ($p < 0.10$), ** ($p < 0.05$), *** ($p < 0.01$)

Table 6: Generalists' relative wage grows over time

Panel A All workers	(1) Base	(2) Control for Occupation	(3) Additional Controls
Generalist (indicator function) interacted with time	0.0012***	0.0007***	0.0007***
	(0.0002)	(0.0001)	(0.0002)
N	1,281,151	1,255,003	1,281,151
Panel B Matched sample only			
Generalist (indicator function) interacted with time	0.0031***	0.0020***	0.0018***
	(0.0006)	(0.0004)	(0.0006)
N	654,687	641,005	654,687

Notes: Dependent variable is log wages. Subjects are 40 to 45 years old. Estimates are for interaction between year and a generalist indicator. All specifications include year indicators and control for 81 fixed effects for interactions between measured C (1 to 9) and N (1 to 9). Column (2) has more detailed fixed effects that also interact with occupation indicators at the 3-digit level (sample requires that occupations are observed). Column (3) controls for eight plant size indicators and 18 additional time trends, each interacted with one of the possible 9 values of C and N. Standard errors clustered at the establishment level. Data cover 1996-2013.

* ($p < 0.10$), ** ($p < 0.05$), *** ($p < 0.01$).

Conclusion

Giving Firms Substance under Bundling

- Production function uses workers' aggregated skills
- Equilibrium matching displays within-firm worker heterogeneity
- and an AKM-style wage equation with the firm effect reflecting sorting of workers across firms

With Costly Unbundling

- Workers sell some of their skills on newly opened markets
- Generalists benefit ...
- ... but the wage "flattens" and firm effects tend to vanish

Ahead:

- Interacting worker's quality and firm's efficiency
- Structural estimation