Understanding Human Capital Intensive Production: Firm Capabilities and Individual Knowledge

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Study of internal economics of organizations: two basic approaches

- Emphasize bounded rationality, need for organizations to acquire and process information
  - Pioneering work: (Simon (57)); Arrow (74); Marshak and Radner (72)

- Emphasize incentive considerations, need for supervision
  - Pioneering work: Mirrlees, Bell 1976
    "The Optimal Structure of Incentives and Authority within organizations"
    - Moral harzard in production of outputs – supervisory hierarchy
      - Principal can invest in observing output of individual
      - And can provide incentive pay
        - PA/ two layer/ multilayer hierarchy
        - Payment schemes, optimal taxation of workers, tournaments

Today: first approach

Organizations designed to produce when knowledge is expensive to acquire and communicate

Motivation (1): Knowledge matters

Historically, output produced with physical capital and labor

traditional prod function approach Y=f(K,L) suitable to this

Consulting, Law, R&D – it is all about leveraging the skill and knowledge of knowledgeable individuals – organization matters

- how is human capital intensive production organized?
- how does this organization affect labor market outcomes?
- How can production functions that take organization into account be empirically estimated?

Heterogeneity

- Why do performance differences between similar teams/firms exist and persist?

- When and why will we observe otherwise identical firms having different productivity /output/profit levels?

Answers

I. Organization of knowledge in production?

Knowledge based hierarchies

II. Heterogeneity?

Differences in skill, magnified (through complementarities) by matching

- Because of matching, a small difference in skill/knowledge is magnified into a large difference in output/other outcomes
  - Scale effects: Lucas (78) Rosen (82)
  - Horizontal matching: O-Ring, Kremer (1993)
  - Scale with matching: Garicano-Rossi Hansberg QJE (Nov 06)
- In work with Thomas Hubbard (NBER WP, 07) we implement this explanation empirically and 'explore' the model empirically:
  - explain performance differences as the result of differences in skill * leverage
  - will discuss this briefly

Answers (2)

but can two firms with identical agents (and rest) have different productivities?

cognitively: what does a firm ‘know' (as separate from individuals)? what does it mean that a firm is good at something? why do we start a new firm when we need to come up with something else?

Answer

III. Sketch a solution related to Cremer, Garicano and Prat (QJE O7): Sunk investments in codes/organizational language /more broadly firm (cognitive) culture

A map

Hierarchies and the utilization of knowledge	Assignment of individuals to firms, heterogeneous skills	Empirics: Tests and estimation	From a collection of individuals to a firm
• Knowledge based hierarchies, JPE 00	• Knowledge Economy (Garicano and Rossi-Hansberg QJE 06)	•Structural estimation of coordination costs in the law: Garicano Hubbard, NBER 06	• Codes (Cremer Garicano and Prat, QJE 07)
	•Offshoring (Antras/Garicano/Rossi0Hansberg, QJE 06)	• Over time	

I. Knowledge Based Hierarchies (Garicano, JPE, 2000)

Idea: when matching problems with solutions is hard, hierarchies increase the utilization of knowledge of experts through the use of less knowledgeable subordinates to protect them from routine problems

The knowledge of expert substitutes for the knowledge of non-expert

Production and knowledge by one worker (I)

Production and Knowledge

Agents face a large number of possible tasks/ problems z

Each problem worth 1 per unit of time if solved; otherwise 0

Learning costs proportional to number of problems learnt

$$c\ \mu(Z)$$

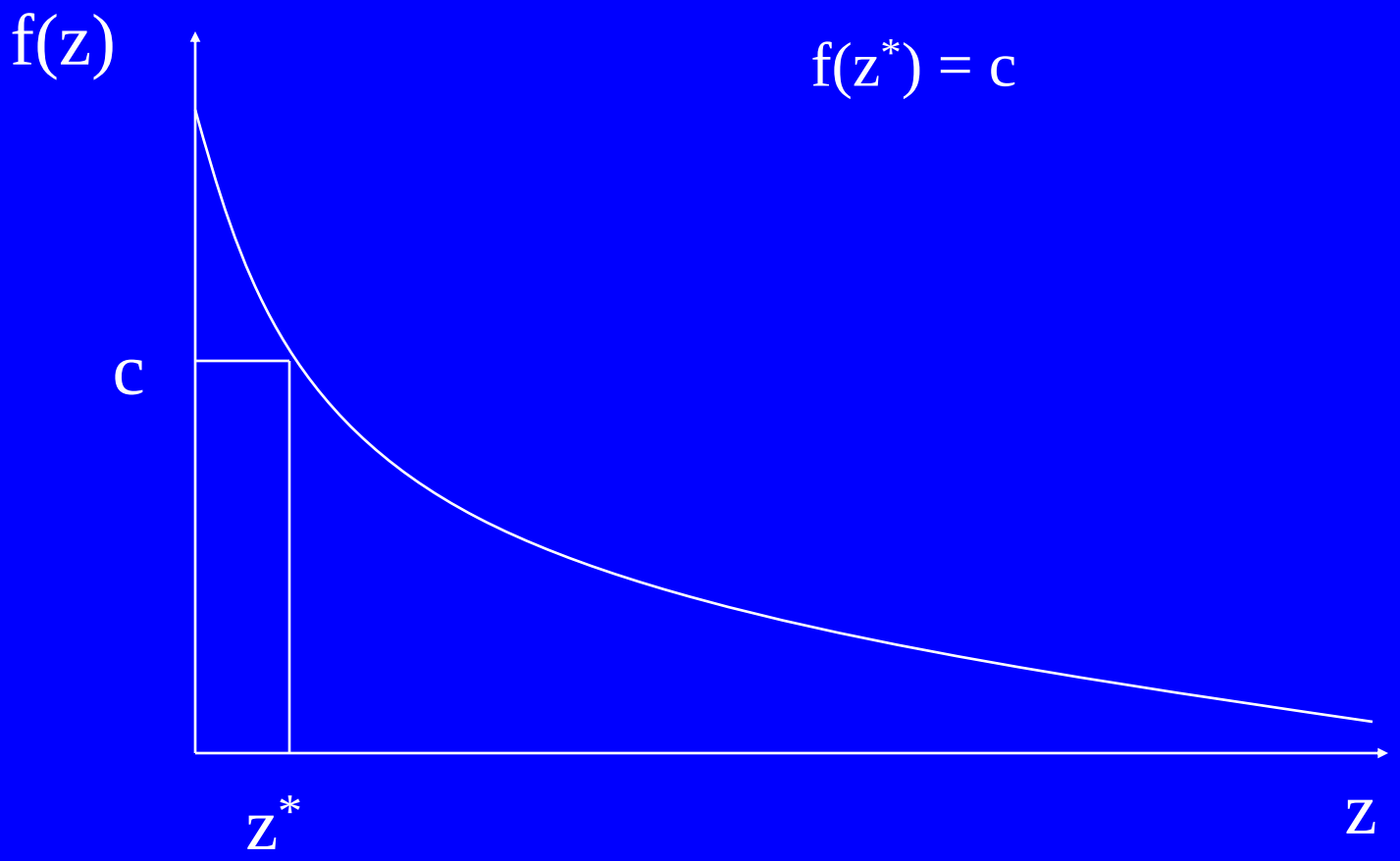
Some problems more common than others.

- probability distribution *f* over the problems
- Tasks ordered from more to less common, so that $f' < 0$

Agent who knows tasks in the interval (z_o, z_1) produces:

$$\int_{z_0}^{z_1} f(z)\,dz$$

Production and knowledge by one worker (III)



Team problem (I)

- Can ask for help
- Helper incurs a helping time cost *h trying to help*
- Cannot know ahead of time if problem known by helper
- Example: two agents with disjoint knowledge Z_1, Z_2:

$$(t_1^p + t_2^p) \int_{z \in (Z_1 U Z_2)} f(z)dz - c\mu(Z_1) - c\mu(Z_2)$$

- Subject to the constraint that $t_i^p + t_i^h = 1$, where t_i^h is the helping time:

$$t_1^h = \left(1 - \int_{z \in Z_2} f(z)dz\right) t_2^p \, h$$

Team problem (II)

- In a team there is a set of worker 'classes,' possibly many, and a share β_i of the available workers is assigned to each class.
- Agents are endowed with a 'list' which says whom they are supposed to ask first, to whom next etc.
  - For example, those in class 1 who have a problem should talk to 3 then to 5 then to 4.
- Then communication of team members is given by:

$$\beta_i t_i^h = \sum_{k:i\in\ell_k} \beta_k t_k^p \left[1 - F\left(\bigcup_{l\leq_k i} Z_l\right)\right] h$$

Team Problem (III)

- Choose:
  - Proportion of workers in it β_i,$\sum_I \beta_i=1$
  - Knowledge Z_i in Z, (possibly overlapping others')
  - List ℓ_i of classes of workers that a worker of class i may ask for help (includes i).
  - Allocation of time to helping other teams (t_i^h) and producing (t_i^p), with $t_i^h+t_i^p=1$.
- To maximize output per capita:

$$y = \sum_i \beta_i \left[Pr(z \in \bigcup_{k \in \ell_i} Z_k) t_i^p - c(Z_i) \right]$$

Characterize solution:

(1) Agents are either specialized problem solvers or production workers

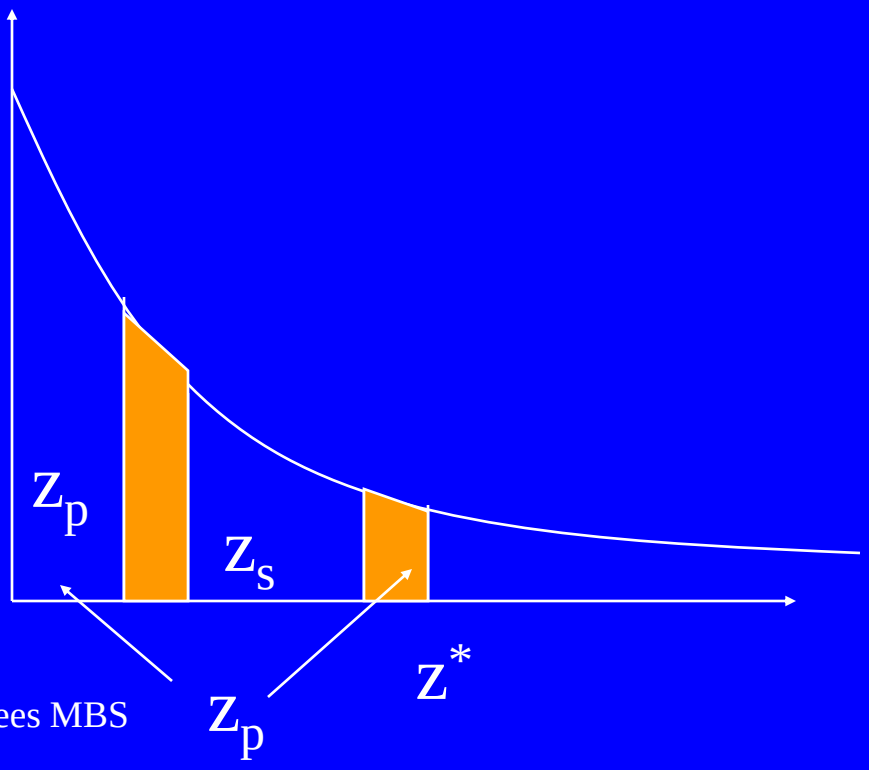
Intuition:

- With CRS, linear substitutability between sizes of different classes and the time, holding knowledge (z_i) constant.
- Place as many workers as possible in the class most productive, subject to having enough workers in other classes to help them.

Characterize solution

(2) Management by exception:

- Production workers know solutions to common problems
- They ask successively problem solvers who know increasingly exceptional problems.
  - Proof: contradiction



Characterize solution

(3) Pyramidal shape:

-Problem solvers further away from production are involved when others could not solve problems

- thus layers increasingly small

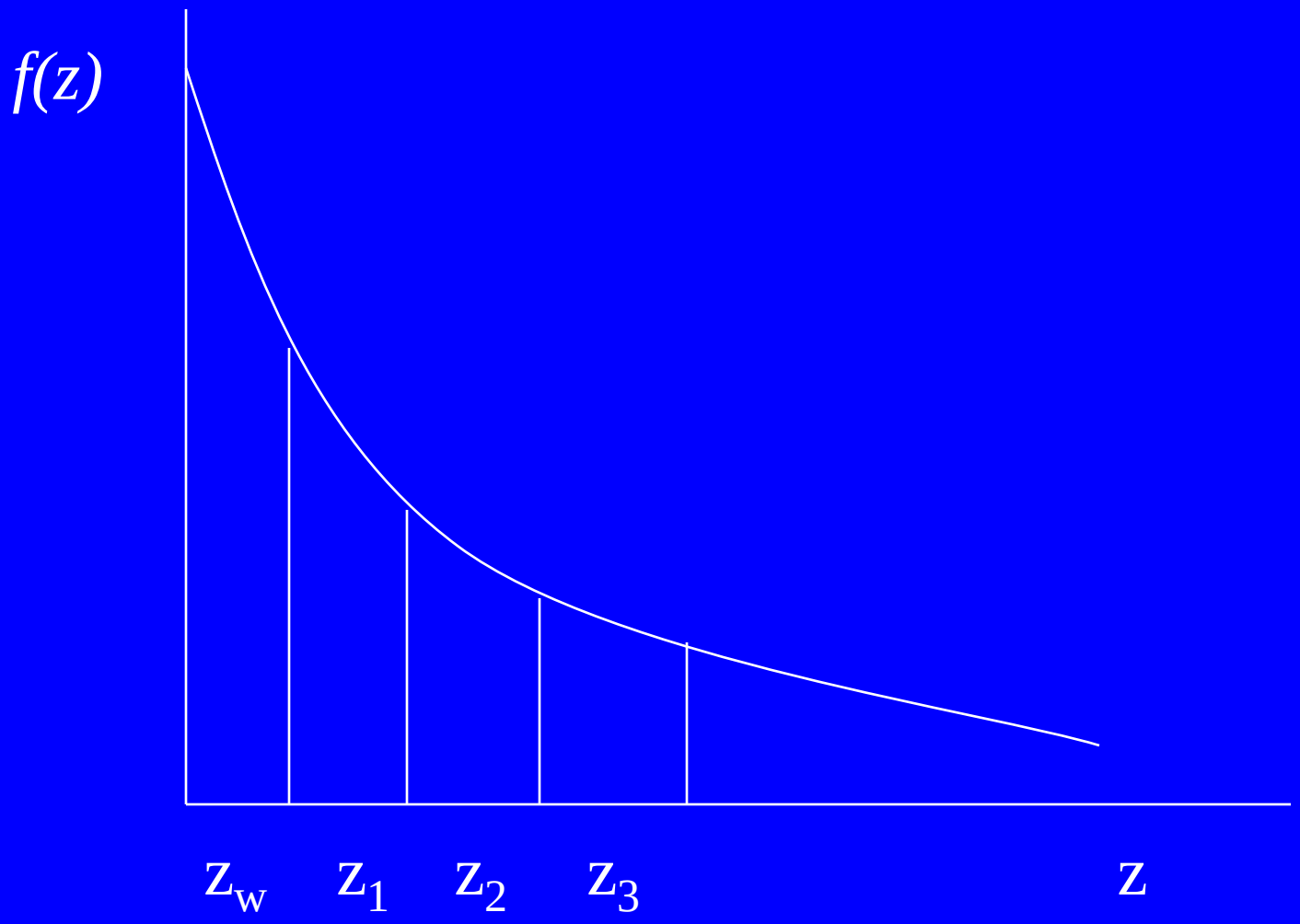
-They also deal with increasingly unusual problems

Note also that possibly several tiers optimal.

The trade-off resulting from extra tier is:

- Increase communication costs
- Decrease knowledge costs, by having less workers learn exceptional problems

Solution: knowledge-based hierarchy



Knowledge based-hierarchies

(1) Agents are either specialized problem solvers or production workers

(2) Management by exception:

- Production workers know solutions to common problems
- They ask successively problem solvers who know increasingly exceptional problems.

(3) Pyramidal shape:

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    - thus layers increasingly small
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Examples

- These principles common in organizations
  - Software customer service /technical support – Orlikowski (1996)
    - Juniors handle front calls
    - Must transfer up calls that they cannot handle
  - Residents/Attendant physician
  - Production workers--mechanical coordinators--production engineers
  - Principle should apply specially within functional units, where matching problems with knowledge is hard.

A specific solution

- We can actually find closed form solutions for hierarchies by using referral prices
- Suppose non-overlapping

Production workers

$$w_0 = \max_{z_0} F(z_0) + (1 - F(z_0))r(z_0) - cz_0$$

Earnings when either a problem is solved or when it is passed on (referred) at a price r

Price depends on how hard problem is

Problem solver's

$$w_i = \max_{z_i} \frac{1}{h}\left(\frac{F(\sum_i z_j) - F(\sum_i z_{j-1}) + (1 - F(\sum_i z_j))r(\sum_i z_j)}{1 - F(\sum_i z_{j-1})} - r(\sum_i z_{j-1})\right) - cz_i$$

Earnings when problem is solved or when passed;

buy for referral and earn a referral fee on non-solved problems

Problem solvers problem (2)

If F is exponential, can write this expression as:

$$w_i = \max_{z_i} \frac{1}{h}(F(z_i)+(1-F(z_i))r(\sum_i z_j)-r(\sum_i z_{j-1}))-cz_i$$

Nothing depends on previous layer except for price; then price is also constant across layers r(z)=r

First order condition

For workers:

$$f(z_0)(1-r) = c$$

For problem solvers:

$$\frac{1}{h} f(z_i)(1-r) = c$$

Three unknowns, two equations

Third equation: $w_0 = w_i$

Results

Equilibrium price of problems (referral fee) (the value of knowledge)

$$r = 1 - h\left(1 - \frac{c}{\lambda} \ln h\right)$$

Refer less valuable if learning expensive (c high)

Refer less valuable if problems complex (λ low)

Refer less valuable if communication cost high (asking more expensive)

Results: knowledge

Knowledge of solvers and workers:

$$z_s^* = \frac{1}{\prime}\ln\left(\frac{\prime}{c} - \ln h\right)$$

$$z_w^* = \frac{\prime 1}{\prime}\ln\left(\frac{h_{\prime}}{c} - h\ln h\right)$$

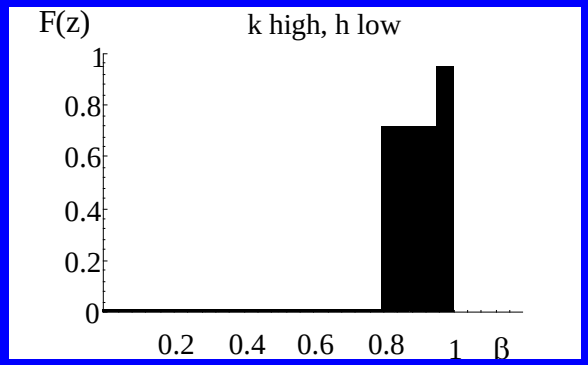
Both decrease if problems harder

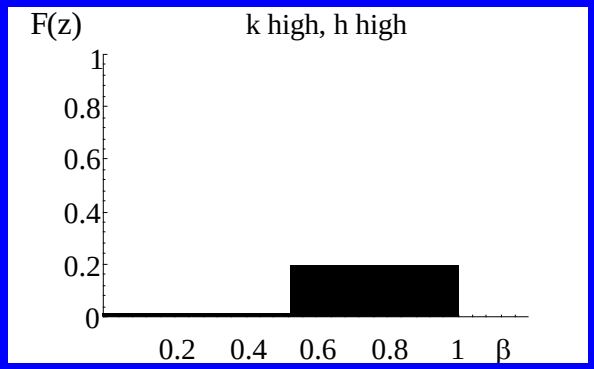
Solvers learn less if communication expensive

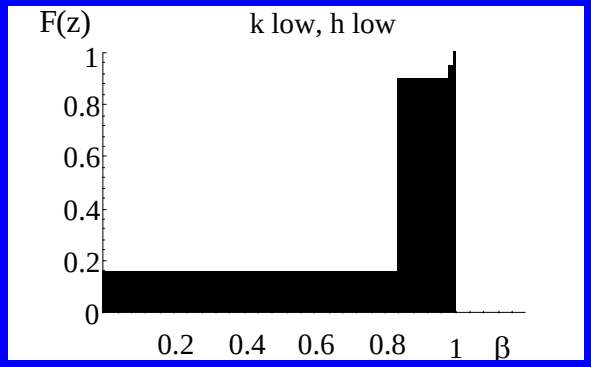
Workers learn more if communication expensive

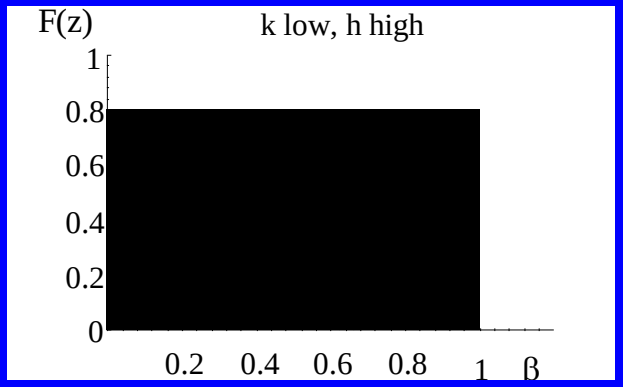
Layers? Impact of info costs on organizational structure (overlapping knowledge)

k=c/λ cost of acquiring knowledge









h=helping/communication cost

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Knowledge Economy

- Main input in production is knowledge
  - individuals (accountants, bankers, managers, doctors) need to know how to solve problems in order to produce
  - individuals have limited time –cannot distribute such knowledge freely–
    - matching (who is allowed to ask questions?) matters
- Complementarities
  - Marginal value of own knowledge is higher if coworkers are smarter
- Thus organization and matching (not just aggregate amount of human capital) matters

Model elements

- A distribution of cognitive skill: $\alpha \sim \phi(\alpha)$
- A distribution of problems that may be learnt: F(z)
- A hierarchical production function

$$\max_{z,n} F(z_l)n_0 - \sum_{l=0}^{L} n_l(c(\alpha_l)z_l - w(\alpha_l))$$

  - Subject to set of time constraints:

$$h(1-F(z_{l-1}))n_0 = n_l$$

Hierarchies and firms

- hierarchies do not have to coincide with firms-- what matters with complementarities is who is working together --whether in firms or in markets is irrelevant
  - E.g a consultant market pay a fee for service
  - E.g. a referral market: buy and sell for the unsolved opportunity

Referral formulation: Again can write decentralized version:

$$w_0 = \max_{z_0} F(z_0) + (1 - F(z_0))r(z_0) - c_0 z_0$$

$$w_i = \max_{z_i} \frac{1}{h}\left(\frac{F(z_i) - F(z_{i-1}) + (1 - F(z_{i-1}))r(z_i)}{1 - F(z_{i-1})} - r(z_{i-1})\right) - c_i z_i$$

Note: complementarities– positive sorting

Positive Sorting-intuition

- Asking questions: if an agent does not know something, he may ask
  - Most questions asked by dumb workers can be answered by anyone – need a smart subordinate for a smart problem solver
  - By having smart workers, avoid dealing with dumb questions and have more effective time- can deal with more workers

What we must generate

Agents must be assigned to different hierarchies, and to different jobs and matched with other agents

- problem then is
  - knowledge acquisition
  - matching
  - equilibrium organization (multiple, heterogeneous hierarchies)
  - equilibrium earnings

Equilibrium conditions

- Labor market clears: Supply of workers equal to demand of workers by managers at each point (an integral equation determining matching function)

- Agents occupational and knowledge choice is optimal

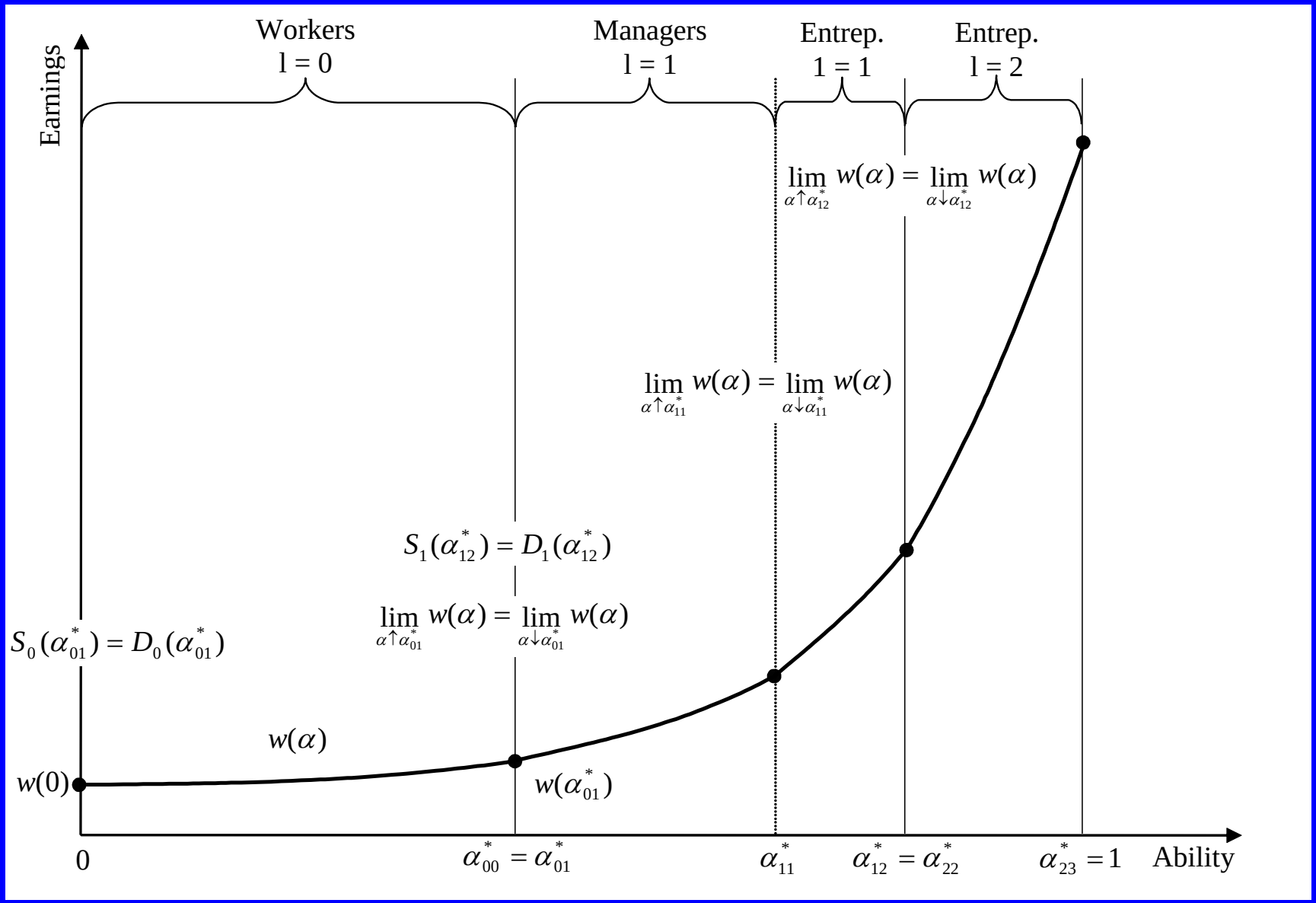
(a differential equation determining wage function)

- Optimization by firms
  - number of layers
  - span of managers
  - knowledge of all agents in organization

Characterizing equilibrium

- No self matching – can produce more without a team – $(n+1)\,F(z) > n\,F(z)$
- Positive sorting
- Stratification by ability
- Existence and uniqueness
- Convexity

Equilibrium earnings



Some results

(1) what does organization do to knowledge acquisition?

- Organization allows for the substitution of own knowledge for asking
  - for less skilled agents, organization decreases their knowledge
- Organization makes more useful the knowledge about hard things (can use it more often)
  - for more skilled agents, organization increases their knowledge

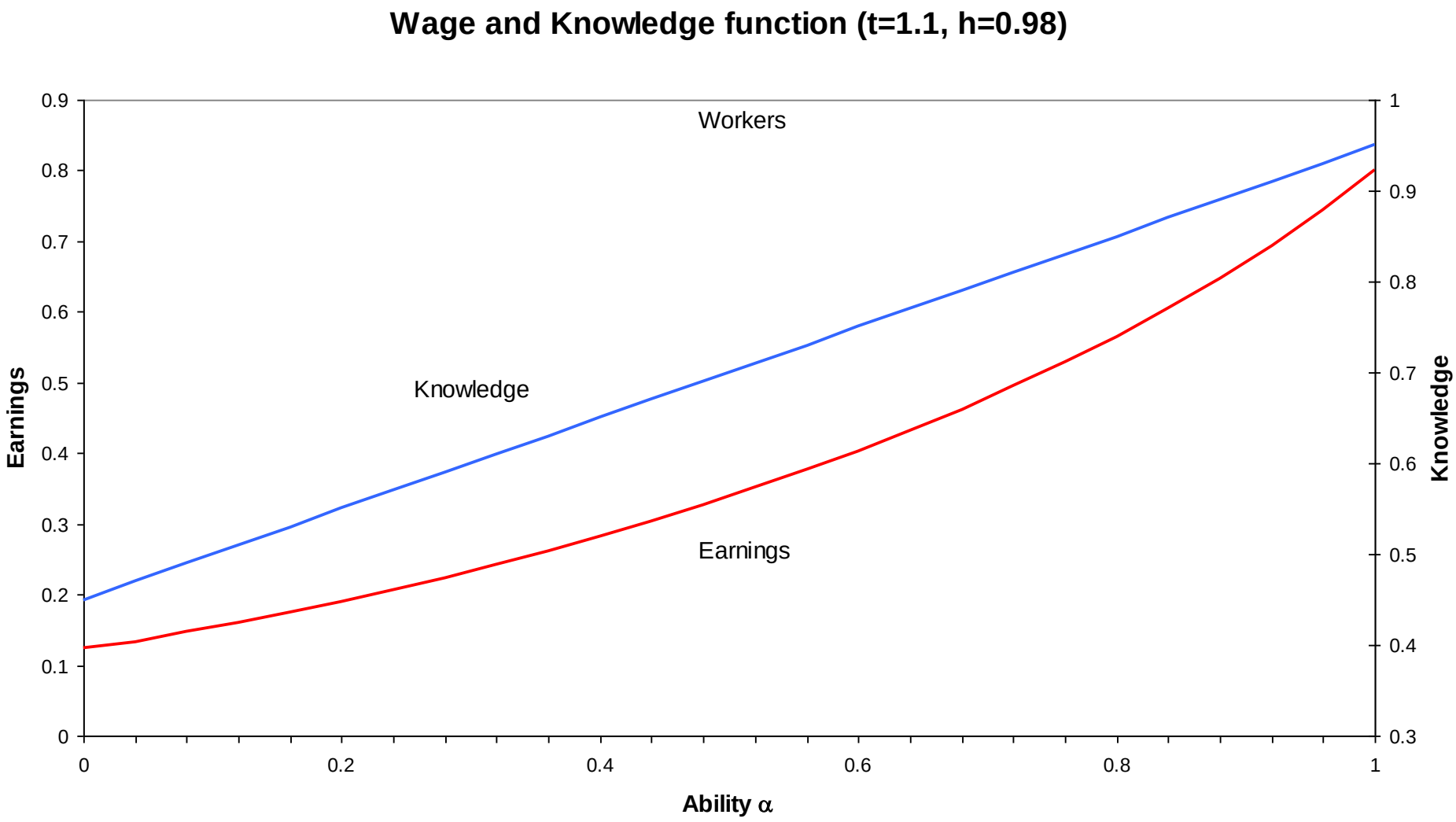
that is organization allows the substitution of the knowledge of less skilled agents for that of more skilled agents

Some results

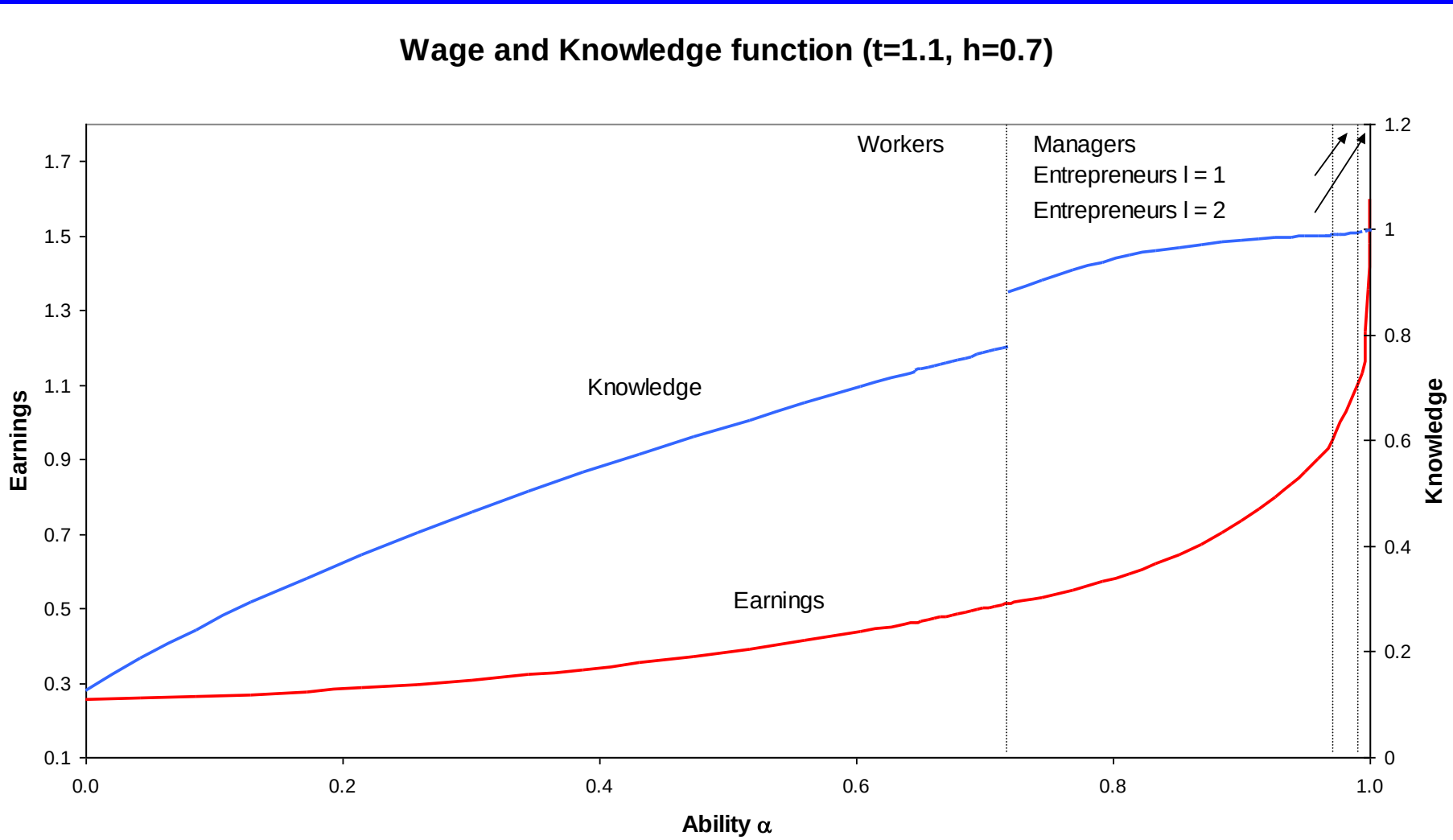
(2) how does this affect inequality?

inequality is linked to the amount of knowledge one has acquired:

- thus organization makes production workers/low ability agents more equal-reduces within inequality
- and high level agents more unequal – increases within inequality
- while increases the gap between them – increases between inequality



when knowledge less costly, autarchy is best if communication is so expensive. Firm size has decreased.



lower communication cost-continued trend in wage inequality-less within workers. More layers

Examples

- Emerging corporations at the end of XIX century
- Communication technology / email
  - increasing gap at top, not bottom?

Some results (2): Knowledge access

- What does better knowledge access do to inequality
  - less reliance on organization – more on own knowledge
  - more inequality at the bottom
  - As evidenced in the 80s early 90s

Some results (3): Offshoring (QJE) (with AGR-H)

- Two different skill distributions corresponding to two countries– allow them to form cross-country teams
- What does offshoring do to inequality and organization?
  - North increasingly specialized in Knowledge
  - Increasing demand for highly skilled –Northern managers
    - Increasing inequality among Northern managers
  - Improved matching for Southern skilled workers
    - more inequality between Southern workers

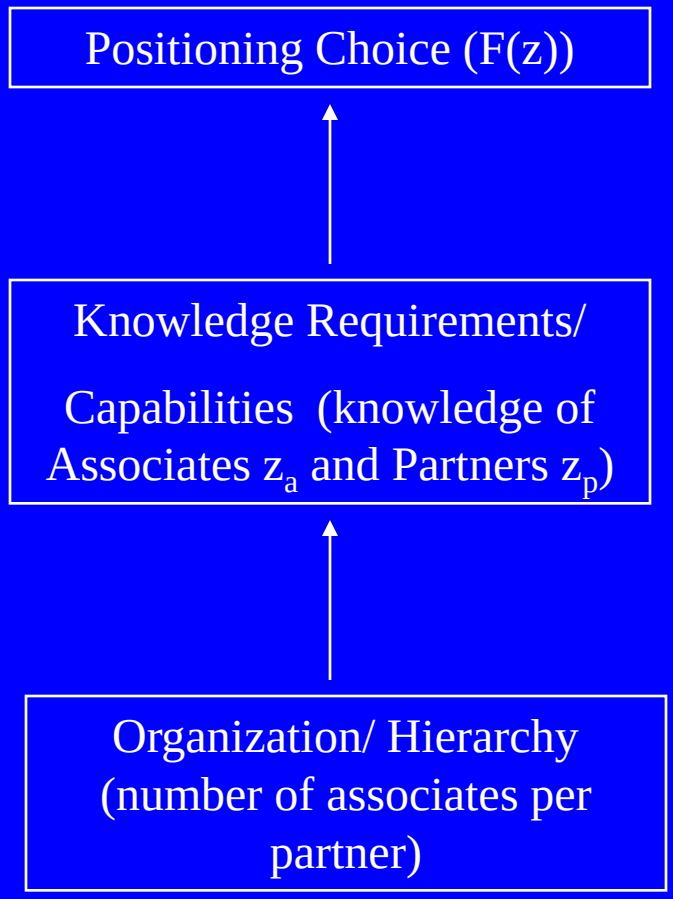
What is new? Labor market and firm structure two sides of same coin

- Changes in cost of communicating information (e-mail etc.)
- Changes in cost of accessing information (data base access)

- Labor market
  - Wage structure
    - Inequality within workers
    - CEO/worker premium
  - Assignment of workers to positions and teams

- Firm structure
  - Distribution of firm size
  - Spans,
  - Number of layers
  - Problems solved and knowledge acquired at each level

Knowledge, Organization and Strategy



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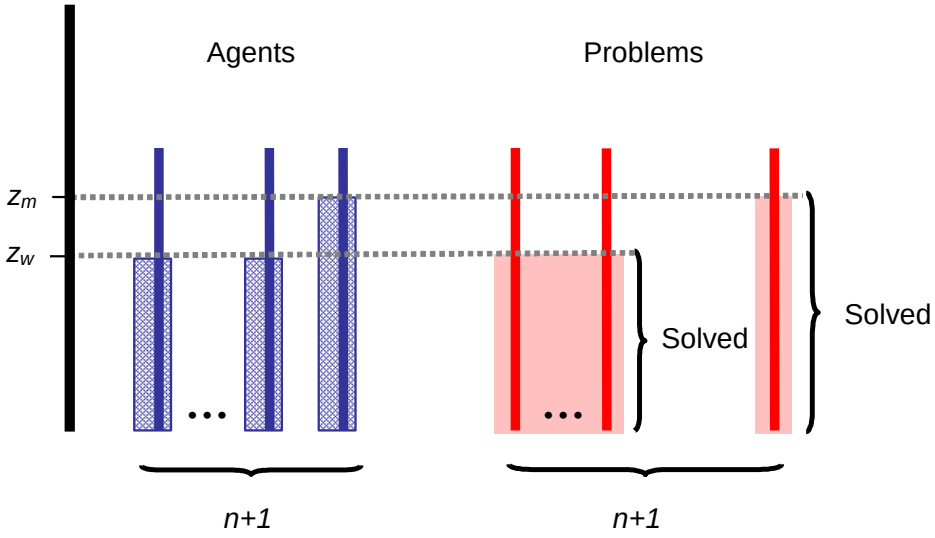
Heterogeneity in performance and hierarchical matching: Garicano and Hubbard 07: "The Return to Knowledge Hierarchies"

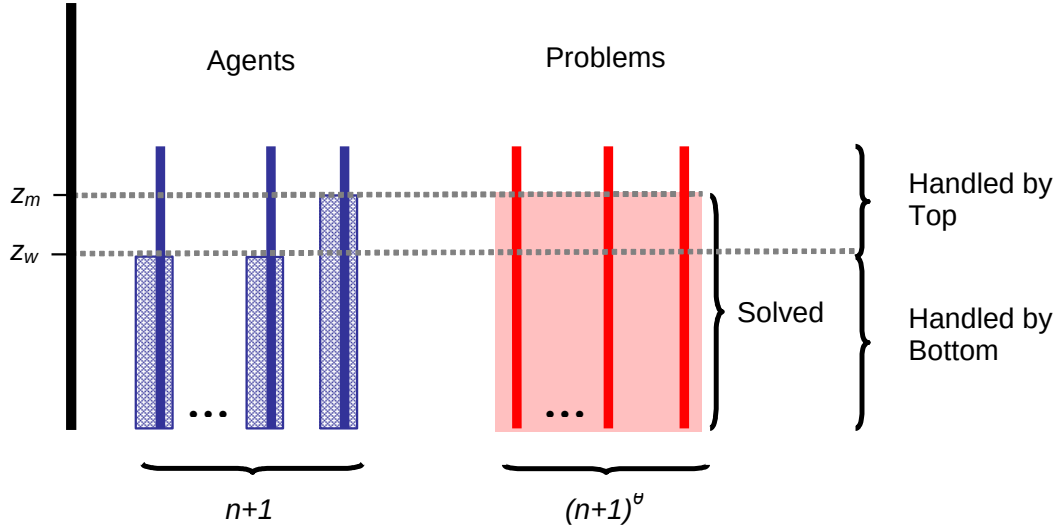
(Model of Garicano and Rossi-Hansberg (QJE 06) simplified 2 levels, exogenous knowledge, parametric prod. fn.)

- Agents endowed with a skill level *z* and one unit of time, distributed G(z).
- Production: application of time and knowledge to clients' problems.
- Agents can work on their own or in hierarchical teams,
  - Agents who work on their own produce z.
  - Hierarchical teams: a manager applies his skill z_m to his (n) workers' time – where workers have skill z_w. $y = z_m f(n(z_w))$
  - Less knowledgeable workers require more help per worker.
    - Managers' time constraint implies $n = n(z_w)$, where $n'(z_w)>0$.

Production Absent Hierarchies



Hierarchical Production



Heterogeneity in performance and hierarchical matching (2): equilibrium

- Equilibrium:

  (1) an allocation of agents to positions (workers, managers, "unleveraged");

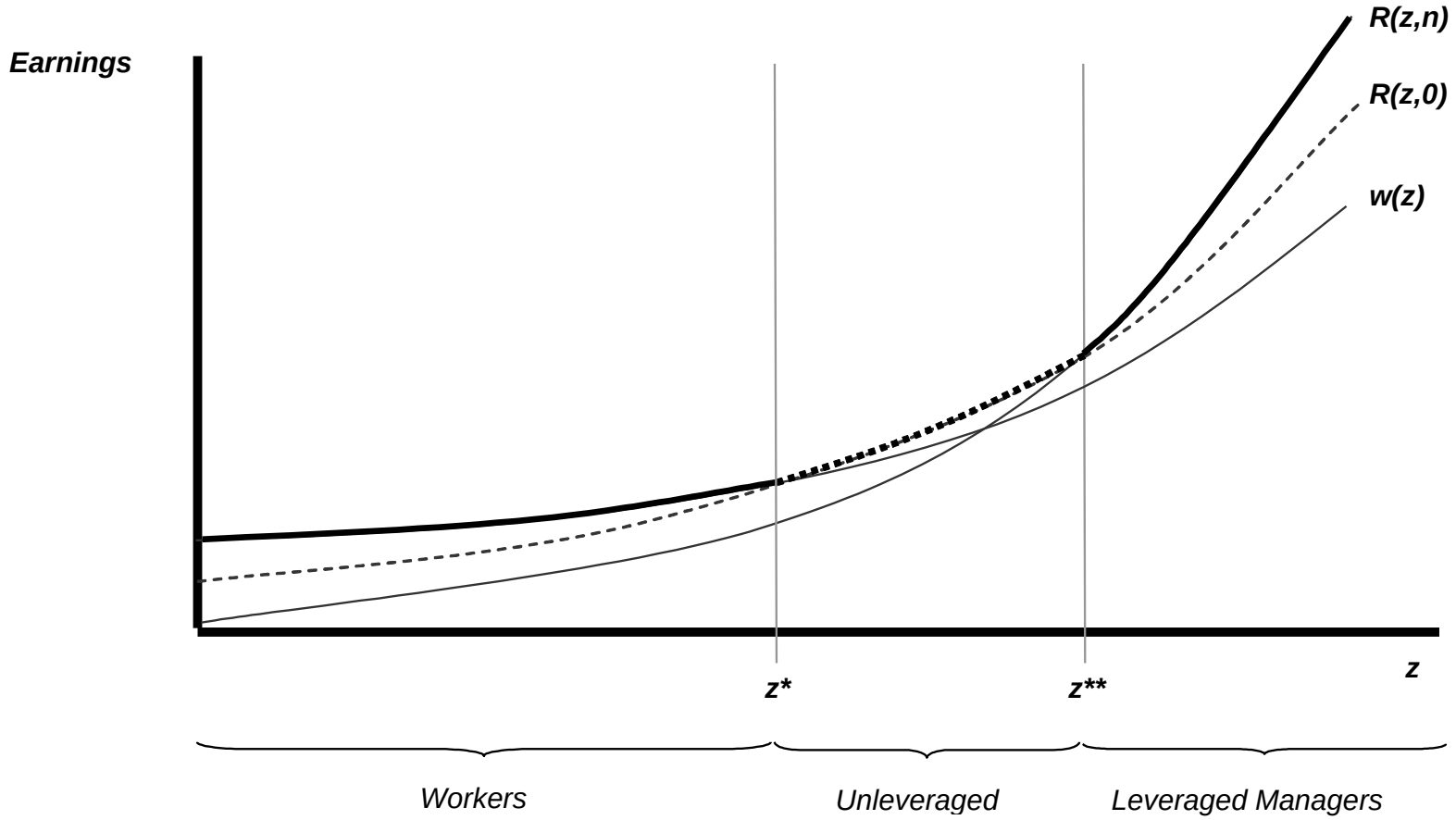
  (2) a matching function that assigns workers (quality and number) to each manager ;

  (3) an earnings function relating agents' skill to their earnings.

Heterogeneity in performance and hierarchical matching (2): Equilibrium

- Properties (GRH 06):
  - Positive Sorting. More highly skilled managers work with more highly skilled workers (only highly skilled workers ask the 'difficult' questions that use adequately skilled managers knowledge.
  - Scale of Operations Effects. More highly skilled managers manager larger teams of workers.
  - Stratification. The least skilled manager is more skilled than the most skilled worker.

Heterogeneity in performance and hierarchical matching (2): Equilibrium



Heterogeneity in performance and hierarchical matching: Law firm Data (3)

- Office-level data on law offices from U.S. Census of Services,
- Contains usual data on revenues, employment, payroll, collected from tax records
- For partnerships (2/3 of lawyers and offices) they also contain data on:
  - Number of partners, associates, non-lawyers.
  - Total payroll to associates, total pay to non-lawyers.
  - Number of lawyers, by field of specialization.
    - The data do not report directly:
      - Earnings of partners.
      - Operating expenses other than payroll.
    - We estimate the relationship between operating expenses and employment, revenues, field using data on offices legally organized as PSOs, and use this to estimate partner earnings at each of our partnerships. These estimates produce earnings distributions that correspond fairly well with other data. (See paper for details.)

Heterogeneity in Performance and Hierarchical Matching (4): Tests

Evidence consistent with positive sorting and scale effects.

Associate earnings, partner earnings, and associates/partner are positively correlated with each other

Evidence consistent with stratification.

Associates earn less than partners, even when comparing associates in offices with many associates/partner to partners in offices with few associates/partner.

- Higher-earning lawyers tend to work in larger markets, but the relationship between earnings and market size is non-monotonic.

Conditional on market size, the earnings distribution tends to be bimodal, with both modes increasing as market size increases.

Econometric Model (5)

Partners rents are given by:

$$R = \max_{z_w} E\left[z_m\left(n(z_w)+1\right)^{\mu}\right] - w\left(z_w\right) n\left(z_w\right)$$

With first order condition (replacing z in workers for n, a sufficient statistic)

$$z_m \mu (n+1)^{\mu-1} = w'(n)n + w$$

Substituting z in,

$$\frac{[R+wn]}{(n+1)}\mu\frac{1}{\mu} = w'(n)n + w$$

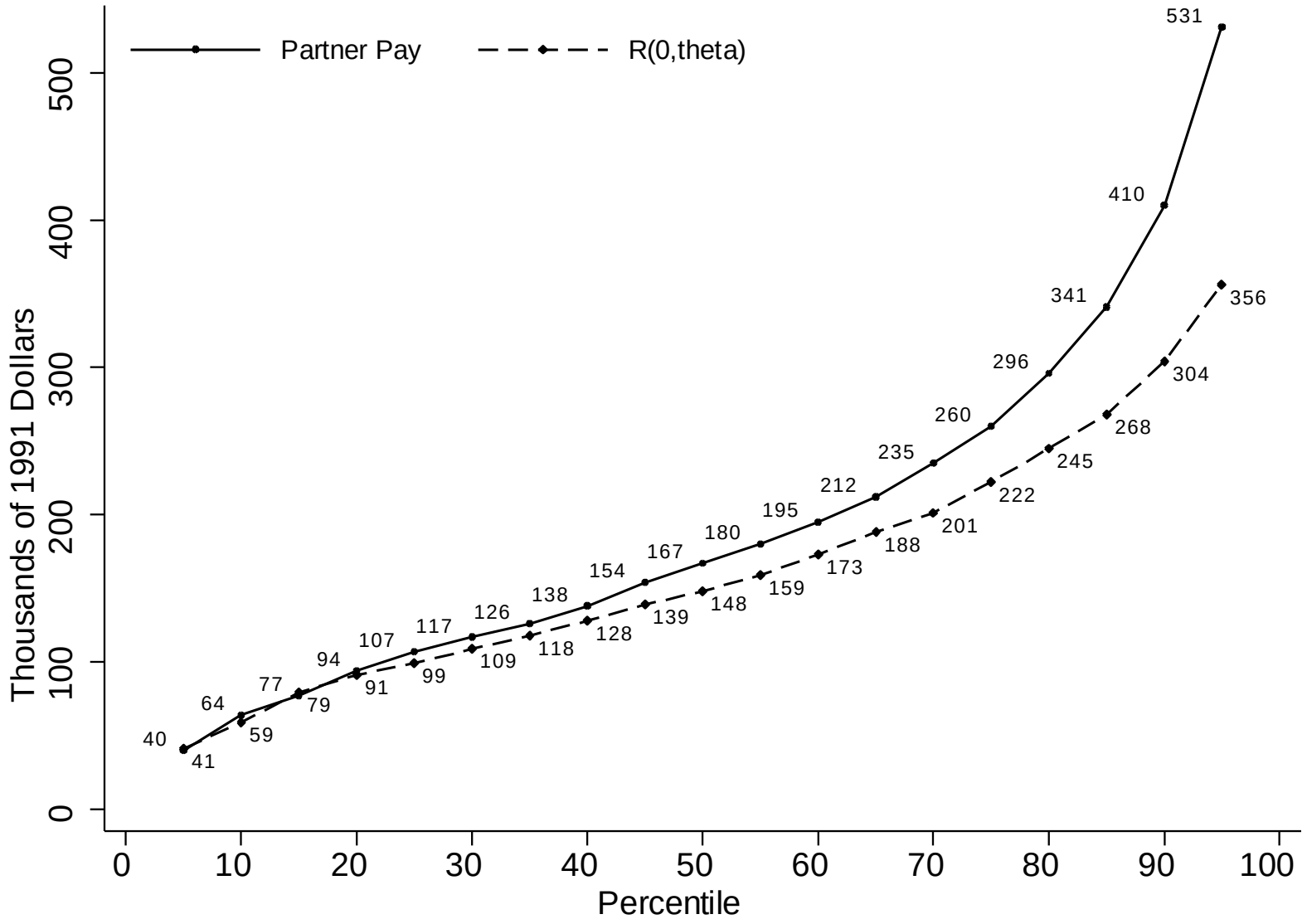
Rewriting Estimating equation

Taking logs and rearranging we have:

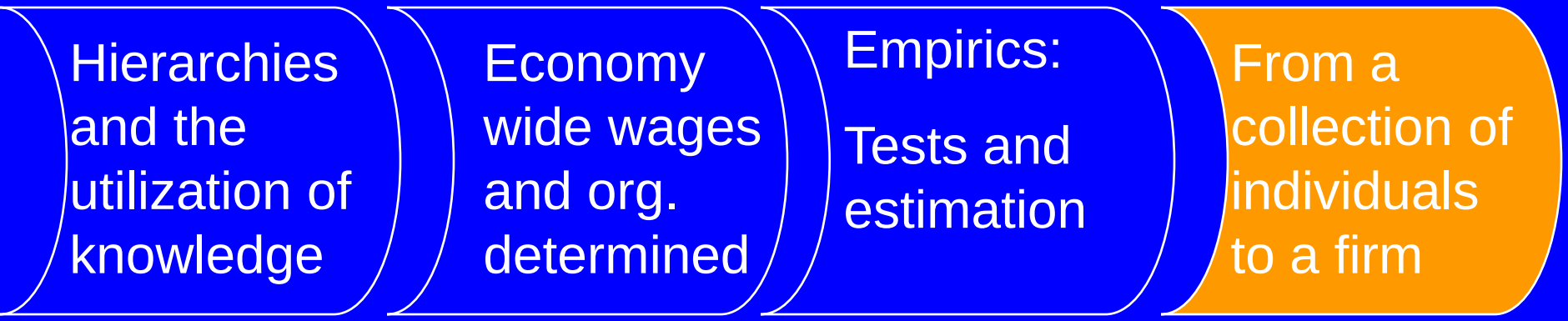
$$\ln AR_i - \ln MC_i = -\ln \mu + \ln \varepsilon_i$$

That is: the returns to scale is the difference between average revenue (recall the additional associate can be leveraged by the manager's talent) and the marginal cost of an extra lawyer (his wage, plus the increase in wage required by higher skill)

Heterogeneity in Performance and Hierarchical Matching (6): Partner pay and counterfactual partner pay



A map



- Knowledge based hierarchies, JPE 00

- Knowledge Economy (Garicano and Rossi-Hansberg QJE 06)
- Offshoring (Antras/Garicano/Rossi0Hansberg, QJE 06

- Structural estimation of coordination costs: Garicano Hubbard 06

- Codes (cremer Garicano and Prat, QJE 07)

Firm's knowledge till now is sum (union) of workers' knowledge

- If associate knows set A he can solve all problems in A, that is $y = 1 \; \forall \; z \in A$
- If partner knows set B, he can solve all problems in B, that is $y = 1 \; \forall \; z \in B$
- If they work together they can solve all of those problems, that is $y = 1$

$\forall \; z \in [A \cup B]$

  - Subject to having enough time to communicate their problems!
    - (this pins down team size, sorting etc.)
- That is, no firm knowledge as separate from individual knowledge--additive

But what are the returns going to firm? Do firms know something? Sketch of idea

(1) some specific firm knowledge– a code or an organizational language

(2) this code is a sunk investment

As the world changes, those firms who faced certain problems in past and created a certain code maybe better or worse adapted

Consequences:

- Returns for firm above or below returns to knowledge + matching
- Some workers may split from firm to create a common code more adapted to new problems – spin-offs for new ideas

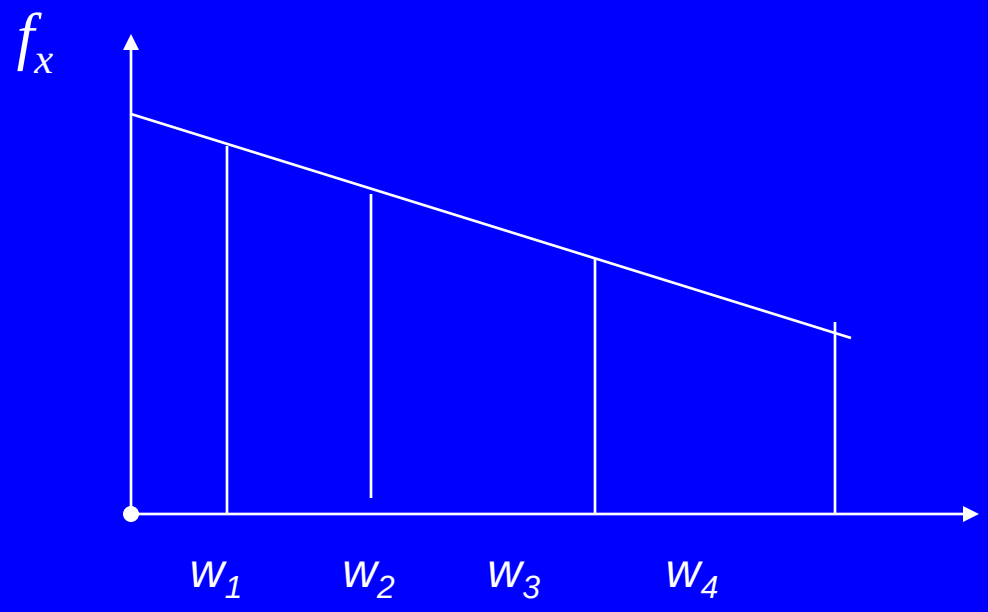
What is a code (Cremer, Garicano, Prat 07)

- "Salesman" draws a client or problem x which requires a solution.
- Ex ante problems distributed $f_x > 0$
- Engineer or expert can solve the problem
  - This requires diagnosis
  - Conditional on knowing what the problem asked is, the answer is instantaneous
- Salesman can classify problems; but not perfectly – bounded rationality

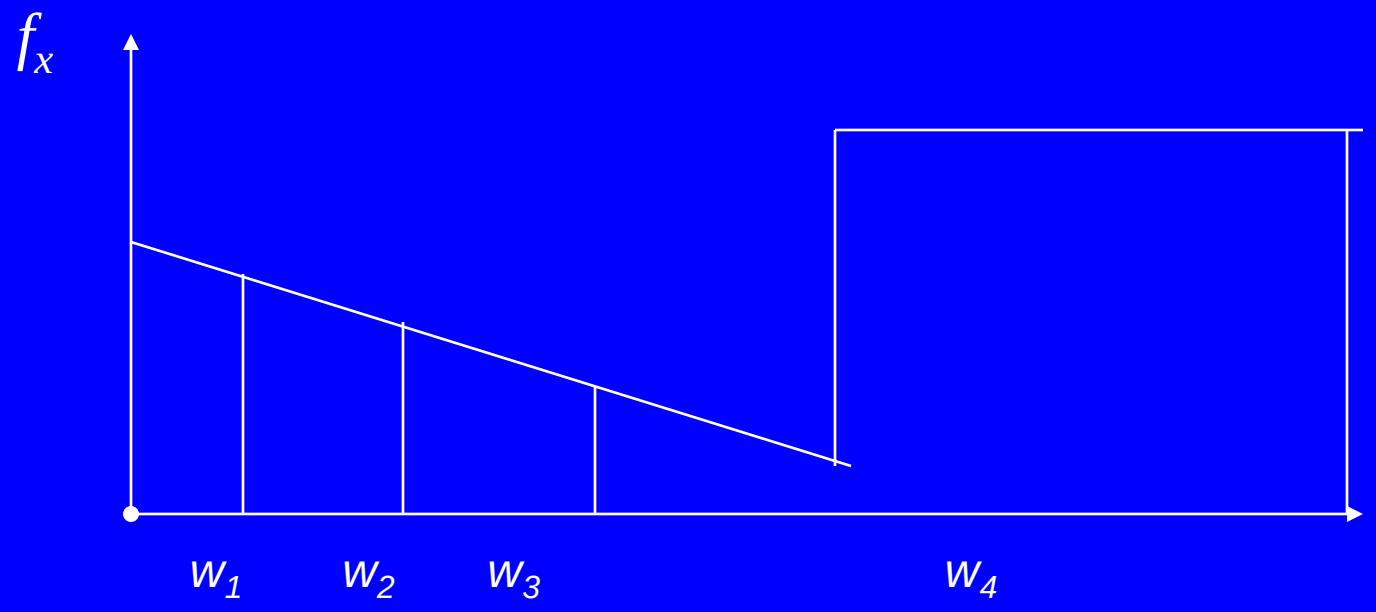
A code is a shared technical language that allows the problem solver to determine and diagnose the problem.

- Formally, a shared code is a partition of X into $W_1,\ldots,W_K$:
  - each k in $\{0,\ldots,K\}$ is a word;
  - W_k is its meaning.

Suppose world changes: before

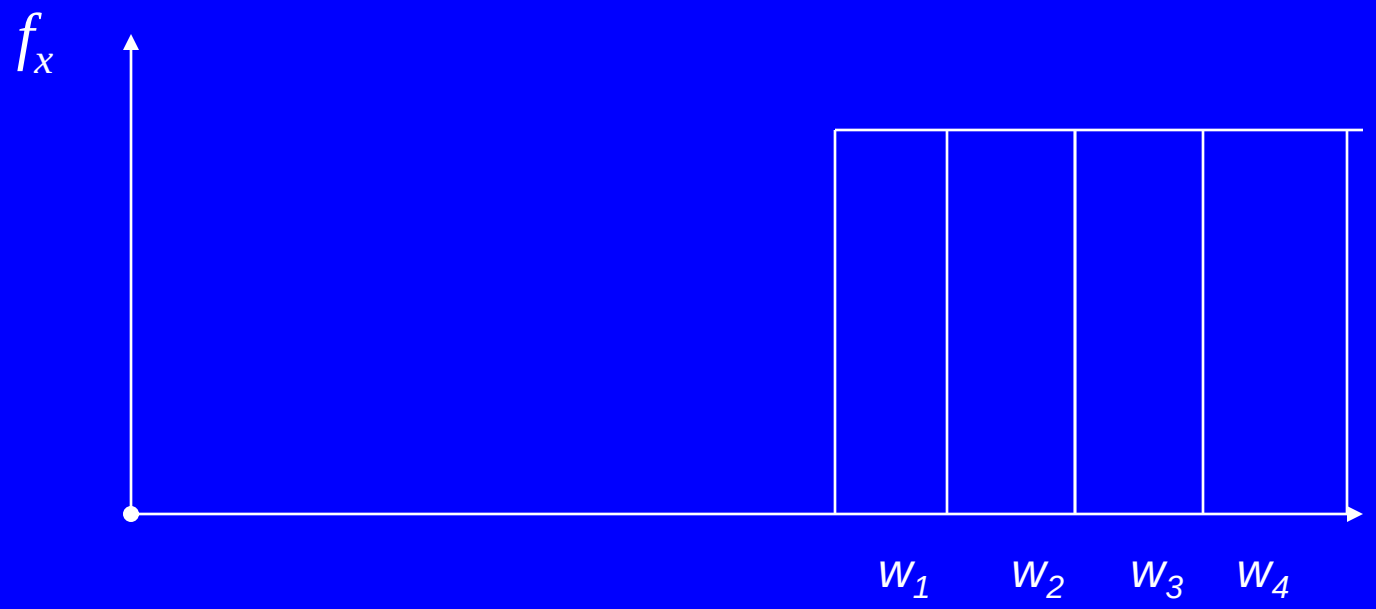


Suppose world changes: after



Old code ill adapted to the new world – e.g all the chemical engineers do not have a good language to talk about digital

One solution: A spin-off



Do not integrate

What is needed for a story like this to work?

- Shared specific human capital
  - This makes it firm / team specific rather than individual

- Sunk

Thus could be (Cremer 93)

- A common code
- A shared knowledge of facts
- A knowledge of rules of behavior

Conclusions

1. Hierarchies can allow individuals to leverage their knowledge

2. We can estimate hierarchical, knowledge intensive production functions– and evaluate how hierarchy contributes to expands return to human capital

3. Substantial heterogeneity in performance can be explained through differences in knowledge and talent enhanced by sorting and matching expanding differences in talent

   Clearly in law, that can go pretty far (think of economics departments or i-banks…)

4. Heterogeneity in performance beyond talent can be accounted for by sunk specific knowledge (e.g. Codes) and other investments
   - But can we ever truly test/find this empirically?