The Return to Venture Capital Firm Formation*

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Abstract

This paper studies empirically the added value of organizations in production. The analysis uses a unique panel data-set which documents partners, investments and investments' outcomes of venture capital firms in California during 1982-2002. First, I present a set of stylized facts which suggest that one important role of venture capital firms is to enable senior venture capital partners to intermediate between investment opportunities and junior partners. Forming firms allows senior partners to exploit private information they have about the quality of investments and the skill of junior partners and to improve the matching between investment quality and partner skill. I quantify the value which is generated by this intermediation by developing and estimating a structural model which endogenizes the number of partners and the skill level of partners within a firm. I find that the value added of Venture Capital firms in California through facilitating the matching between investments and skill increased the industry productivity during 1982-2002 by $1.8 bn.

1 Introduction

Empirical research has made significant progress in quantifying economic tradeoffs involving oligopolistic competition, consumer behavior or regulation in a specific market. In these studies each firm is a single profit maximizing unit, which operates as a monopoly or strategically interacts in the market with other firms, in a static or dynamic framework. However, we know very little empirically about the magnitude of the value added of firms in organizing production by different individuals. The goal

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of this paper is to quantify this added value in industries where human capital is the main input into production. The role of organizations in production is measured by estimating a model in which the optimal number and the optimal composition of workers in the firm are determined by trading-off the benefits and costs of increasing the size of the organization.

I estimate the model using a unique data-set which documents the partners and investments of Venture Capital firms in California in 1982-2002. The Venture Capital industry is an attractive environment to investigate these issues. Venture capitalists' human capital is extremely important when producing venture capital services (creating a deal-flow of investment opportunities, evaluating these potential investments, and monitoring and assisting the portfolio companies). Also, the composition of the VC firms as well their investments are well documented. By combining information from three data sources, I construct a panel data-set which includes information about the VC partners, their investments in portfolio companies, and the outcomes of these invesntments for all Venture Capital firm in California during 1982-2002.

In the first part of the paper, I report a set of stylized facts about the industry. I use the panel data in order to learn about firms' growth (by recruiting junior partners) as well as when firms break-up (when partners spin-out and form new firms). Then, I examine the performance of VC firms and VC partners over time. These facts motivate the different components in the structural model I estimate and explain how the relevant parameters are identified by the data in the structural estimation.

The first empirical fact I document and later incorporate in the structural model is the positive relationship between exogenous changes in aggregate demand for investments (deal-flow) in each field and the number of junior partners recruited by senior partners who specialize in the field. I argue that this fact together with the findings on partners' spin-outs suggest that organizations allow experienced senior partners to leverage their knowledge and skill by working with junior partners.

Senior partners have private information about investment opportunities' quality and juniors' skill and operate as intermediaries matching investments with junior partners. By recruiting junior partners and sharing the deals' revenue with them, the senior partners can credibly commit to refer to junior partners only high quality deals. In addition, firm formation allows senior partners to credibly commit to entrepreneurs that they will refer the deals to junior partners who were carefully selected.

This interpretation is consistent with the benefits from in-firm referrals as suggested by Garicano and Santos (2004).[1] The complementarity between the quality of the entrepreneurs and the quality of the partner who executes the deal is the source of the firm's added value. The organization of partners into firms enables the senior partners to use their private information and thus to improve the matching between deal quality and junior partner's skill.[2]

In order to quantify the added value of the assortative matching between senior and junior partners the model needs to recover from the data the skill of individual partners. I use information about board memberships of venture capitalists in portfolio companies over their career together with the value generated by these investments. This information together with assumptions about persistence and evolution in individuals' skill over time allow me to estimate the skill of each venture capitalist.

These two elements, the exogenous variation over time in deal flow in each field, and the assumption about persistence in individuals' skill over time, identify the model parameters. The structural model which is presented and estimated in the second part of the paper allows me to perform the following counterfactual. In a world without organizations, when senior partners have access to deals which they do not have time to execute by themselves, they cannot truthfully reveal the deals' quality to junior partners. Similarly, entrepreneurs cannot trust senior partners to refer their project only to high skill junior partners. In such a world, the deals which are not executed by the senior partners are randomly assigned to junior partners and there is no sorting between deal quality and junior partners' skill. By comparing the observed output with the counterfactual output, I find that the value added of Venture Capital firms in California through facilitating matching between deals and junior partner skill increased the industry productivity during 1982-2002 by $1.8 bn.

The next section reviews the related literature. Section 3 describes the data and presents the stylized facts. The structural model is presented in section 4. Section 5 reports the results. Finally, section 6 concludes.

[1] A different source of leverage can be vertical specialization as suggested by Garicano (2000). In this case the senior partner assists the junior partners in executing the "more difficult" parts of the tasks. Since the data cannot distinguish how dominant each story, the model estimates should be interpreted as the total benefit from leverage.

[2] Another potential role of the organization (and the ex-ante revenue sharing arrangement) is cooperation between senior partners as suggested by Itoh (1991). There is no variation in the data that affects the benefits from such cooperation, therefore I do not study it in my empirical analysis.

2 Related Literature

The paper contributes to the literature studying partnerships. Empirical works such as Abramitzky (2005), Gaynor and Gertler (1995), and Lang and Gordon (1995) emphasize the role of risk sharing in forming partnerships. I show that in the venture capital industry risk sharing alone cannot explain dynamic patterns in firm reorganization, which is consistent with the presence of benefits from private information sharing (or referrals) as demonstrated by Garicano and Santos (2004). The only prior work to examine empirically the benefits of in-firm referrals is Garicano and Hubbard (2005).

A second literature to which this paper contributes is the literature studying complementarities between workers and the equilibrium assignment of individuals to firms. Lucas (1978), Rosen (1982), Kremer (1993), Kremer and Maskin (1996) examine theoretically the relationship between different production functions and the industry's equilibrium organization and earning patterns of individuals. Garicano and Hubbard (2006) were the first to quantify the returns to organizational form by studying empirically the effect on productivity of problem-solving hierarchies in law firms. I build on their paper and quantify the role of organizations in a different industry in which an important value added of firms is facilitating private information within the firm.

Other related literature, which is surveyed by Lazear and Oyer (2007), studies the matching between firms and workers. These papers investigate empirically in which environments we expect total productivity to increase when mixing low skill and high skill workers, and in which environments firms would be segregated by worker skill. I use individual venture capitalists' performance over their career to show that in the venture capital industry there is positive sorting between high skill senior and junior partners. Then, I exploit variation in the benefits of teamwork to quantify how much value this matching creates.

The literature on firm boundaries is also relevant. This literature studies the role of contract incompleteness in determining the boundaries of the firm. Grossman and Hart (1986) model the tradeoff in the boundaries of firms in the vertical chain. In their model ownership rights are allocated ex-ante in a way which minimizes ex-ante investment distortions. Distortions result from the right of parties to make investments which improve their outside option in future bargaining that do not

increase the total surplus.[3] The tradeoff in this paper also results from contract incompleteness. The benefit from integration is sharing of private information. On the other hand, moral hazard coordination costs and other contracting costs make integration costly.

3 Data

This section explores two aspects of the data. The first goal is to show that dynamic patterns in the organization of venture capital firms are consistent with the hypothesis that the boundaries of venture capital firms reflect variation in the benefits from referrals. I find that benefits from private information sharing together with limitations on contract space explain venture capital firm recruiting decisions as well as separation between partners. The observed organizational changes are not consistent with other potential benefits from revenue sharing agreements.

In addition to explaining venture capital firm boundaries, the contractual approach has implications for firm productivity. The contracts allow senior partners to refer opportunities to juniors whose skill fits the opportunities' value, and therefore improve the matching between opportunities and skill. In order to quantify the contribution of the firm contracts to the industry productivity we need to learn about the distribution of human capital in the industry. The second goal of this section is to investigate the extent to which observed and unobserved variables can explain variation over time and across venture capital firms. The structural model builds on these results when it makes assumption about the human capital process.

3.1 Summary Statistics

A unique feature of the data-set is the combined information, in the firm-period level, about each firm composition of partners together with the firm investments. Table 1 reports summary statistics of the full sample. The sample includes information about 1986 partners in 182 firms during a 20 years period, $1982 - 2002$, which was sampled every 4 years. The mean partner is observed for 1.83 periods, while the mean firm survives in the sample for 2.53 periods.

The panel-data illustrates the dynamics in the organization of the firms. Table 2 reports statistics

[3]See Hart (1995) and Gibbons (2004) for a comprehensive survey of the property right approach and a review of the theories of the firm respectively. Whinston (2001) discusses the related empirical work.

about firm size and partner turnover for a sub sample of 278 firm-period observations for which we observe at least one more period in the data. In each period there are 4.11 partners in the average firm. About 3 of them continue in the firm to the next period, while on average 1.15 leave the firm. The average stay ratio is 0.75. Conditional on survival, firm size increases by 0.82 partners. To compensate for the partners who leave on average 1.97 new partners join a firm each period.

3.2 The Benefits from Referrals and Recruiting of Junior Partners

When the demand for investments in a certain field increases, we expect time constrained venture capitalists with knowledge in this field to share more information with more partners. Since the spot market does not support trade in information, the knowledgable senior partners need to commit ex-ante to refer only high quality opportunities. Such commitment is possible by recruiting junior partners to their firms and including the revenue they generate in the revenue sharing arrangement. According to this argument, when there is an increase in demand, firms expecting a larger increase in the arrival rate of deals recruit more junior partners. I test this prediction below by studying the relationship between firm's expected arrival rate of deals and its recruiting decisions.

The interpretation of demand for venture capital services is different from demand for standard goods. As opposed to firms which sell consumption goods, venture capitalists often initiate the transaction by themselves. Also, they are not paid directly; in return for their service they receive equity in the portfolio company. Thus, we should think about growth in demand as an increase in the amount of business opportunities outside the VC industry for which venture capitalists as financial intermediaries can create value. The term "deal-flow" is used in the VC industry to describe access to investment opportunities, and I will use it as another way to describe demand for VC services.

I construct a variable which represents the expected number of deals as a function of observed variables. I assume that $E[DEALS_{fkt}]$, the expected number of deals in firm f in field k at period t, equals the product of the aggregate growth in deal-flow in field k between periods $t-1$ and t, $GROWTH_{kt}$, and the number of deals in this field made by the firm in the previous period, $DEALS_{fk,t-1}$:

$$E[DEALS_{fkt}] = GROWTH_{kt} * DEALS_{fk,t-1} \tag{1}$$

Equation 1 should be interpreted in the following way. Partners get access to deals through different activities such as participating in board meetings, working with portfolio companies, with lawyers and investment bankers. Partners who executed more deals in the past have access to more individuals and firms with whom VC do business. Thus, when there is an increase in demand this access is leveraged in proportion to the aggregate growth in deal-flow. The interaction between amount of previous deals and demand growth reflects this leverage. When a partner has executed more deals in the previous period, or when there is growth in her field, she expects to have more investment opportunities in the current period. Note however that deal flow rate is different from the quality of deals. Partners in a top tier firm who execute high quality deals can have access in the model to larger or smaller quantity of deals compared to partners in a bottom tier firm.

The ratio between the aggregate number of deals in each field in every two consecutive periods is presented in Figure 1. While there is some co-linearity, especially between the fields *Communications and Media* and *Computer Related* there is also significant variation over time. Table 3 reports the field growth rate summary statistics. The number of deals in field k which the partners in firm f made during the previous 4 years are reported in Table 4.

I study the relationship between the expected deal-flow to the firm and the firm recruiting decisions by estimating the following regression with the constraints $\beta_k \equiv \beta$, $\gamma_k \equiv \gamma$ and $\delta_k \equiv \delta$:

$$Juniors_{ft} = \alpha + \sum_k \beta_k E[DEALS_{fkt}] + \sum_k \gamma_k GROWTH_{kt} + \sum_k \delta_k DEALS_{fk,t-1} + \phi_{ft} \qquad (2)$$

The variable $Juniors_{ft}$ is the number of partners that joined firm f in period t.[4] Summary statistics of the independent variables in the constrained equation are reported in Table 4. Equation 2 was estimated with a control for the number of partners who left the firm. The results are reported in Table 5. We find a positive and significant relationship between the deal-flow to senior partners and the number of junior partners which are recruited by the firm. According to specification $Model1$ in the first column, a one standard deviation increase in expected deal flow increases the number of new partners by $0.067 * 5.52 = 0.37$.[5] The other columns in Table 5, show the effect of seniors' deal-flow

[4]There are a few cases in which partners with experience as venture capitalists join established firms. As a robustness check the equation was also estimated with the number of unexperienced partners in the firm as the dependent variable.

[5]Since deal-flow is a product of two variables, we should think about the counterfactual as the effect of growth across firms with different experience levels.

on the recruiting of juniors is robust to using the stay ratio, as well as excluding leaving partners or year dummies.

This result supports the hypothesis that the boundaries of venture capital firms reflect the benefits from referrals. It is robust to different types of firm contract, as long as it includes a component of ex-ante revenue sharing. The competing hypothesis, risk diversification as the source of benefits from revenue sharing, cannot explain the regression results of Equation 2. When deal flow rate grows, the average number of deals per partner increases. Thus, partners are more diversified and we do not expect firm size to increase.

3.3 Contract Costs, Contract Limitations, and Firm Break-up

Separation between partners who used to work in the same firm and opted to work in different firms suggest that there are limitations on the set of possible contracts or that there are costs to contracting which sometimes dominant the benefits.

Table 6 reports the results from estimating a Probit regression in which the the dependent variable is a dummy which equals 1 if a partner leaves her firm and starts a new firm. The results are consistent with contracting costs which increase with the number of senior partners. An increase of one standard deviation in the number of partners increases the probability of spinout in 4.2% at the mean of the independent variables (the probability in the mean of the independent variables is 8%). An increase of one standard deviation in the mean experience of the peers increases the probability of spin-put by 3% at the mean of the independent variables.

The break-ups may reflect constraints on the technology of production or on contract space which induces senior partners with human capital which is significantly different from their peers' human capital to leave.

3.4 Venture Capital Firm Performance

In order to quantify the contribution of in-firm referrals to industry productivity we need to estimate the distribution of human capital across partners in the industry. Other scholars have investigated how observed and unobserved venture capital firm characteristics explain variation in firms performance. Kaplan and Schoar (2005) show that the returns of venture capital firms are persistent across the

sequence of funds they manage. Sorensen (2006) shows that the number of previous deals of a venture capital firm has a significant effect on the likelihood of deal success. Gompers et al (2006) find that funding by an experienced VC firm increases the probability of success, but only for entrepreneurs without a successful track record. Hochberg et al (2007) find that funds of better networked VC firms, measured by the firm's position in the network of relationships established through syndicated investments, perform better.

Table 7 presents summery statistics about deals performance. The mean probability of IPO is 0.19 and it varies dramatically across industry groups. The experience variables present statistics about the years of experience as venture capitalists of the partners in each firm. The distribution of the *Fund sequence* and *Firm prev. rounds* variables imply that there is significant variation across firms in terms of previous investments.

In order to study how observed variation in partners years of experience affect deals performance I estimate a Probit regression in which the dependent variable is IPO dummy of the portfolio company. I add average years of experience as an explanatory variables in addition to year and field dummies. The regression results are reported in Table 8. I find that firms with more experienced partners perform better. The coefficients of *Exp mean* and *Exp mean squared* are significant and suggest that there is a concave relationship between average number of partners' years of experience and firm performance. This result is consistent with accumulation of human capital or with discovery of innate ability.

Next, I examine whether controlling for observed experience there is persistency in the performance of venture capital firms. The results in column *Model* 5 in Table 8 are consistent with the findings of Kaplan and Schoar (2005). We learn the last period IPO rate of a firm has positive and significant effect on IPO probability controlling for company field and period effect. In order to further examine the persistency I estimate two specifications of a fixed effect regression:

$$Profit_{ft} = \alpha + D_{fkt}\beta_k + \nu_f + \varepsilon_{ft} \tag{3}$$

where

$$\varepsilon_{ft} = \rho\varepsilon_{f,t-1} + \eta_{ft} \tag{4}$$

I calculate a rough estimate for firms period profit by multiplying the amount they invest in each period by ratio of companies which had an exit times. According to the results reported in Table 9 in the standard fixed effect model ($\rho = 0$) 50% of the variation in firms profit is explained by firm fixed effect. The second specification is an autoregressive process of order one (AR(1)). This specification estimates $\rho = 0.30$.

The persistence in firm performance suggests that while a portion of the variation in performance is explained by observed variation in experience there is also a significant portion which is not observed in the data. This result is consistent with the fact that firms belong to different tiers according to the quality of partners. The portion of partners quality which is not observed by the econometrician may reflect information which is observed to individuals in the industry: the track record of the firm partners or their background before becoming venture capitalists. Similarly there is a portion in the human capital of juniors which is observed by the firms but not by the econometrician. For example the previous positions of the individual as an entrepreneur. When junior partners and firms choose each other, their decisions may be based on these factors.

Since measuring the contribution of firms to productivity requires estimating the distribution of partners human capital, the structural model which is presented in section 4 controls for sorting based on unobserved quality between senior and junior partners. By modeling explicitly the equilibrium in the market for junior partners we can recover from firms productivity the distribution of observed and unobserved components of human capital. In addition, referrals between partners with different skill imply that the production function is nonlinear. The structural model enables us to have nonlinearities in the production function.

4 Model

The model seeks to measure the contribution of firms to production of venture capital services. The ex-ante contract allows senior partners to leverage their human capital and share private information with junior partners who have the right skills. Studying empirically the role of firms in facilitating private information is challenging. By its nature, private information is not observed by agents in the industry and obviously not by the econometrician. Moreover, venture capitalists have superior

information about the quality of their peers which is also not observed.

Still, I show that by exploiting observed changes over time in deal flow rate together with assumptions about the equilibrium in the labor market for partners and about the production technology, we can quantify how contracts determine firm boundaries and firm productivity. I present a model which includes all these features and quantifies the contribution of contracts to productivity.

4.1 Model Time-line

I model venture capital firms recruiting decisions and production during the years 1982-2002. The model includes six periods, each corresponds to 4 years in the sample. In each period t the following events take place:

1. At the beginning of the period all firms form expectations regarding the expected deal flow rate in each field during the period. Based on the expected quantity of deals to which senior partners in the firm will have access they decide how many juniors to recruit. The aggregate demand for juniors in the industry is N_t.

2. There are N_t juniors who seek to join established firms. The distribution of juniors skill does not vary over time (a partial equilibrium model).

3. Firms choose juniors and juniors choose firms. The decisions are based also on components of seniors and juniors human capital which are not observed by the econometrician. The matching between juniors and firms is stable.

4. Each firm produces venture capital services where senior partners can either execute deals by themselves or refer them to juniors in their firm.

5. The firm profits are realized.

4.2 "Production" of a Deal

There are three inputs to production: the deal, characterized by its quality q, the productivity, k, of the partner who executes it, and the partner's time. Deal quantity is measured by the amount of venture capitalist time they require. Each partner has one unit of time, but may attract more deals

than she can execute. The profit from executing a deal, which requires t units of time, with quality q, by a partner with skill k is: $\pi = tqk$.

4.3 Partners Human Capital

The human capital of partner i, $Z_i \in R$, determines the quality of deals and opportunities which the partner attracts as well as her post investment productivity. It depends on the quality of individuals or firms outside the venture capital industry who want to do business with the partner such as entrepreneurs, limited partners and lawyers. It also reflects the quality of individuals that the partner can recruit for business which is related to the portfolio companies: potential customers, potential employees to key positions, firms that acquire start-ups, investment banks, etc. The vector Z includes the Z_i values of all the partners in all firms in all the periods.

Assumption 4.1. *Denote the quality of deals which are attracted to a partner with human capital Z_i by $q(Z_i) \in R$. Let $k(Z_i) \in R$ be the partner's post investment productivity. I assume that:*

$$q(Z_i) = k(Z_i) = exp(Z_i). \tag{5}$$

4.4 Preferences in the Market for Juniors

Let F be the set of firms in the market and J the set of juniors. Each firm f is a set of senior partners $i \in f$. The benefit of firm $f \in F$ from hiring junior partners depends on the revenue from deals which are referred to the juniors by the seniors. Assume that junior partners do not bring deals to the firm and each has one unit of working time available. Also assume that the referred deals are allocated randomly across juniors. This assumption about the technology is responsible for the complementarity between senior partner human capital. Define $\psi(f)$ to be the referrals function, the average quality of the deals which are referred to juniors in firm f :

$$\psi(f) = \frac{\sum_{i \in f} q(Z_i)}{|f|} \tag{6}$$

Firms' preferences over juniors are based on their skill, k. A firm which hires a set $B \subseteq J$ of juniors assigns them to tasks in the following way. First, the firm chooses the subset $B' \subseteq B$ which includes the best H_f juniors. The profit generated by junior $j \in B'$ is $\psi(f)k(Z_j)$.

I assume that the firm retains a portion λ of the increase in profits and the the juniors' share is $1-\lambda$. The increase in firm f profit from hiring set of junior partners B is:

$$\pi_{f,B} = \lambda\psi(f)\Sigma_{j\in B'}k(Z_j) \tag{7}$$

Each one of the H_f juniors $j \in B'$ earns a wage:

$$V_{j,f} = (1-\lambda)\psi(f)k(Z_j) \tag{8}$$

4.5 Matching in the Labor Market for Juniors

Let q_{ft} be the quality of deals which senior partners in firm f bring to their firm in period t. Denote by S_{ft} the set of senior partners in firm f in period t. Assume that the deals' quality, q_{ft}, equals the mean of the seniors' human capital:

$$q_{ft} = \frac{1}{|S_{ft}|}\sum_{s\in S_{ft}} Z_{st}$$

where Z_{st} is the human capital of senior s in period t. Also, define $D(\beta, E[DEALS_{ft}])$ to be the expected amount of time which is required to execute deals which seniors cannot execute due to time constraints. The definition of $E[DEALS_{ft}]$, the expected deal-flow to firm f in period t, was presented in subsection 3.2. Finally, the cost of increasing the organization size, $C(\gamma, |S_{ft}| + |B|)$, reflects team work and contracting costs such as bargaining costs, moral hazard, coordination, etc.

The valuation equation of recruiting a subset of juniors B is

$$V_{ftB} = \lambda * min(|B|, D(\beta, E[DEALS_{ft}])) * q_{ft} * \frac{1}{|B|}\sum_{j\in B} Z_j - C(\gamma, |S_{ft}| + |B|) \tag{9}$$

where we assume that the firm retains a portion λ of the juniors' output (and the juniors' share is $1-\lambda$).

4.6 Outcome Equation

Venture capital firms typically invest each period in number of portfolio companies and in each company in multiple rounds of investment. A deal d is defined as one or more investments of a certain VC firm in a certain portfolio company. Deals are classified into the following groups:

- Deals for which the firm is the lead investor and typically has a representative in the board

- Deals for which the firm is not a lead investor

The outcome of deal d is:

$$Y_{ftd} = q_{ft} * k(Z) + \varphi_{ftd} \tag{10}$$

where Z is the average human capital of partners in the firm which is the lead investor.

4.7 Partners Human Capital Process

The human capital of partner i at period t is given by the following equation:

$$Z_{it} = \theta E_{it} + \varepsilon_i \tag{11}$$

where E_{it} is the number of year of experience as venture capitalist and ε_i is individual fixed effect. More experienced partners are more skilled since first there is a selection process in which partners learn about their ability and second partners accumulate industry specific human capital over time.

The preferences which π and V represent have these attributes:

1. Junior partners have preferences over individual firms independent on who are the other junior partners which are hired.

2. Firms have preferences over subsets of juniors which satisfy the *substitutability* property. It means that if a firm prefers a subset of workers S' when it faces a set $S \supseteq S'$ which includes a junior w, then it will continue to want to hire w when it needs to choose from any subset of S which includes w. It is consistent with the idea that a firm continues to want to employ a certain junior even if some of the other juniors become unavailable.

4.8 Equilibrium in the Market for Juniors

I derive the conditions for equilibrium in the market for juniors using the following definitions and proposition from Roth and Sotomayor (1990).

Definition 1. *A matching μ is blocked by junior j if she prefers to be self employed than to work in $\mu(j)$.*

Definition 2. *A matching μ is blocked by firm f if the firm prefers to hire only a subset $S \subset \mu(f)$ of the juniors it hires at μ.*

Definition 3. *A matching μ is blocked by a junior-firm pair (j, f) if j and f are not matched at μ but would both prefer if f hired j.*

Definition 4. *A matching μ is* stable *if it is not blocked by any individual agent (a junior or a firm) or any junior-firm pair.*

Definition 5. *A matching μ is* group stable *if there is no other matching μ' and a coalition A which might consist of multiple firms and/or juniors such that:*

1. *Every junior in A who is matched by by μ' is matched to a firm in A.*
2. *Every junior in A prefers her new match to her old one.*
3. *Every firm in A is matched at μ' to new juniors only from A, although it may continue to be matched with some of its "old" juniors.*
4. *Every firm in A prefers its new set of juniors to its old one.*

Proposition 4.1. *When firms have substitutable preferences the set of stable matchings equals the set of group stable matchings.*

Since the preferences of firms over juniors satisfy the substitutability requirement, according to Proposition 4.1 the set of *group stable* matchings and the set of *stable* matching are the same. Therefore a matching μ is stable if and only if the following three conditions hold:

1. It is not blocked by a junior j: $\forall\ j \in J\ \ V_{j,0} < V_{j,\mu(j)}$
2. It is not blocked by firm f: $\forall\ f \in F, S \subset \mu(f)\ \ \pi_{f,S} < \pi_{f,\mu(f)}$
3. It is not blocked by a junior-firm pair (j, f): $\forall\ j \in J$ *and* $\forall\ f \in F\ \pi_{f,\mu(f)\cup\{j\}} \leq \pi_{f,\mu(f)}$ or $V_{j,f} \leq V_{j,\mu(j)}$

For the preferences in equations 9 and 8 the set of sufficient conditions for stable matching can be reduced further and described in terms of bounds on partners' human capital. Define for junior partner j, the set $\overline{j}$ which includes all the junior partners in all firms f' for which the value of the referrals function $\psi(f')$, defined in equation 6, is larger than $\psi(\mu(j))$. In a stable matching the human capital of junior partner j, Z_j, cannot be larger than:

$$\overline{Z}_j = min_{k \in \overline{j}} Z_k \tag{12}$$

Otherwise the matching is blocked by a pair (j, f'), since according to the firm preferences in equation 9 firm f' prefers $\mu(f') \cup j$ over $\mu(f')$. Similarly the juniors preferences in equation 8 imply that j prefers firm f' which has better referrals over $\mu(j)$.

Using a similar argument we can construct a lower bound on the human capital of junior j. Define the set $\underline{j}$ to be all the junior partners in firms f' for which the value of the referrals function $\psi(f')$ is smaller than $\psi(\mu(j))$. The human capital of junior partner j, Z_j, cannot be smaller than:

$$\underline{Z}_j = max_{k \in \underline{j}} Z_k \tag{13}$$

Otherwise the matching is blocked by a pair $(j', \mu(j))$.

Equivalently, we can define the equilibrium restrictions on the possible values of human capital of senior partners. Consider the average human capital of senior partners in firm f, Z_f, and define $\overline{f}$ to be the set of all firms which recruited more skilled juniors than the juniors which joined firm f. Let $\psi_{min}(\overline{f})$ be the minimum value of the referral function for firms in the set $\overline{s}$. In a stable matching the human capital of senior s, Z_s, satisfies:

$$Z_f < \psi_{min}(\overline{f}) \tag{14}$$

Otherwise, there is a pair (j, f) which blocks the match, where j is more skilled than the juniors in f, but was originally recruited by firm f'.

Following similar arguments a lower bound on Z_f is:

$$Z_f > \psi_{max}(\underline{f}) \tag{15}$$

where $\underline{f}$ and ψ_{max} are defined analogically to the definitions of $\overline{s}$ and ψ_{min}.

Definition 6. *Define Γ_μ as the set human capital vectors $Z \in R^N$ which are consistent with matching μ. These are all the vectors which satisfy equations 13 and 12 or equivalently satisfy equations 14 and 15.*

The production technology creates complementarities between the skill of senior partners and the skill of juniors in the same firm. Due to these complementarities there is Positive Assortative Matching (PAM) between juniors and seniors.[6] This implies also that there is a unique equilibrium in the market for juniors in which the best juniors are matched with the best firms. Any matching which does not perfectly sort juniors and firms based on quality must require restrictions on Z which are not consistent with Γ_μ.

4.9 Firm Production Technology

The senior partners in firm f attract to the firm deals with average quality $\psi(f)$. The deals are assigned to other senior and junior partners in the firm according their field of specialization and time availability. I assume that the scope of specialization and time constraints are the dominant factors when assigning deals inside the firm and therefore the allocation of deals to partners in the firm is random conditional on deal quality and partners skill. Under these assumptions about the production technology firm profit is:

$$Y_{ft} = N_{Sft} * \psi(f) * exp(Z_{ft}) + \psi(f) * \sum_{j \in J_{ft}} exp(Z_{jt}) \tag{16}$$

where J_{ft} is set of junior partners, NS_{ft} is the number of seniors, and Z_{ft} is the skill of the seniors.

4.10 Econometric Model

I assume that all the senior partners in firm f at period t have the same skill Z_{ft}, which is given by the following equation:

$$Z_{ft} = \theta_{SEN} E_{ft} + \varepsilon_{ft} \tag{17}$$

[6]The theory of partnerships shows also that fixed sharing rule or even some element of redistribution in the profit sharing also create PAM. Farrell and Scotchmer (1988) present a model in which an equal sharing rule induces PAM and also determines firms' size. Levin and Tadelis (2005) show that when clients have disadvantage in assessing the quality of employees, profit sharing allows firms to commit about the quality of the workers.

Here E_{ft} is observed average experience of senior partners in firm f, and θ_{SEN} is a parameter to be estimated. The error term, ε_{ft}, is a component of human capital which is unobserved by the econometrician but is observed by all partners in the industry. The unobserved component, ε_{ft}, evolves over time as an autoregressive process of order one (AR(1)):

$$\varepsilon_{ft} = \rho\varepsilon_{ft-1} + \eta_{ft} \tag{18}$$

where η_{ft} are i.i.d. and distributed $N(0, \sigma_\eta^2)$.

Each period, junior partners join the industry. The human capital of each junior is drawn from the distritbuted $N\left(\theta_{JUN}, (\sigma_\eta^2/(1-\rho^2))^2\right)$. The equilibrium in the market for juniors generates constraints on the quality of juniors which join firm f (see Equations 13 and 12). The average quality of junior partners in firm f at period t is J_{ft}.

I assume that $\psi(f) = exp(Z_{ft})$. The profit function we get:

$$Y_{ft} = N_{Sft} * \psi(f) * exp(Z_{ft}) + \psi(f) * \sum_{j \in J_{ft}} exp(Z_{jt}) + \varphi_{ft} \tag{19}$$

where, Y_{ft} is the firm profit and again N_{fJ} and N_{fS} are the number of junior and senior partners in firm f respectively. I allow a firm-period specific shock to profits φ_{ft}, where $\varphi \sim N(0, \sigma_\varphi^2)$.

4.11 Likelihood

The likelihood function is the probability of getting Z which are consistent with Γ_μ (defined in Definition 6), and observing firm profits Y conditional on parameters and observed partners experience:

$$L(\mu, Y|\sigma_\eta, \rho, \theta, \sigma_J, \sigma_\varphi, E) = \int_{Z \in \Gamma_\mu} P(Y, Z|\sigma_\eta, \rho, \theta, \sigma_J, \sigma_\varphi, E) dG(\varphi) \tag{20}$$

5 Structural Model Estimation

The constraints which are derived from the equilibrium in the juniors market create dependency between the human capital of juniors in firm f and the human capital of partners in other firms in the industry. Since there is a portion of human capital which is not observed by the econometrician this dependency requires integrating over the human capital of all firms in the same period. In addition, there is dependency over periods in the human capital of partners in the same firm due to

the autoregressive process. These constraints imply that all the unobserved components of human capital (for all firms in all periods) are jointly distritbuted. ML estimator requires for each trial of parameter values to calculate the equilibrium for every realization of the error terms. This process will be very slow since most of the draws violate the matching equilibrium conditions.

Bayesian estimation together with Gibbs Sampler and data augmentation enables us to generate draws from this joint distribution, by treating the unobserved components of human capital as parameters and by drawing each one conditional on all the other unobservables (Sorensen (2006) and Park (2006)). Gibbs sampling is a specific method for generating a Markov Chain Monte Carlo (MCMC). This iterative procedure converges to the posterior distribution. We can think about the parameters which represent the unobserved human capital as an unobserved firm state variable. I use the estimated distribution of this state variable of each firm when performing counterfactuals.

The estimation of the structural model can be described in the following way. We are looking for human capital parameters $\sigma_\eta, \rho, \theta, \sigma_J$ which explain the observed variation in firm profits across firms and over time, given the observed affiliation of partners with firms in each period. The estimation uses the assumptions we make about the equilibrium in the market for juniors and about the referrals technology in the firm.

5.1 Conditional Distribution of Parameters

The model parameters are drawn from the conditional distribution $P(param|Data, otherparameters)$ using Metropolis Hastings. The latent human capital of senior partners in firm f at period t, Z_{ft}, are drawn from the conditional distribution:

$$P(Z_{ft}|Z_{f,t-1}, Z_{ft+1}, Y_{ft}, \sum_{j \in J_{ft}} exp(Z_{jt})) \tag{21}$$

I deal with the nonlinearity in the production function by exploiting the fact that conditional on Z_{ft}, the variables $Z_{f,t-1}$, Z_{ft+1}, and Y_{ft} are independent and normally distritbuted and therefore we can use Bayes Rule to calculate Equation 21.

The conditional density of junior partners is truncated normal by $\overline{Z_{it}}$ and $\underline{Z_{it}}$ which are defined in equations 12 and 13.

5.2 Identification and Counterfactuals

The identification is based on the assumption that the recruiting decisions are exogenous and result from aggregate changes over time in deal-flow rate in different fields. The assumption we make about

- The equilibrium in the market for junior partners.
- How deals are referred inside the firm (production technology).
- The stochastic process of human capital evolution over time.

allow us to estimate the human capital distribution parameters from the observed firm profits.

In the counterfactuals the human capital estimates allow to measure the contribution of revenue sharing arrangements to industry productivity. The firm contract induce a better match between opportunities and skill which improves productivity compared to the spot market. The predicted aggregate production without firm is calculated by computing first the production of seniors. Then for each period all the deals which are referred to juniors are pooled together and assigned randomly to the group of juniors who joined the industry at that period.

5.3 Results

I estimate the model by setting a flat prior for the parameters and normal prior to the unobserved human capital components which are treated as parameters. The structural model estimates are reported in Table 10 and the prediction of industry productivity according to the model is reported in Table 11. Firm profits are calculated using the mean of the estimated augmented human capital variables of each firm in each period. We learn that the model predicts relatively well industry productivity in the years before 2002. In the year 2002 the model significantly under the aggregate output. It may be because the specification which is estimated is two restrictive. I expect that a more flexible specification of seniors and juniors human capital will provide better explanatory power.

Next I perform the counterfactual of comparing the output of partners with and without firms. Figure 5 presents the distribution of deals quality, partners skill, and deals outcomes in 1994. Figure 6 show what would be the productivity of juniors in a world without firms when referred deals are randomly assigned to juniors.

Table 12 summarizes the counterfactual of juniors productivity with and without firms. We find that firms improved productivity of junior venture capital partners in California during the sample period by $1.8 bn.

6 Conclusions

This paper studies the value added of forming Venture Capital firms to the productivity of venture capitalists, by facilitating private information sharing in the firm between senior and junior venture capitalists. Using a unique data-set, I estimate a structural model which studies the benefits and the costs of increasing the size of Venture Capital firms. According to the model estimates forming VC firms improved productivity of junior venture capital partners in California during the sample period by $1.8 bn.

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A Data-set Construction

The commercial database *VentureXpert* is the source of information about funds raised, rounds of investments, and portfolio company exit events. It was matched with the directory *Pratt's Guide to Venture Capital Sources* which documents all the venture capital firms in the United States and has been published since 1970.[7] For each firm, the directory typically reports firm name, firm contact information, names of individual venture capitalists, their title (for example managing partner, partner, principle) and firm's preferences in terms of stage of investment, geography and industry. I collected information for every firm in California from the directory every four years, from 1982 to 2002. I have constructed a data-set that includes, for each year, the firms, the names of the venture capitalists as well as the individual venture capitalists' titles.

In order to examine the comprehensiveness of *Pratt's Guide* directory, I have cross checked the match partner-firm-year for a sub sample by comparing it with the information from prospectuses filed by portfolio companies. In these prospectuses, the companies report for each venture capitalist in the board, the VC firm she works as well as short biography that often includes previous positions in VC firms. I also cross referenced a sub sample with the Secretary of State Filing. I compared partners' names for firms which were registered as limited partnership, and also verified for the years in which firms were active and raised new funds. A similar comparison was made with VentureXpert data about years of fund raising. In general, I did not find any major discrepancy between *Pratt's Guide* and the other sources. The most common inconsistency is firms sometimes appear in the directory

[7] There are four editions between 1970 and 1977, and since 1981 the directory has been published every year.

only few years after their founding.

I create the sample I use in the analysis following two criteria. There are two types of venture capitalists: associates and partners.[8] Associates typically do not have extensive working experience and they are many times Business School graduates in the beginning of their career. Due to their short career their network of contacts and the access they have to new opportunities inside and outside the VC industry is relatively small. Associates' share in the firm profits is usually negligible, less than 1%. Partners, on the other hand, typically have a significant part in the profits, more than 1%. They have longer working experience; either as associates for 3-5 years or as entrepreneurs or senior managers outside the VC industry. I use only partners in my analysis.

The second restrictions on the sample is regarding the definition of firms as VC firms. The two sources, *VentureXpert* and *Pratt's Guide*, include information also about banks subsidiaries and corporations VC funds which make VC investments. Since such firms may differ from independent firms in terms of inflow of opportunities, and I also suspect that *Pratt's Guide* may not report accurately all the venture capitalists in their stuff, I exclude them from the sample. I only include firms which are defined as "Private equity firm investing its own capital". I also exclude firms which invested in less than 20 companies during the sample period.

[8]VC firms often make a more refined separation within these two layers, however the distinction between partners and associates is, in general, consistent across all firms.

B Tables and Figures

Table 1: Summary Statistics of Full Sample

Variable	Unit of obs.	Observations	Mean	Std. Dev.	Min	Max
Years of experience	Partner-Period	1986	3.86	5.12	0	20
Periods in Sample	Partner	1088	1.83	1.28	1	6
Num. of Partners	Firm-Period	460	4.32	2.96	1	18
Mean Years of exp.	Firm-Period	460	3.94	3.85	0	20
Funds Raised	Firm-Period	460	1.38	1.28	0	6
Rounds of Investment	Firm-Period	460	53.33	61.67	0	375
Deals	Firm-Period	460	20.43	20.64	0	135
Capital Raised ($M)	Firm-Period	441	159.28	356.82	0	2637.7
Periods in Sample	Firm	182	2.53	1.58	1	6

The directories were samples every 4 years between 1982 to 2002. There are 6 periods of 4 years. Variables in the period level report aggregate value for the 4 years period. A deal is defined as one or more rounds of investments in the same portfolio company.

Table 2: Summary Statistics Firm Dynamics

Variable	Observations	Mean	Std. Dev.	Min	Max
Number of Partners	278	4.11	2.61	1	18
Staying Partners	278	2.95	1.93	0	11
Leaving Partners	278	1.15	1.64	0	14
Change Num Partners	278	0.82	2.33	-8	12
nextpd new partners	278	1.97	2.43	0	17
Stay Ratio	278	0.75	0.26	0	1

Unit of observation is firm-period. The sub sample includes only firms that survive to the next period (2002 obs. are excluded).

Table 3: Summary Statistics Demand

Variable	Observations	Mean	Std. Dev.	Min	Max
GROWTH (total)	5	523.4	655.43	-141	1289
GROWTH (Communications and Media)	5	155.8	191.77	-19	422
GROWTH (Computer Related)	5	289.8	419.81	-171	818
GROWTH (Semiconductors/Other Elect)	5	42.4	103.87	-66	176
GROWTH (Biotechnology)	5	12.2	30.3	-22	60
GROWTH (Medical/Health/Life Science)	5	23.2	97.69	-130	119

Unit of observation is a 4 years period.

Table 4: Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
DEALS (total)	276	19.04	18.15864	0	94
DEALS (Communications and Media)	276	2.92	3.973662	0	27
DEALS (Computer Related)	276	8.09	8.823504	0	49
DEALS (Semiconductors/Other Elect)	276	1.86	2.401128	0	11
DEALS (Biotechnology)	276	1.36	2.116402	0	13
DEALS (Medical/Health/Life Science)	276	2.74	3.934564	0	20
DEALS	276	12.91	13.57	0	63
GROWTH (1000 deals)	276	0.54	0.62	-0.14	1.29
E[DEALS] (Deals*GROWTH 1000)	276	2.31	5.52	-4.71	36.66
spin-out	278	0.094	0.29	0	1
peer-mean-exp	278	3.57	3.32	0	16

Unit of observation is firm-period. Sub sample includes only firms that survive to the next period (2002 obs. are excluded).

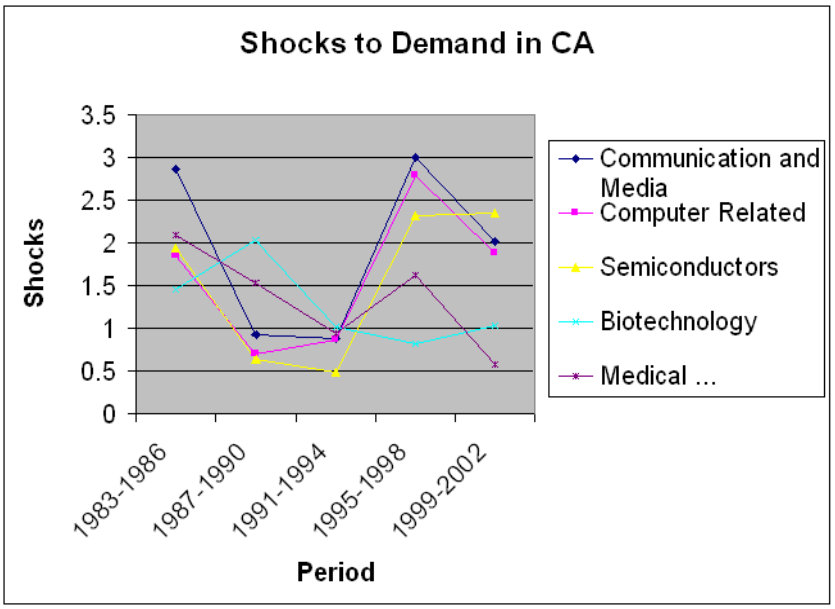

Figure 1: Aggregate Number of Deals

Table 5: OLS Regressions: Recruiting of Junior Partners

	Model 1 b/se	Model 2 b/se	Model 3 b/se	Model 4 b/se
E[DEALS]	.067*	.118***		.078**
	(.03)	(.04)		(.03)
E[DEALS] (stay ratio adj.)			.058**	
			(.03)	
GROWTH	–.052	.272	–.361	.564**
	(.59)	(.64)	(.61)	(.25)
$DEALS_{t-1}$	.033***	.017		.035***
	(.01)	(.01)		(.01)
$DEALS_{t-1}$ (stay ratio adj.)			.022**	
			(.01)	
Firm Leaving Partners	.529***		.419***	.542***
	(.07)		(.08)	(.08)
1986 Dummy	–1.235*	–.628	–1.418*	
	(.73)	(.79)	(.73)	
1990 Dummy	–1.593**	–1.243	–1.811**	
	(.73)	(.80)	(.74)	
1994 Dummy	–1.381***	–1.495***	–1.252***	
	(.32)	(.35)	(.33)	
1998 Dummy	.000	.000	.000	
	(.00)	(.00)	(.00)	
2002 Dummy	.000	.000	.000	
	(.00)	(.00)	(.00)	
Constant	1.618**	1.960***	1.976***	.322
	(.64)	(.70)	(.65)	(.25)
R^2	.374	.253	.367	.324
No. of cases	276	276	276	276

Unit of observation is firm-period.

Table 6: Spin-outs

	Model 1 dy/dx /se
num partners	0.016
	(.0053)
peers mean years exp	0.009
	(.0046)
$PseudoR^2$	.0765
N	276

Predicted value on mean value of indep. vars. y=0.08

Table 7: Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
IPO	5415	0.19	0.4	0	1
Fund size	4331	160	239	0.1	1956
Communications and Media	5415	0.18	0.38	0	1
Computer Related	5415	0.44	0.5	0	1
Semiconductors/Other Elect	5415	0.11	0.31	0	1
Biotechnology	5415	0.057	0.23	0	1
Medical/Health/Life Science	5415	0.13	0.33	0	1
Non-High-Technology	5415	0.099	0.3	0	1
Exp mean	5415	3.9	3.2	0	16
Exp median	5415	3.3	3.8	0	16
Exp min	5415	0.6	2.1	0	16
Exp max	5415	8.6	6.4	0	20
Firm prev. rounds	5415	245	283	1	1445
Fund sequence	4108	3.9	3.2	1	19
Firm founded	5415	1982	9.6	1961	2000

Unit of observation is a first round firm-portfolio company investment. Exp variables describe statistics about the partners' years of experience as venture capitalists.

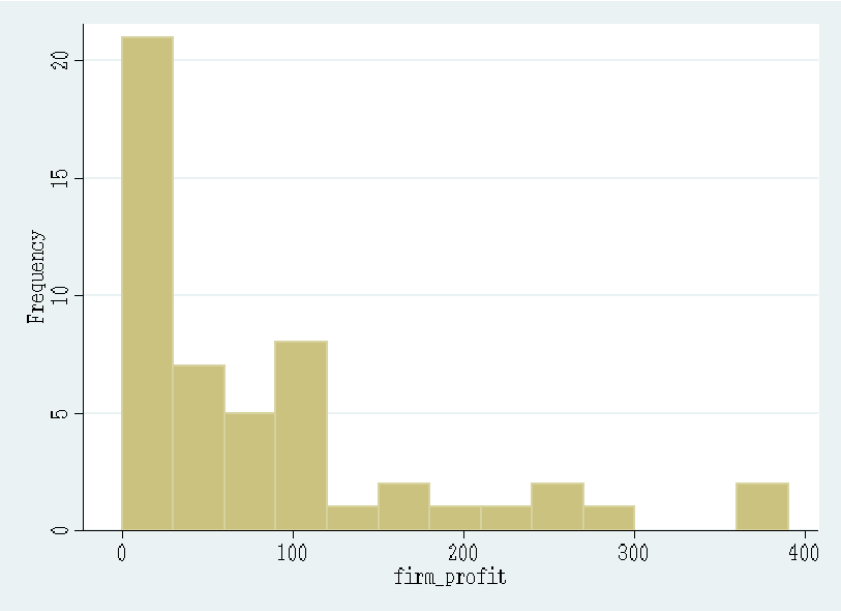

Figure 2: Distribution of firm profits in 1994

Table 8: Probit Regressions deals performance

	Model 1 dY/dX/se	Model 2 dY/dX/se	Model 3 dY/dX/se	Model 4 dY/dX/se	Model 5 dY/dX/se
Exp mean	.015**	.018***	.013*	.008	
	(.01)	(.01)	(.01)	(.01)	
Exp mean squared	–.001**	–.001***	–.001	–.001**	
	(.00)	(.00)	(.00)	(.00)	
Fund Sequence			.006**		
			(.00)		
Exp median				.007**	
				(.00)	
Last pd. IPO rate					.189***
					(.06)
Communications and Media (d)	–.106***		–.120***	–.106***	–.092***
	(.01)		(.02)	(.01)	(.02)
Computer Related (d)	–.193***		–.217***	–.194***	–.185***
	(.02)		(.02)	(.02)	(.02)
Medical/Health/Life Science (d)	–.104***		–.121***	–.104***	–.096***
	(.01)		(.02)	(.01)	(.01)
Non-High-Technology (d)	–.148***		–.169***	–.148***	–.125***
	(.01)		(.01)	(.01)	(.01)
Semiconductors/Other Elect (d)	–.103***		–.116***	–.103***	–.092***
	(.01)		(.02)	(.01)	(.02)
directoryyear==1982 (d)	.066**		.098**	.057*	
	(.03)		(.04)	(.03)	
directoryyear==1986 (d)	–.006	–.056***	.022	–.013	.007
	(.02)	(.02)	(.03)	(.02)	(.02)
directoryyear==1990 (d)	.030	–.027	.051**	.024	.088***
	(.02)	(.02)	(.02)	(.02)	(.03)
directoryyear==1994 (d)		–.042**			
		(.02)			
directoryyear==1998 (d)	–.118***	–.164***	–.122***	–.117***	–.083***
	(.01)	(.02)	(.01)	(.01)	(.01)
directoryyear==2002 (d)	–.230***	–.256***	–.244***	–.228***	–.203***
	(.01)	(.01)	(.01)	(.01)	(.02)
R^2	.155	.124	.144	.156	.198
No. of obs	5415	5415	4108	5415	2416

The dependent variable is an IPO dummy.

Table 9: Firm Profits Fixed Effect and AR(1) Regression

	Model 1 b/se	Model 2 b/se
Y1986	12.502	2.282
	(22.79)	(19.94)
Y1990	40.152*	23.534
	(23.66)	(21.70)
Y1994	76.638***	52.920**
	(24.36)	(22.52)
Y1998	121.762***	87.044***
	(24.26)	(21.40)
Y2002	94.907***	51.430**
	(25.63)	(20.89)
Constant	–1.128	16.692
	(20.01)	(18.59)
rho		.31
Sigma u	90.54	43.59
Sigma e	91.56	93.57
fraction of variance due to fe	0.49	0.17
N	384	384

Table 10: Structural model parameter estimates

Parameter	Mean	Std. Dev.
Theta Seniors	0.3044	0.09
Sigma Eta	0.7205	0.16
Rho	0.5611	0.1
Theta Juniors	0.4131	0.04

The reported statistics are calculated from the simulated posterior distribution of the parameters.

Table 11: Model Prediction of Industry Output

Year	Profits (Actual)	Profits (Predicted)
1982	861	824
1986	1,605	1,241
1990	2,793	2,021
1994	4,044	3,298
1998	8,842	6,446
2002	7,756	4,429

Output is in $bn.

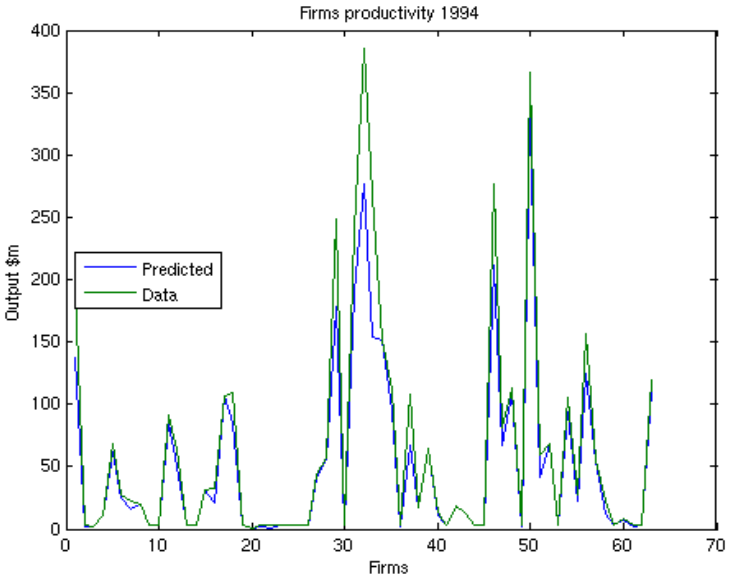

Figure 3: Firm Production in 1994

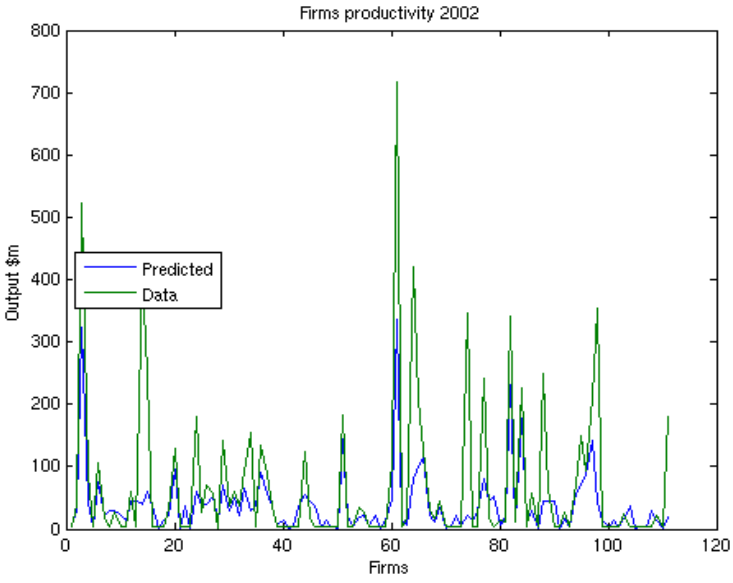

Figure 4: Firm Production in 2002

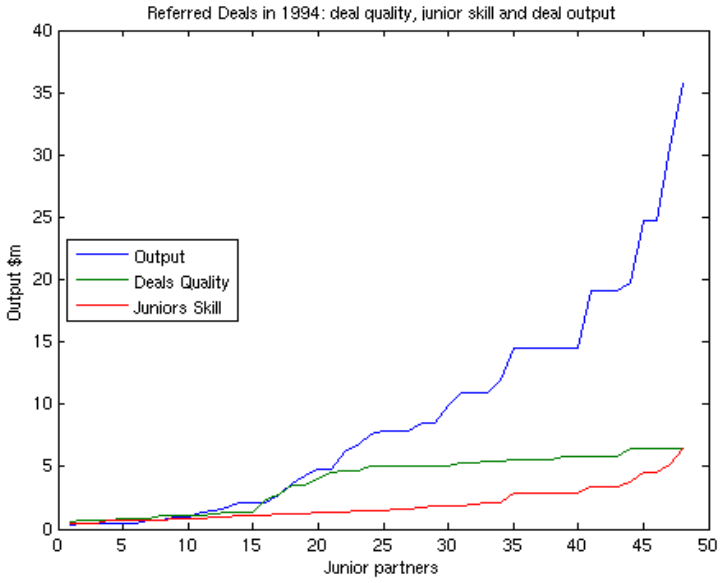

Figure 5: Referrals in 1994

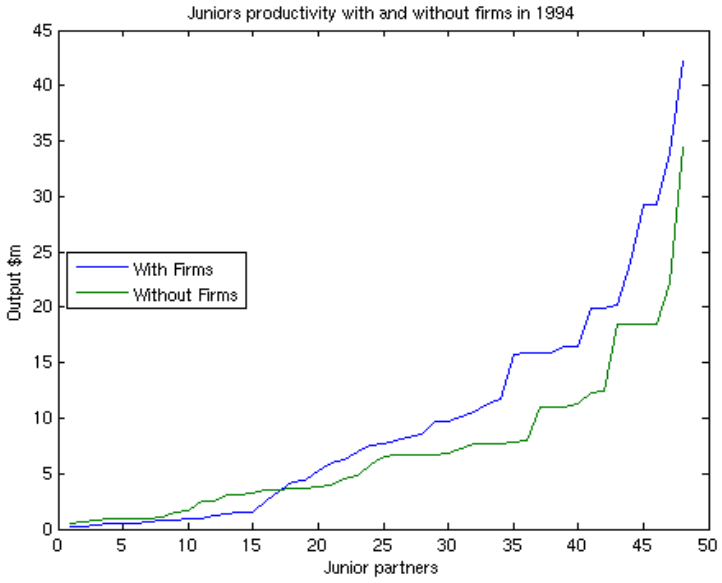

Figure 6: Juniors Productivity Counterfactual in 1994

Table 12: Juniors output counterfactual

Year	With Firms	Without Firms	Difference in $M	Difference in %
1986	490	353	137	38.81
1990	742	467	275	58.89
1994	469	348	121	34.77
1998	904	588	316	53.74
2002	2,409	1,504	905	60.17
Total	5,014	3,260	1,754	53.80

Output is in $M.