# Endogeneous Matching in University-Industry Collaboration:

## Theory and Empirical Evidence from the UK

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# Inter-organisation collaboration

- Science and innovation requires **inter-organisation collaboration**

- both **within** institutional markets: (university) or (industry)
  - Coauthorships across academic groups (Wagner and Leydesdorff 2005)
  - Research joint ventures among firms (Caloghirou et al 2003)

- and **across** institutional markets: (university-industry)
  - Joint research, consulting, training : important channels of knowledge transfer (Agrawal and Henderson 2002, Cohen et al 2002)
  - Links widespread (Perkmann et al 2013)

- We study the collaborations between academics and firms in research projects, in two sided market framework

# Example of a (two-sided market) collaboration (2007)

- Professor Sir Colin John Humphreys of Cambridge University
- Specializes in electron microscopy and analysis
- Prolific researcher of top university; his research considered basic

FEI™

- FEI: world leading company in production of electron microscopes
- Research-intensive firm, heavily oriented towards basic research

# Is this the most common pattern?

- Do top academics collaborate with top firms, whereas less productive academic researchers collaborate with less productive firms?
- Do they collaborate because they conduct similar types of research?
- Do more prolific individuals get their most preferred partners?
- They choose each other because of individual or institutional characteristics?
- Are less productive or more applied academics more likely to stay independent?

# Benefits and costs of collaboration

- Academics claim that collaboration:
  - provides with funds and insights (Lee, 2000; Mansfield 1995)
  - but might bias selection of topics and methods (Florida and Cohen, 1999)

- Firms report that collaboration:
  - gives them access to new university research and discoveries (Lee, 2000)
  - even if some of them have little commercial value (Jensen et al., 2003)
  - concerned with academic structure & culture (Dasgupta and David, 1994)

- Trade-off: Complementarities (Ability-based characteristics are complementary, Mindruta 2013) vs divergent interests.
- Participants might not be willing to collaborate with everybody, or able to collaborate with whom they prefer.

# This paper

- Which partnerships form? Who stays independent? On what it depends?
  - **Vertical**, ability-based (e.g. capacity to produce scientific output)
  - **Horizontal**, affinity-based characteristics (e.g. type of research)
  - Individual or institutional characteristics
- Theoretical model with predictions on:
  - **Flexible** value function that can accommodate different scenarios
  - **Matching**: which partnerships form and who stays independent (two-sided market matching model)
- Empirical analysis using new dataset:
  - Research projects funded by the UK's EPSRC
  - Publications of academics and firms

# Model

Market with m academics $\mathcal{A} = \{A_1, ..., A_m\}$ and n firms $\mathcal{F} = \{F_1, ..., F_n\}$

Each academic or firm can:

- develop a research project on its own: "non-collaborative" project
- or form a firm-academic partnership: a "collaborative" project
- Each academic / firm has certain attributes
  - (i) ability (scientific level, patents, know-how) ($\delta$)
  - (ii) type of the project she/it does best ("appliedness" in the interval [0,1]) (x)

# Value of a collaborative project

- Collaboration among a given academic A and a given firm F, with abilities $\delta_A \geq 0$, $\delta_F \geq 0$ and the type (degree of appliedness) $x_A$, $x_F \in [0, 1]$. Transfers among them are possible.
- Value increases with both partners' ability, and that this effect can be enhanced or reduced by their heterogeneity in terms of types of research.

Ability

Distance in type

$$\Pi^c(A, F) = (k + \delta_F + \delta_A)^\beta (1 + t|x_F - x_A|)^\alpha - C$$

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Ability

Distance in type

$$\Pi^c(A,F) = (k + \delta_F + \delta_A)^{\beta} (1 + t\,|x_F - x_A|)^{\alpha} - C$$

- The value can have decreasing returns to scale with respect to the abilities of the participants ($\beta < 1$, substituable abilities), constant RTS ($\beta = 1$), or increasing RTS ($\beta > 1$, complementary abilities).
- Heterogeneity can be negative for profits ($t < 0$), neutral ($t = 0$) or positive ($t > 0$).
- The effect of the distance can also be concave ($\alpha < 1$), linear ($\alpha = 1$) or convex ($\alpha > 1$) making the marginal effect of the distance to be decreasing, constant or increasing as the distance increases.

# Value of a non-collaborative project

- Academics may also run projects on their own, and academic ($\delta_A$, $x_A$) will obtain

$$\Pi_A^n(A) = (k_a + \delta_A)^\beta - c_a$$

- as firms may do

$$\Pi_F^n(F) = (k_f + \delta_F)^\beta - c_f$$

# The market equilibrium

- Market $\mathcal{A} = \{A_1, \ldots, A_m\}$ , $\mathcal{F} = \{F_1, \ldots, F_n\}$, with heterogeneous academics and firms (in $x$ and $\delta$)
- A matching function $\mu$ identifies collaborative and non-collaborative partners.
- A matching can be positive or negative assort, or neither of the two:
  - A matching $\mu$ is positive assort wrt ability if academic $A_i$ with a higher ability than academic $A_{i'}$ has a partner $\mu(A_i)$ with higher or equal ability than the partner $\mu(A_{i'})$ of $A_{i'}$.
  - Similar for type.
  - A matching is positive assort in terms of ability-distance pair if a more able participant from one side of the market is matched with a more distant partner from the other side.

# Partnerships formed

- An outcome $(\mu, \mathcal{T})$ is an equilibrium (or stable) outcome if it is immune to blocking by any firm, academic, or firm-academic pair.
- Standard result: any equilibrium matching $\mu$ is efficient (it maximises total surplus)
- The matching is positive assort wrt a characteristic $y$ iff it is efficient

$$\Pi^c(A_i, F_j) + \Pi^c(A_{i'}, F_{j'}) \geq \Pi^c(A_i, F_{j'}) + \Pi^c(A_{i'}, F_j)$$

- It is often used $\frac{\partial^2 \Pi^c}{\partial y_A \partial y_F} \geq 0$ $\left(\text{or } \frac{\partial^2 \Pi^c}{\partial y_A \partial y_F} \leq 0\right)$

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  which is a sufficient condition *when the function is characteristic increasing*

$$\frac{\partial \Pi^c}{\partial y_A} \geq 0 \text{ and } \frac{\partial \Pi^c}{\partial y_F} \geq 0$$

- Ability is a vertical characteristic:

  The equilibrium matching is positive (resp. negative) assortative in terms of ability iff $\beta \geq 1$ (resp. $\beta < 1$)

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- Type is an horizontal characteristic

  The equilibrium is positive (resp. negative) assortative in terms of type if $t \leq 0$ and $\alpha \leq 1$ (resp. $t > 0$ and $\alpha > 1$).

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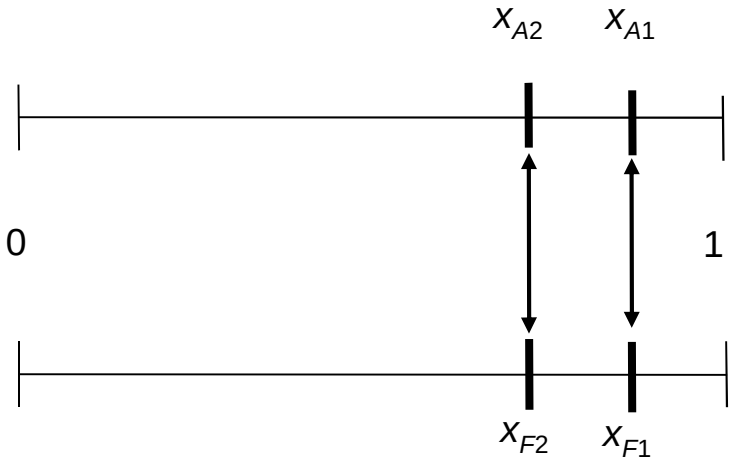
  In other cases it depends. Take $t < 0$ and $\alpha > 1$

positive
assortative



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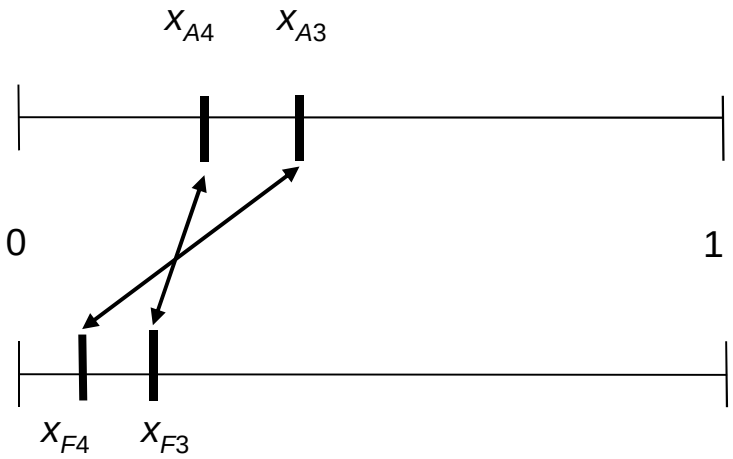
negative assortative



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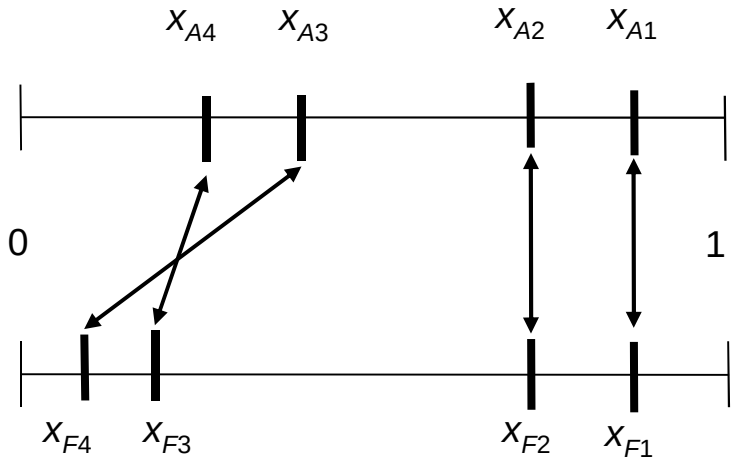
  In other cases it depends. Take $t < 0$ and $\alpha > 1$

neither of the two



# Interaction between type and ability

- The equilibrium matching is positive (resp. negative) assortative in terms of the academic's ability-distance pair if and only if $t \geq 0$ (resp. $t < 0$)

- The equilibrium matching is positive (resp. negative) assortative in terms of the firm's ability-distance pair if and only if $t \geq 0$ (resp. $t < 0$)

(Distance behaves as a vertical characteristic)

# Data

- Teams of academics and possibly firms research project's proposals:
  - EPSRC (main UK government agency for funding in engineering)
  - Calendar census of 40 major universities (Banal-Estañol et al forthcoming)

- Sample: all 5,855 projects of our academics in 2005-2007
  - Around 35% are collaborative (involve private firms)

- WoS publications:
  - 44,399 for the 2,411 academics in 2000-2007
  - 201,296 for the 1,735 firms in 2000-2007

# Main project-specific variables

- Proxies for ability of project's academics, PI and firms:
  - (i) Count and (ii) "impact-factor-weighted" sum of publications for the team and the PI
  - For the six years prior to the start of the project

- Proxies for type preference: Narin (1976) journal classification (updated by Hamilton for the NSF in 2005):
  - (1) applied technology and (2) engineering and technological science
  - (3) applied and targeted basic research and (4) basic scientific research
  - Type: (1) + (2) / (1) + (2) + (3) + (4)

# Other variables

- Project characteristics (from EPSRC) :
  - start year, holding organization
  - principal investigator, co-investigators, and industry partners
- University demographics (from the 2008 Research Assessment Exercise Results and the Higher Education Statistics Agency):
  - number/performance of all engineering academics
  - research funds
- Firm demographics (from FAME and ORBIS):
  - sector, employees, turnover, …..

# Descriptive statistics

| **Vertical attributes** | Observations | Mean | St dev | Median | Min | Max | Corr. academics' impact | Corr. PI's count | Corr. PI's impact | Corr. firms' count | Corr. firms' impact |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Academics' count (x100) | 5855 | 0.106 | 0.146 | 0.059 | 0.000 | 2.237 | 0.889*** | 0.562*** | 0.502*** | 0.194*** | 0.172*** |
| Academics' impact (x100) | 5855 | 0.169 | 0.309 | 0.070 | 0.000 | 5.261 | | 0.534*** | 0.636*** | 0.223*** | 0.219*** |
| PI's count (x100) | 5067 | 0.036 | 0.037 | 0.027 | 0.000 | 0.350 | | | 0.854*** | 0.067*** | 0.058*** |
| PI's impact (x100) | 5067 | 0.056 | 0.081 | 0.028 | 0.000 | 0.920 | | | | 0.120*** | 0.137*** |
| Firms' count (x1000) | 2057 | 0.749 | 1.836 | 0.080 | 0.000 | 17.625 | | | | | 0.901*** |
| Firms' impact (x1000) | 2057 | 1.448 | 5.173 | 0.066 | 0.000 | 58.543 | | | | | |

| **Horizontal attributes** | Observations | Mean | St dev | Median | Min | Max | Corr. PI's type | Corr. firms' type | Corr. respect impact |
|---|---|---|---|---|---|---|---|---|---|
| Academics' type | 5519 | 0.656 | 0.328 | 0.750 | 0.000 | 1.000 | 0.947*** | 0.368*** | -0.343*** |
| PI's type | 4674 | 0.666 | 0.343 | 0.780 | 0.000 | 1.000 | | 0.343*** | -0.396*** |
| Firms' type | 1563 | 0.579 | 0.284 | 0.600 | 0.000 | 1.000 | | | -0.123*** |

| **Aggregate attributes** | Observations | Mean | St dev | Median | Min | Max | Corr. university active res. | Corr. firms' turnover | Corr. firms' employees |
|---|---|---|---|---|---|---|---|---|---|
| University research funds | 5933 | 6.259 | 3.974 | 5.484 | 0.123 | 12.167 | 0.908*** | 0.089*** | 0.111*** |
| University active researchers | 5933 | 14.243 | 7.220 | 12.875 | 0.800 | 29.310 | | 0.118*** | 0.106*** |
| Firms' turnover | 1580 | 10.830 | 25.128 | 1.150 | 0.000 | 178.525 | | | 0.538*** |
| Firms' employees | 1549 | 3.524 | 6.306 | 0.819 | 0.000 | 47.250 | | | |

# Empirical strategy

- We use both Fox's (2008) "maximum score estimation" method
  - estimates the parameters of the production function
  - relies on a "rank order" property: matchings that generate more surplus in a deterministic setup are more likely to be observed.
- Gompers et al's (2012) "probit-counterfactual" approach
  - estimates the likelihood of an agent ending up with her actual partner rather than with an alternative counterfactual partner
  - assumes that the choices that generate more utility are more likely to be realized.

# Fox approach

- For our value function

$$\Pi^c(A,F) = (k + \delta_F + \delta_A)^{\beta} (1 + t\,|x_F - x_A|)^{\alpha} - C$$

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| Measure of ability<br>Academic unit | (1)<br>Impact<br>Academic team | (2)<br>Count<br>Academic team | (3)<br>Impact<br>PI |
|---|---|---|---|
| Parameter t | -1.67<br>( -1.87, -1.29) | -1.77<br>(-2.06, -1.05) | -1.67<br>(-1.88, -0.59) |
| Parameter α | 0.19<br>(0.19, 0.30) | 0.11<br>(0.06, 0.20) | 0.09<br>(0.08, 0.18) |
| Parameter β | 3.56<br>(1.96, 4.55) | 5.66<br>(5.32, 8.70) | 3.64<br>(3.09, 6.64) |
| Total inequalities | 98701 | 98701 | 77586 |
| % inequalities satisfied | 64.3 | 64.4 | 63.0 |

# Fox approach

Negative assortative in terms of the academic's ability-distance pair

- For our value function

$$\Pi^c(A,F) = (k + \delta_F + \delta_A)^{\beta} (1 + t|x_F - x_A|)^{\alpha} - C$$

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# Fox approach

With t < 0, positive assortative in terms of type

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# Fox approach

Positive assortative in terms of ability

- For our value function

$$\Pi^c(A,F) = (k + \delta_F + \delta_A)^{\beta}(1 + t\,|x_F - x_A|)^{\alpha} - C$$

| Measure of ability<br>Academic unit | (1)<br>Impact<br>Academic team | (2)<br>Count<br>Academic team | (3)<br>Impact<br>PI |
|---|---|---|---|
| Parameter t | -1.67<br>( -1.87, -1.29) | -1.77<br>(-2.06, -1.05) | -1.67<br>(-1.88, -0.59) |
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# Fox linear value

$$\Pi^c(A,F) = \gamma_1 \delta_A \delta_F + \gamma_2 |x_A - x_F| + \gamma_3 \delta_A |x_A - x_F| + \gamma_4 \delta_F |x_A - x_F| + \iota_A \iota_F - C$$

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To interpret the parameters in terms of positive or negative assortative

- the matching is positive assortative in terms of ability if $\gamma_1 \geq 0$ (cross-partial derivative)
- the matching is positive assortative in terms of academic ability or firm ability on one side and distance between types on the other if $\gamma_3 \geq 0$ (or $\gamma_4 \geq 0$)
- However, the effect of the horizontal characteristics is again more complex.

# Fox linear value

$$\Pi^c(A,F) = \gamma_1 \delta_A \delta_F + \gamma_2 |x_A - x_F| + \gamma_3 \delta_A |x_A - x_F| + \gamma_4 \delta_F |x_A - x_F| + \iota_A \iota_F - C$$

The effect of the horizontal characteristics depend on the populations.

The sign of $\gamma_2$ provides direct evidence of the effect of the distance but only indirect evidence of the nature of the matching in terms of type.

For example, if $\gamma_2 \leq 0$ the positive assortative matching is always efficient.

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The signof $\gamma_2$ provides direct evidence of the effect of the distance but only indirect evidence of the nature of the matching in terms of type.

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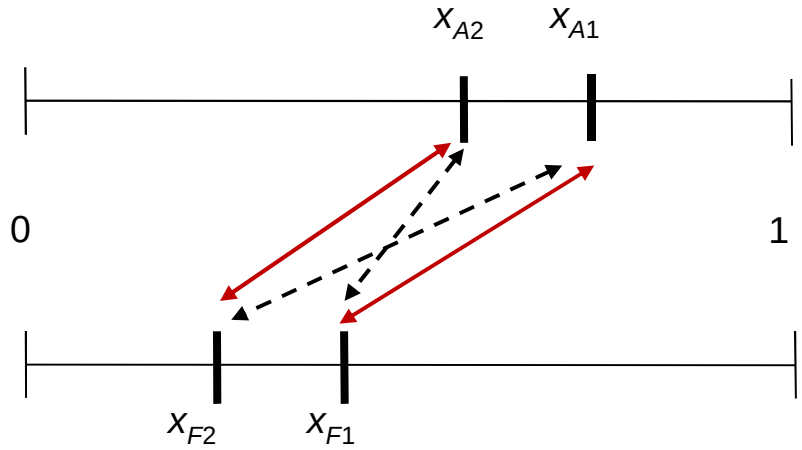



$$x_{A_1} = 0.6,\ x_{A_2} = 0.4$$
$$x_{F_1} = 0.3,\ x_{F_2} = 0.1$$

# Fox linear

| Measure of ability<br>Academic unit | (1)<br>Impact<br>Academic team | (2)<br>Count<br>Academic team | (3)<br>Impact<br>PI |
|---|---|---|---|
| Academics' ability*Firms' ability | 7,33 | 12,57 | 18,64 |
| | (6.49, 10.24) | (7.31, 18.19) | (8.19, 25.84) |
| Type distance | -17,42 | -16,40 | -13,91 |
| | (-21.10, -15.08) | (-24.73, -13.55) | (-19.37, -12.81) |
| Academics' ability*Type distance | -6,47 | -7,52 | -51,89 |
| | (-8.93, -2.45) | (-8.31, 2.78) | (-101.29, -33.71) |
| Firms' ability*Type distance | -4,39 | -5,47 | -2,74 |
| | (-7.93, -4.15) | (-10.78, -3.28) | (-6.03, 0.59) |
| Total inequalities | 98701 | 98701 | 77586 |
| % satisfied | 64,3 | 64,3 | 62,2 |

# Fox linear

| Measure of ability<br>Academic unit | (4)<br>Impact<br>Academic team | (5)<br>Count<br>Academic team | (6)<br>Impact<br>PI | (7)<br>Size<br>University | (8)<br>Performance<br>University |
|---|---|---|---|---|---|
| Academics' ability*Firms' ability | 4,67 | 5,89 | 15,83 | | |
| | (3.56, 7.44) | (2.30, 8.53) | (13.84, 26.94) | | |
| Academics' type*Firms' type | 49,83 | 21,94 | 53,71 | | |
| | (46.75, 83.28) | (-4.37, 30.54) | (50.20, 86.82) | | |
| Unis' agg ability*Firms' agg ability | | | | 0,14 | 0,07 |
| | | | | (0.01, 0.20) | (-0.01, 0.11) |
| Unis' type*Firms' type | | | | 6,38 | 7,4 |
| | | | | (-9.61, 10.42) | (-11.46, 10.01) |
| Total inequalities | 98701 | 98701 | 77586 | 98701 | 98701 |
| % satisfied | 64,2 | 64,0 | 62,1 | 57,0 | 56,8 |

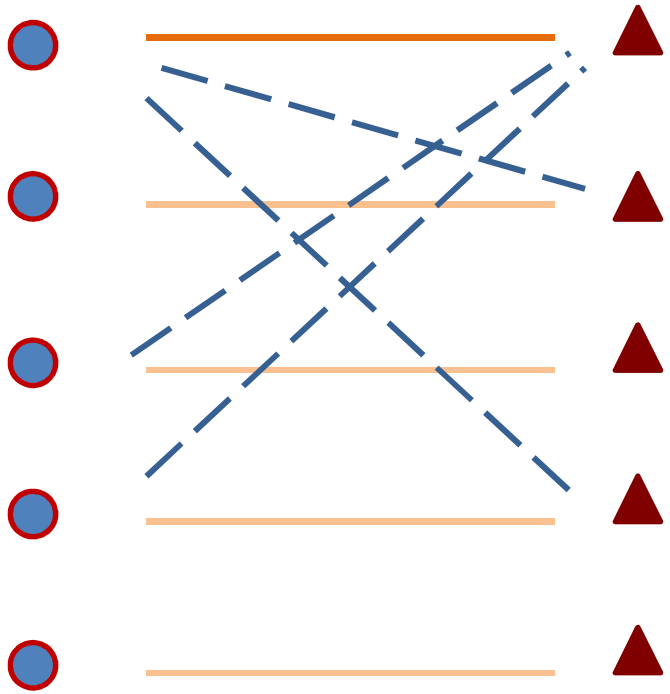
# Probit

- We construct plausible set of counterfactual pairs (control group)
  - available alternatives to the actual partners
  - used to analyze which partnerships form
  - as in Agrawal et al (2008) and Gompers et al (2012)

- To the team of academics of each actual partnership, we associate a random selection of two teams of firms, which
  - are different from the actual team of firms
  - are in the same sector as the actual team of firms
  - participate in an alternative project in the same year

- Assign similarly to each team of firms of each partnership two teams of academics

# Counterfactuals



| | (1) Categories (medians) | (2) Categories (quartiles) | (3) Distances of Quartiles | (4) Distances of Ranks |
|---|---|---|---|---|
| Both above median in impact | 0.014 | | | |
| | [0.010] | | | |
| Both below median in impact | 0.012 | | | |
| | [0.014] | | | |
| Both in 1st quartile in impact | | 0.061*** | | |
| | | [0.017] | | |
| Both in 2nd quartile in impact | | 0.028* | | |
| | | [0.016] | | |
| Both in 3rd quartile in impact | | 0.033** | | |
| | | [0.016] | | |
| Both in 4rd quartile in impact | | 0.038 | | |
| | | [0.076] | | |
| Both above median in type | 0.069*** | 0.069*** | | |
| | [0.012] | [0.012] | | |
| Both below median in type | 0.084*** | 0.077*** | | |
| | [0.012] | [0.012] | | |
| Distance of quartiles in impact (1 unit) | | | -0.040*** | |
| | | | [0.011] | |
| Distance of quartiles in impact (2 units) | | | -0.038*** | |
| | | | [0.013] | |
| Distance of quartiles in impact (3 units) | | | -0.031* | |
| | | | [0.018] | |
| Distance of quartiles in types (1 unit) | | | -0.025** | |
| | | | [0.012] | |
| Distance of quartiles in types (2 units) | | | -0.080*** | |
| | | | [0.013] | |
| Distance of quartiles in types (3 units) | | | -0.112*** | |
| | | | [0.015] | |
| Distance of rank of impact | | | | -0.022** |
| | | | | [0.011] |
| Distance of rank of types | | | | -0.101*** |
| | | | | [0.011] |
| Observations | 7323 | 7323 | 7323 | 7323 |

# Collaborating vs staying independent

- Take the case $\alpha < 1$, $\beta > 1$ and $t < 0$.
- We only have information from non-collaborative academics.
- It depends on the population distributions but we should expect:
  - more able academics are more likely to collaborate, as the net gains are more likely to compensate for the net costs.
  - if the types of the academics are in general more basic than those of the firms then the most applied academics (and the most basic firms) collaborate, whereas the most basic academics (and the most applied firms) remain independent.

# Collaborate or not (for the academics)

| Measure of ability<br>Academic unit | (1)<br>Impact<br>Academic team | (2)<br>Count<br>Academic team | (3)<br>Impact<br>PI | (4)<br>Medians | (5)<br>Ranks | (6)<br>Aggregate |
|---|---|---|---|---|---|---|
| Academics' ability | 0.092** | 0.259*** | 0.074 | | | 0.084** |
| | [0.038] | [0.058] | [0.118] | | | [0.037] |
| Academics' type | 0.234*** | 0.231*** | 0.205*** | | | 0.233*** |
| | [0.022] | [0.021] | [0.024] | | | [0.021] |
| Academics above median in impact | | | | 0.033** | | |
| | | | | [0.015] | | |
| Academics above median in type | | | | 0.141*** | | |
| | | | | [0.015] | | |
| Rank academics' impact | | | | | 0.100*** | |
| | | | | | [0.024] | |
| Rank academics' type | | | | | 0.250*** | |
| | | | | | [0.024] | |
| University performance | | | | | | -0.013 |
| | | | | | | [0.026] |
| University size | | | | | | 0.048 |
| | | | | | | [0.030] |
| Observations | 5513 | 5513 | 4671 | 5513 | 5513 | 5517 |

# Summary

- Theoretical model proposing a functional form that
  - depending on the value of the parameters, allow for the prediction to be a matching positive or negative assortative, or neither of the two, in terms of ability and type of research, and their interactions.
  - clarifies that the sufficient conditions for positive or negative assortative matching in a horizontal characteristic.

- Empirical results that
  - using Fox´s method that suggest that there is positive assortative matching in terms of ability and type while the matching is negative assortative in terms of ability-affinity pairs.
  - is robust when we consider a linear profit function
  - or when we use the probit approach.

- In addition, we show that
  - affinity-based characteristics are relatively more important than ability-based ones.
  - the characteristics at the individual-researcher level are more relevant than those at the institutional level.
  - we show that the most able and the most applied academic researchers prefer to develop collaborative projects, rather than stand-alone ones.

# Back to our leading example

- Do top academics collaborate with top firms, whereas less productive academic researchers collaborate with less productive firms? **YES**
- Do they collaborate because they have similar preferences? **YES**
- Do more prolific individuals get their most preferred partners? **YES**
- Choose each other because of individual or institutional characteristics? **individual**
- Less productive or more applied academics more likely to stay alone? **YES** and **NO**

THANK YOU!