Business Partnerships and the Commercialization of Inventions*

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Abstract

We find that business partnership formation is extremely important for commercialization success of invention-based ventures. Projects run by partnerships had mean revenues approximately ten times greater than projects run by solo-entrepreneurs. This may be due to both added value from business partners and due to selection. A model shows how selection on invention quality and demand for financing can jointly arise. Empirical tests indicate strong selection on invention quality and external financing. After controlling for selection effects and inventor heterogeneity there still remains a significant effect of partners' ability on project success. Our smallest estimate of value added indicates approximately an 80% increase in revenues conditional on commercialization and a 55% increase in the probability of commercialization at the sample mean.

1 Introduction

One important question in the entrepreneurial finance literature is the extent to which early stage financers bring value added to start-ups. While there has been work analyzing the value added delivered by institutional investors to new firms, relatively little is known about the value added from informal venture capital, a sector which by some estimates is as large or larger than the formal venture capital (VC) sector.[1] We estimate the relative importance of informal

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[1] For example, Reynolds (Reynolds, 2005) reports the informal investor sector to $162 billion per year over the period 2000-2004, while formal venture capital were reported to provide $45 billion per year to start-ups during 2000-2003. Amounts have dropped drastically since, and Sohl, 2010, report U.S. angel investors to have provided $17.6 billion in financing for 57,225 projects in 2009. Notably, informal venture capital have different objective and modes of operation than venture capital funds. The investors typically make only a few investments at a time (on average 4 in one study), tend to invest substantially smaller amounts than VCs (about $75,000 on average in one study), invest their savings on their own or in syndication with other private persons, and they more often than

venture capital by relying on a survey which documents the human, social, and financial capital contributions of business partners to inventive projects. The raw data from the survey shows an extremely important effect of business partners for commercialization success; the rate of commercialization of projects run by partnerships is five times larger than those run by solo entrepreneurs, and the revenues of projects undertaken by partnerships are almost ten times as large as those run by solo-entrepreneurs. The survey answers on the provision of human, social, and financial capital contributions, with some assumptions, allows us to identify how much of these gross effects represents the value of obtaining human and social capital while controlling for selection on project quality and the demand for financing.

Business partnerships are important for the economy; approximately 10% of all U.S. businesses are partnerships and 18% of business receipts are from partnerships.[2] Business partners appear even more important for start-ups. For example, in the panel study of entrepreneurial dynamics, 52% of start-ups were partnerships (Ruef, Aldrich, and Carter, 2003). Our characterization of potential partners reflect high net worth individuals, often with some prior business and/or entrepreneurial experience. We do not put any restrictions on the social relations between the partner and the original founder. Business partners are assumed to join the original founder with at least one of three useful resources: financial capital, human capital, and/or social capital. These partners take on substantial risk. In our sample the average pre-revenue external investments are approximately $27,600 (2003 Cdn $), when the average probability of commercialization is 0.11. Reflecting conventional wisdom, the business press commonly advises entrepreneurs to partner with such people in order to increase the chances to commercialize their ideas. However, the empirical evidence on the value of this advice is scattered.[3] More importantly, little is known about the mechanisms through which business partnerships are formed.

Documenting that early stage financiers provide a real impact to start-ups has been difficult. There are several complicating factors when trying to quantify the value added of early

VCs invest in early-stage deals. They are geographically widely distributed and make most investments locally. As opposed to institutional investors they, typically, do not rely on traditional control mechanisms such as board control, staging or contractual provisions, but rather spend time 'hands-on' in the business or exercise control through other mechanisms such as trust or social influence. Many are active investors who seek to contribute their experience, knowledge and contacts to the investee and often invest in sectors where they have had previous experience, but many others are passive investors (e.g. the wealthy local lawyer) who may happen to come across investment opportunities in the course of conducting business. For further descriptive evidence of the informal venture capital sector, see Harrison, Mason, and Robson, 2010; Kerr, Lerner, and Schoar, 2010; Mason, 2009; Van-Osnabrugge and Robinson, 2000; Wong, Bhatia, and Freeman, 2009.

[2]Statistics of Income, http://www.irs.gov/taxstats/article/0,,id=175843,00.html The approximately 3.1 million U.S. partnerships in 2007 had 18.5 million partners. Excluding limited and limited liability partnerships (popular investment vehicles in the movie and construction industries), there were 852,000 U.S. partnerships with 3.9 million partners.

[3]Cressy, 1996 and Åstebro and Bernhardt, 2003 both report substantial effects on the survival of new firms of the number of owners.

stage financiers – self-selection and sorting being of primary concern. For instance, If inventions commercialized by partnerships have higher revenues than inventions commercialized by solo entrepreneurs it may reflect that partners provide value added in the form of human or social capital, but it may also reflect that partners join inventors with better inventions, or that inventors are credit constrained and primarily enlist partners to obtain financing. The policy implications are vastly different depending on the answer; in the latter case one might ask if there are available policies to relax credit constraints. In the former case one might instead ask for policies to improve the efficiency of the market for finding business partners. Both policies are currently in use in Europe to stimulate business formation (Mason, 2009), but without apparent knowledge of their respective efficacy. Thus, understanding the mechanisms behind partnership formation matters both for economic policy and business strategy.

To disentangle selection effects from value added, we develop a model of invention commercialization with business partner selection. Our model describes the choice of an individual deciding whether to commercialize an invention on her own or to form a partnership. Individuals are endowed with both an invention and limited wealth. Partners can provide ability to increase the productivity of capital, and may also relax liquidity constraints. Forming a partnership involves a sunk cost. Partnership formation therefore depends on the partner's potential contribution of ability and the extent to which an inventor is liquidity constrained.

The model shows how selection on invention quality and demand for financing can jointly arise. A first result is that partners are more likely to join inventors with inventions of high quality because these inventions allow partners to obtain a higher return as compensation for their effort. A second insight is that inventors with high quality inventions - whom are more likely to be liquidity constrained - are more likely to seek partners for financing. Therefore, selection into partnership can arise due to heterogeneity in the quality of inventions and the financial needs of inventors. Another modeling result refers to the identification of the contribution of partners' abilities. We show that among all potential partners the better partners are more likely to end up working with inventors because they can generate higher productivity of capital. In light of this result, reduced-form estimates of partnership formation should be interpreted as a treatment-on-the-treated rather than a treatment effect.

We test the implications of our model in reduced form regressions on data from 761 invention projects through a survey of Canadian inventors using the Invention Assessment Program at the Canadian Innovation Center (CIC) (for survey details see Åstebro, Jeffrey, and Adomdza, 2007). These data reveal that in approximately 21 percent of the projects the inventor was joined by partners. The primary reason for the inventor to create a partnership was to obtain human capital

(65%), followed by obtaining financing (52%), and social capital (43%), indicating a broad array of resources provided by partners.

Regression analysis show that there is selection into partnerships based on the quality of the invention and the demand for financing. To make the first point, we use two measures of pre-partnership invention quality; the invention's commercial quality as assessed by the CIC and research and development (R&D) expenditures. The high-quality assessed invention projects were twice as likely to be joined by a partner as the low-quality projects. And the average R&D expenditures were over four times larger for project eventually joined by partners than for solo-runs. To make the second point, we test two model predictions stating that a) the probability to form a partnership with financing should increase with invention quality, and b) the partnership effect should decline once controlling for the amount of external financing and c) the marginal return to external financing should be less than for internal financing. Regression analysis support expectations.

Accounting for selection on invention quality and financing in Tobit regressions reduces the effect that forming a partnership has on commercialization success by a factor of approximately three. However, the remaining partnership effect is as large as the mean probability of commercialization. This effect may exists because partners contribute significant abilities or because of heterogeneity not yet accounted for.

We use two alternative approaches to control for additional heterogeneity. In the first approach we control for selection on measurable inventor characteristics using a propensity score weighted Tobit model. This further reduces the effect size of the partnership dummy. There is, however, a strong remaining effect of partnership formation on the probability of commercialization as well as revenues. The size of the remaining partnership coefficient represents between 41% and 54% of its original size. This effect represents an increase in the probability of commercialization of between 0.06 and 0.10 percentage points when the mean probability of commercialization is 0.11, and approximately a doubling in revenues conditional on commercialization.

In the second approach we control for unobserved heterogeneity. To do so we test an implication of our model: once controlling for the capital investment, a partner that exclusively provides financing should not provide any further value added to the project. If a partnership effect remains in such a project, that effect must therefore indicate selection into partnership on unobservables. We can thus construct a lower bound on the value added of partner ability when separating out selection on unobservables. Implementing this specification, we find a lower bound of partner value added representing between 0.08 and 0.11 percentage points increase in the probability of commercialization, and a doubling in revenues conditional on commercialization. Both approaches thus deliver the same message: the value added of partners' ability is very large.

Our paper is related to those examining the value added of formal venture capital to entrepreneurs. This literature tries to identify if VC financing improves business performance, and if VCs additional resources (such as a big rolodex) add value to the start-up [Hellmann and Puri, 2000; Hellmann and Puri, 2002; Hochberg, Ljungqvist, and Lu, 2005], Puri and Zarutskie, 2008; Chemmanur, Krishnan, and Nandy, 2009]. Kerr, Lerner, and Schoar, 2010 summarizes this literature stating that so far it has been a challenge to clearly document value added by early stage investors. Several papers show that the reputation of a VC acts as a signal of the quality of the venture, indicating that some VCs may be selected by entrepreneurs because they add value beyond financing [Megginson and Weiss, 1991; Hsu, 2004; Sorensen, 2008]. Closest to our paper is Kerr, Lerner, and Schoar, 2010 who empirically demonstrate a positive effect of obtaining angel financing using a regression discontinuity approach, "which removes the endogeneity of funding and many omitted variable biases" (Kerr, Lerner, and Schoar, 2010, p. 5). Our paper differs from Kerr et al. in at least three important aspects. First, we have two proxies of pre-partnership invention quality (the CIC assessment and the pre-partnership inventor's R&D expenditures). Second, we provide a formal model of the partnering process to identify the precise effects of selection versus value added, which help us to empirically estimate selection effects rather than try to remove them. And finally, we differ by empirically identifying the marginal effect of partner ability conditional on these selection effects while also purging estimation from the effect of observed and unobserved heterogeneity in two distinct ways.

Related is also a large literature on teamwork efficiency, which analyze bargaining issues and contract design primarily as it applies to team production in large established firms (see review by Lazear and Shaw, 2007). In this paper we abstract away from bargaining issues, which nevertheless might be important.

Our work also contributes to the literature on the choice of entrepreneurship. In a related paper, Lazear (Lazear, 2005) develops a theory of entrepreneurs as jacks-of-all-trades where he assumes that the entrepreneur must perform all business tasks and the choice of entrepreneurship is a strict function of his worst skill. The model we propose differs from Lazear's in that we allow individuals to add partners to obtain the required skills. Furthermore, our work is distinct to Holmes and Schmitz, 1990 who develop a theory of entrepreneurship with specialization and business transfers. We focus on the process and benefits of partnerships and with good reason abstract from the possibility that the inventor may instead transfer her invention to others.[4]

[4] We find only 5 inventors out of 770 that were able to transfer their idea for cash to another entity. Those 5 are deleted from analysis.

Finally, Evans and Jovanovic, 1989 studied the degree to which personal wealth provides a binding liquidity constraint for a single individual's choice between entrepreneurship and wage work. We instead focus on individuals that already have an entrepreneurial idea and whom may find partners to relax liquidity constraints for commercial entry.

2 A model of selection into business partnerships

The economy is populated by inventors and business partners. Inventors are randomly endowed with inventions of quality Q and assets Z.[5] The quality and assets are distributed with cdf $F_{Q,Z}$ and are independent.[6] Business partners can contribute complementary human and/or social capital as well as financing. The partner's social and human capital are randomly drawn from a cdf F_β. Every inventor meets a partner with positive probability. Inventions can be commercialized by the inventor on her own or with a partner.[7]

If the invention is commercialized by the inventor on her own, the profits are $V^S = QK^\alpha + r(Z - K)$ where K is the amount of commercialization capital invested in the business, r is the interest rate (i.e., the opportunity cost of capital), and $\alpha \in (0, 1)$. The complementarity between the commercialization capital and the invention quality implies that a higher quality of the invention will produce a higher marginal product of capital at all levels of capital. As a result some inventors may have insufficient assets to fully fund the capital investment. We consider that inventors can borrow against their assets to fund capital investment (as in Evans and Jovanovic, 1989). If $Z < K$, the inventor borrows $(Z - K)$ and pays $r(Z - K)$ at the end of the period. An inventor with assets Z will be able to borrow an amount $(1 - \lambda)Z$ and invest up to $K \leq \lambda Z$, where $\lambda > 1$. Whenever the optimal capital investment is higher than the inventor's borrowing capacity the inventor will be liquidity constrained.

If the invention is commercialized with a partner, the capital is leveraged by $A(\beta)$, the partner's ability. The partner may also provide financing beyond what can be borrowed based on wealth to release an inventor's liquidity constraints. The joint profits then are $V^P = A(\beta)QK^\alpha + r(Z-K) -$

[5] A sequential version of this model where inventors choose an investment level to create an invention of quality Q can be found in the appendix.

[6] In an extended version one may separately introduce the inventor's entrepreneurial ability. We do not add this complication because Q can be considered representing also the inventor's ability. In the empirical analysis we analyze the robustness of results by allowing entrepreneurial ability to vary in some specifications.

[7] We abstract away from deciding on the number of partners; our stylized partner could therefore also be interpreted as the endowments of a set of partners. We also disregard the case where the inventor directly sells the invention. Our simplified model holds for the majority of partnerships since most partnerships are between two individuals. For example, in the Panel Study of Entrepreneurial Dynamics, out of 421 start-ups with partners, 74% had two members, 13% had three members, 7% four, and 5% had five or more (Ruef, Aldrich, and Carter, 2003). A slightly expanded version of our model would characterize selection of multiple partners by setting the opportunity cost to nτ where n is the number of partners.

τ.[8] We constrain $A(\beta) \geq 1$ indicating that partners do not reduce productivity. For simplicity we hereon reduce notation to A for partner ability, although $A(\beta)$ is some function of a vector of human and social capital. Partners' ability contribute towards a higher productivity of capital for a given level of invention quality.[9] An additional benefit of a partnership is that business partners can contribute external financing. We assume that partners are sufficiently financially endowed that partnerships can reach the unconstrained level of capital investment that maximizes profits. The parameter τ is a sunk cost to form a business partnership. We interpret it as the partner's opportunity cost to join the partnership. For simplicity, we assume that invention quality, inventor wealth, and the partner's ability are observable by the two parties in a meeting.

An inventor chooses to form a business partnership if the profit from that, V^P, is higher than the profit from a solo-entrepreneurship, V^S. Whenever the increase in profits from adding partner ability and/or financing is above the cost of partnership, a business partnership will be formed, assuming contracting is efficient.[10] The partnership formation problem is most succinctly characterized by considering the difference between profits for (i) partnership and (ii) solo-entrepreneurship. The profits are evaluated at the capital investment that maximizes their respective profits subject to liquidity constraints. The difference in the profits of partnership and solo-entrepreneurship, depending on whether or not an inventor is liquidity constrained ($Q \leq \frac{r}{\alpha A}(\lambda Z)^{(1-\alpha)}$), is

$$V^P - V^S = \left\{ \begin{array}{ll} [Q\left(\frac{\alpha Q}{r}\right)^{\alpha/(1-\alpha)} - r\left(\frac{\alpha Q}{r}\right)^{1/(1-\alpha)}][A^{1/(1-\alpha)} - 1] - \tau & \text{if} \quad Q \leq \frac{r}{\alpha A}(\lambda Z)^{(1-\alpha)} \\ \\ [Q\left(\frac{\alpha Q}{r}\right)^{\alpha/(1-\alpha)} - r\left(\frac{\alpha Q}{r}\right)^{1/(1-\alpha)}][A^{1/(1-\alpha)} - 1] + & \text{otherwise} \\ [Q\left(\frac{\alpha Q}{r}\right)^{\alpha/(1-\alpha)} - r\left(\frac{\alpha Q}{r}\right)^{1/(1-\alpha)} - Q\left(\lambda Z\right)^{\alpha/(1-\alpha)} + r\left(\lambda Z\right)^{1/(1-\alpha)}] - \tau & \end{array} \right\}$$

The top equation equals the difference in profits for a non-capital-constrained project with and without a partner. The first bracketed term of that equation is necessarily positive and increasing

[8] Inventors are assumed to form a partnership rather than hiring employees because it is hard to write employment contracts when commercialization efforts (while observed by the contractual parties) are not verifiable by a third party (Grossman and Hart, 1986).

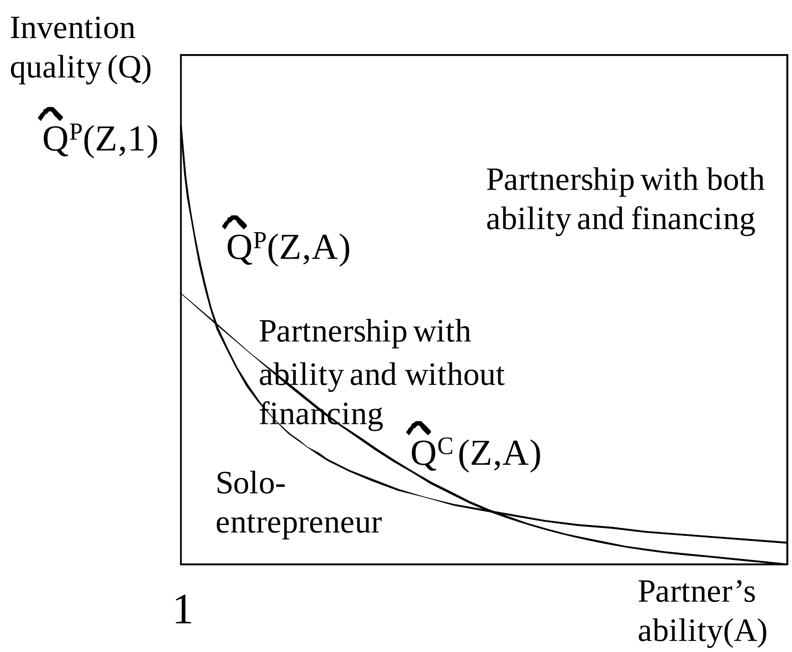
[9] An alternative interpretation is that partners leverage the quality of the invention. Both interpretations are possible, adopting the alternate does not change the comparative statics that follow.

[10] Efficient contracting implies that we are agnostic about how the surplus is split. There is no strictly preferred way to determine the division of surplus and, while it has sometimes been derived from an explicit bargaining game, it has been more common to assume that each party's share of the surplus is given exogenously. For example, in one well-known model of teamwork production, Kremer (Kremer, 1993, p. 585) simply notes that "the division of a firm's output among its heterogeneous workers [is] determined by a complex bargaining problem." Our model could consider potential inefficiencies associated with moral hazard problems of partnership production (see Holmstrom, 1982), but since we have no data on partnership structure, predictions from such an extension would not be testable. Instead, we assume that all inefficiencies associated with partnerships are scaled by the parameter τ.

with Q. The second bracket is also positive and its magnitude depends on the partner's ability. The last term, τ, is the sunk costs to run a partnership. All together these terms represent the value added of the partner's ability when the inventor is not liquidity constrained. The partnership is formed exclusively to add human and/or social capital.

The second equation shows the difference in profits between partnership and solo-entrepreneurship for those inventions where an inventor is liquidity constrained. As in the top equation, the first two bracketed terms together represents the value added of the partner's ability. The bottom term separately identifies the value added of partner financing. The term is the difference between the profits of a liquidity constrained entrepreneur that received financing from a partner and the profits for the same entrepreneur that did not receive external financing. This difference is the contribution of a business partnership exclusively formed to increase the capital investment level from the constrained investment level, λZ, to the unconstrained level, $\frac{\alpha Q}{r}$. This term is therefore positive. The last term is again the sunk cost to form a partnership. The partnership is formed to add external financing as well as human and/or social capital.

Figure 1: The Decision to Partner as a function of A and Q given fixed inventor assets Z



The partnership optimal decision are illustrated in Figure 1 and 2. In Figure 1 invention quality (Q) is plotted against partner ability (A) for a given level of assets; in Figure 2, invention quality

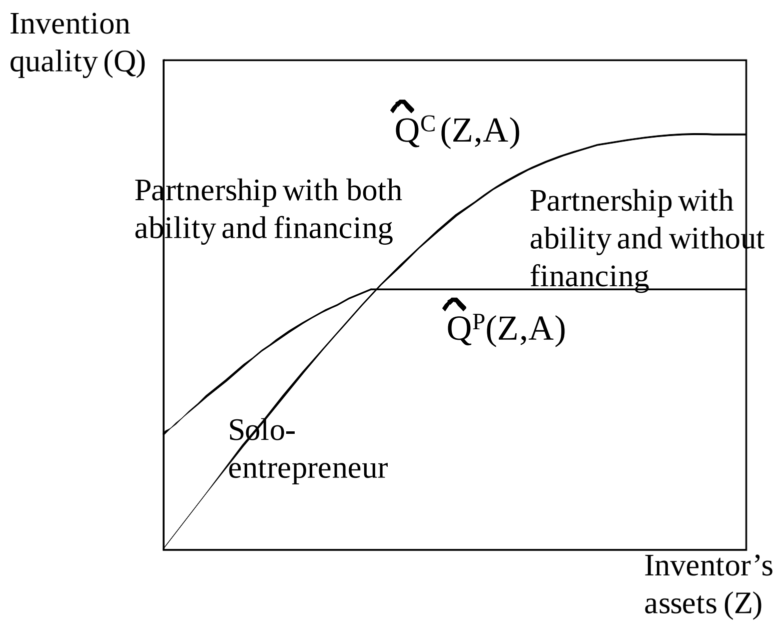


Figure 2: The Decision to Partner as a function of Z and Q given fixed partner ability A

(Q) is plotted against inventor's assets (Z) for a given level of partner ability.[11] Both figures are divided into two main regions – solo-entrepreneurship and partnership – by the threshold $\widehat{Q}^P(Z,A)$, where $\widehat{Q}^P$ is the value of Q where $V^P = V^S$. Given a partner's ability and the inventor's assets, the inventor will form a partnership if and only if the invention quality is above the threshold $\widehat{Q}^P(Z,A)$, which implies that $V^P > V^S$. Conversely, if the invention quality is below this threshold, the inventor will commercialize the invention without a partner. In Figure 1, the threshold $\widehat{Q}^P(Z,A)$ decreases with the partner's ability indicating that the higher the ability of the partner, the lower the invention quality needed for an inventor to be indifferent between commercializing the invention with or without a partner. In Figure 2, the threshold $\widehat{Q}^P(Z,A)$ initially increases with the inventor's assets up to a sufficiently large level of inventor assets; above this level of assets, the threshold $\widehat{Q}^P(Z,A)$ remains flat. It is flat because at intermediate levels of quality and when the inventor's assets are sufficiently high the inventor is not liquidity constrained.

A prediction that follows from this model is that when invention quality increases, the probability to form a partnership increases. This is because a higher invention quality facilitates the amortization of the sunk costs to form a partnership. As a result, we should expect a positive correlation between pre-partnership invention quality and inventions commercialized in partner-

[11] The formal proofs of the following results are in the appendix.

ships. A second prediction from the model is that the higher the ability of the partner that the inventor meets the higher the probability of partnership. This implies that conditional on a partnership being formed, the average ability of a partner should be strictly higher than the ability of the average potential partner. Both predictions are probabilistic because there is a probability of meeting a partner and there is ex ante uncertainty about the ability of the partner. These predictions have important implications for the estimation of value added. There will be selection into partnerships based on invention quality, and there will be selection into partnerships based on the partner's ability. Estimation of the marginal impact of the partner's ability on profits must therefore take into account the selected quality of the partner that joins a partnership and control for the quality of the invention.

The region with partnership formation is further divided into two areas by the threshold $\widehat{Q}^C(Z, A)$ – partnerships with financing and partnerships without financing. $\widehat{Q}^C$ defines the quality level above which the inventor is liquidity constrained. In Figure 1, the threshold $\widehat{Q}^C$ decreases with the partner's ability indicating that the higher the partner's ability the lower is the invention quality above which an inventor is liquidity constrained. In Figure 2, the threshold $\widehat{Q}^C$ increases with the inventor's assets because the higher the inventor's assets are the lower is the invention quality above which an inventor is liquidity constrained. Partnerships with ability and without financing are located in the region above $\widehat{Q}^P$ and below $\widehat{Q}^C$ in both Figures 1 and 2. These partnerships do not require a partner for financing reasons, the partner's contribution of human and/or social capital outweighs the cost of partnering. There are two characteristics about these partnerships that are worth noticing. First, partnerships with ability and without financing exist only for intermediate levels of invention quality; for higher levels of invention quality there will always be external financing as the inventor's liquidity constraint will eventually bind; and for lower levels of invention quality a partnership may only be profitable when external financing releases liquidity constraints (inventor's assets are low) and therefore partners will provide both ability and financing. Second, for the intermediate levels of quality, decreasing invention quality further may temporarily increase the proportion of partnerships with no financing while the overall proportion of partnerships may decrease, as can be seen in Figure 1. The explanation is that the relative benefit of the contribution of partners' ability holds up better than the drop in value added of external financing as invention quality diminishes.

The partnerships providing ability and financing are located above both the cutoff $\widehat{Q}^P$ and $\widehat{Q}^C$ in both Figures 1 and 2. In both figures the proportion of partnerships with ability and financing increase with invention quality. This is because inventors holding higher quality inventions, who will be more likely to be liquidity constrained, will also be more likely to form partnerships with financing. A prediction that follows from this result is that the probability to form a partnership with both ability and financing increases with invention quality. This prediction suggests that there will be selection into partnerships based on demand for financing. This selection effect may have important implications for estimating value added depending on the determinants of the demand for external financing. Figure 2 shows that the partnerships with both ability and financing are characterized by inventions that range from high to low levels of invention quality. The partnerships with higher level of invention quality involve external financing because the inventor's liquidity constraints are more likely to bind. Instead, partnerships of low invention quality may only be profitable when inventor's assets are low and therefore partners must provide both ability and financing. These partnerships area located at the bottom left corner of Figure 2. If the demand for external financing originates from these lower quality inventions, the selection effect on demand for financing will be less. These results suggest that to assess the importance of selection on demand for financing we must compare the mean invention quality in partnerships with both ability and financing against partnerships with ability but without financing. If the mean quality in partnerships with both ability and financing is lower than the quality in partnerships with ability but without financing, then the proportion of inventors with sufficiently low assets in the economy will be large and the selection on demand for financing will be less.

Finally, it is posible that if invention quality is sufficiently high a partner without ability may join simply to release credit constraints by providing cash. Partnerships that provide only financing are located at the top left corner of Figure 1.

To summarize this discussion, there will be three types of partnerships; those where partners only bring financing, those where partners provide both ability and financing, and those where partners only provide ability. The extreme cases with only financing and only ability, if well represented in our empirical setting, may provide opportunities to identify the marginal value of partner ability versus the value of releasing liquidity constraints. A first testable prediction of the model was that when invention quality increases, the probability to form a partnership increases. This implies selection on quality. The second prediction was that the higher the ability of the partner that the inventor meets the higher the probability of partnership. This implies selection on partner ability. A third prediction was that the probability to form a partnership for both ability and financing increases with invention quality. This prediction implies selection on demand for financing. Finally, we showed that the mean invention quality in partnerships with both ability and financing can be lower than for partnerships with ability and without financing if the proportion of inventors with sufficiently low assets in the economy is large.[12]

[12] If we for the moment assume uniform distributions of assets and invention quality in the inventor population,

3 Data

We focus our empirical analysis on a sample of independent inventors; that is, individuals who decide to develop inventions outside their regular employment duties. Many inventors may not have great entrepreneurial or business skills and may lack the financial capital necessary to commercialize their inventions. Further, they may lack the benefits of working in a large organization in terms of access to a multitude of internal resources such as a lab, cash, skilled colleagues, and an established marketing and distribution network. They may thus find it particularly useful to have others join them in their commercialization efforts. A construction business, corner store, personal service or restaurant (the most common start-ups), may not require large up-front investments, but commercializing new products involve using significant business skills and capital investments. Studying independent inventors should thus likely provide an excellent opportunity to examine the role of informal venture capital, partnership mechanisms, and their outcomes.

It is costly, given their scarcity, to find independent inventors among the general population. To economize on search costs, we use a list of independent inventors, self-identified through their use of the services of the Canadian Innovation Centre (CIC). The CIC charges a fee for assessing the inventor's project. The assessment results in an overall recommendation that is either positive or negative. Our sample frame consists of inventors that had asked the CIC to evaluate their inventions between 1994 and 2001. Of these, we had current addresses for 1,770 which we contacted by surface mail in 2004. We were then able to contact 934 by telephone, and from these we obtained 830 completed telephone surveys. All data except the invention evaluations are self-reported. We use list-wise deletion to remove observations with missing data on R&D investments, partnership, or revenue, and 5 observations where the IP was sold or licensed, leaving 761 observations for analysis. The data primarily contains information on pre-CIC research and development (R&D) expenditures, pre-partnership invention quality assessment by the CIC, post-CIC commercialization expenditures, a dummy for the creation of a partnership to commercialize the invention, the type of capital partners bring (human capital, social capital, and financing), the amount of external financial capital, whether or not the invention was commercialized, total commercialization revenues, and year and industry classification codes. There are also sundry

and a uniform distribution of partner ability, the most likely type of partnership is that where partners bring both financing and abilities. However, skew or bimodal distributions of quality, assets or ability in the economy may temper this prediction. An additional conclusion from the model is that the pool of solo-entrepreneurs will consists of two types; those with low quality inventions which are not liquidity constrained and those with higher quality which are liquidity constrained but which did not find a suitable partner. The fraction of liquidity constrained solo-entrepreneurs as well as the fraction of partnerships varies across economies as a function of the preponderance of potential partners (with financing and abilities) in the economy, and the distribution of invention quality and assets in the inventor population.

inventor and invention characteristics in the survey that we employ when computing partnership propensity scores.

3.1 Summary statistics

The modal inventor age is 45-54 and the modal educational attainment is high school, although about 26% of the inventors had some professional or graduate education. While the identification of inventors relies on a specific, focal, invention submitted to the CIC for review it does not imply that the individuals are predominantly one-shot inventors. To the contrary, the sample is dominated by long-term serial inventors. Fifty-four percent of them had spent six or more years developing inventions, and 75% had worked on more than one invention. Eleven percent developed the invention as part of their normal duties at work. Twenty-three percent were stimulated by something at work, a majority of which (72%) were not required to innovate at work. Descriptions of some inventions reveal most to be "user-driven". The sources of invention are thus quite varied.

Only 14% reported they were unemployed, home-makers, retired, disabled, or on sick leave during the time that they were developing their focal invention. Most (59%) were full-time employees, while 27% were either part-time employed or self-employed when developing their invention. The median invention development effort on the focal invention was performed in 1997, and 95% of respondents had attempted to develop their focal invention before 2003.

With regards to the inventions, 24% were rated as of high quality by the CIC and given a positive recommendation, suitable to develop further at least as a part-time effort. The other 76% were deemed of low quality and inventors were recommended to stop further development. Thirteen percent of the inventions had environmental or energy applications, 14% automotive, 14% medical or health, and 16% security or safety applications. Inventions involving high technology (9%) and industrial equipment (14%) were also relatively frequent. Successful consumer-oriented inventions included a new milk container design, a washable sanitary pad, and a home security light timer that imitates typical use. Other inventions had business applications. These inventions included an aligner and printer for photographic proofs, a tractor-trailer fairing that enhances fuel efficiency, a re-usable plug to insert in wooden hydroelectric poles after testing for rot, and a computerized and mechanically integrated tree harvester. Thus, the inventions varied substantially in technological complexity and market potential.

The pre-commercialization investments in the inventions reveal to be far larger than in the ordinary start-up. For example, the 1992 Characteristics of Business Owners database report that the majority of U.S. start-ups (approximately 60%) were started or acquired with no cash outlay or with less than $5,000 (U.S. Department of Commerce, 1997.) In contrast, the average R&D

investment for the inventors is Cdn. $24,000 and the additional commercialization investment is another Cdn. $22,500 (2003 values). The total pre-commercialization capital in this sample is thus approximately ten times that of the average start-up.

4 Partnerships and the commercialization of inventions

We first report some descriptive statistics on partnerships and solo-entrepreneurs. In approximately 21% of the projects the inventor was joined by someone to commercialize the invention. The primary reason for the inventor to create a partnership was to obtain human capital (66%), followed by obtaining financing (53%), and social capital (43%).[13] Figure 1 suggested four potential choices for an inventor: no partnership; partnership only with financing provided; partnership with financing and ability provided; and finally partnerships only with ability provided by the partner. Table 1 can be used to compute the proportions of these outcomes. As stated above, 79% are without a partnership. Among the partnerships, in 16% of the cases there were only financing provided, in 37% there were both financing and ability provided by partners, and in 46% of the partnerships there were only ability provided.

The fact that a significant number of inventors are joined by someone to commercialize their invention suggests that there may be benefits to partnership. Indeed, we find that working with partners is positively correlated with the probability that inventions are commercialized. Table 1A shows that partnerships have a probability of commercialization of 0.30, which is about five times larger than that of projects run by solo-entrepreneurs. (The unconditional probability of commercialization is 0.11). The presence of partners is also positively correlated with revenues. Table 1B shows that the mean present value of revenues of all projects were $68,415. Projects run by solo-entrepreneurs had mean revenues of $24,549; mean revenues from projects run by partnerships were approximately ten times as much; $235,829.

While solo entrepreneurship dominates the data there appears to be enough variation to examine partnership selection mechanisms and benefits. Importantly, not all partners provide financing indicating a potential value added effect through human and/or social capital.

Examining further the raw data, Table 2A shows that the rates of commercialization are higher for projects where partners provided either social capital (33.3%) or human capital (30.2%) than for projects where partners provided financing (25.9%). Table 2 further reports that the

[13] We asked the inventor "Did you ever team up with other people trying to commercialize the invention?", if yes, we further inquired: "Why did you team up with other people?" with the following options read: "You needed to have your skills complemented by their skills", "They had contacts that were useful", "You needed the capital they provided", "They had resources that were useful (land, equipment, plant)" and "Other". In analysis the two categories prior to "other" are collapsed into one.

Table 1: Commercialization, Invention Quality, R and D Expenditures and Revenues by Solo-entrepreneurs and Teams.

The sample consists of 761 inventions from inventors that had asked the Canadian Innovation Center (CIC) to evaluate their inventions between 1994 and 2001. The table is divided into two parts. Panel A describes the percentage of inventions that were commercialized in partnerships, and the percentages of partnerships where partners provided only financing, both financing and ability, or only ability. Panel B presents characteristics of inventions commercialized by partnerships and solo-entrepreneurs. These characteristics are: the percentage of inventions with a positive CIC assessment; the probability of commercialization; and the means of the R and D expenditures, the commercialization investment, and the commercialization revenues. All data are in Cdn 2003 dollars.

A. Percentage of projects with partnerships and contributions by partners

Percentage partnerships (%)	21.0
Contributions among partnerships (%)	
Only financing	16.5
Both financing and human/social capital	37.3
Only human/social capital	46.2

B. Characteristics of projects commercialized by partnerships and solo-entrepreneurs

	All	Partnership	Solo-entrepreneur
Percentage with positive CIC review (%)	23.4	38.4	19.4
Mean R&D expenditures ($) by inventor prior to the CIC review	24,101	95,209	5,500
Probability of commercialization (%)	11.0	30.4	6.0
Mean commercialization investment ($)	22,493	58,078	12,964
Mean commercialization revenues ($)	68,415	235,829	24,549

mean value of discounted present value of revenues of successfully commercialized inventions differs significantly depending on the contribution of partners. The average project revenue where partners provided human capital or social capital is $893,607 and $483,025, versus $659,117 where partners provided financing. These data are clearly suggestive of partner value added. But further examination of the raw data tempers this conclusion. It also appears that, conditional on commercialization, both the pre-partnership invention quality and the partnership investments are higher, in particular for those projects which are joined with partners providing human capital (panel C). In the end, revenues depend on the quality of the invention, partnership formation, value added, and capital investments. In the next sections we will try and disentagle these various effects.

4.1 Selection into partnership

Selection on invention quality The theoretical model predicts a positive correlation between pre-partnership invention quality and the probability of partnership formation. To investigate selection on invention quality, we classify inventions into two categories; high quality inventions will be those with a CIC positive assessment, the rest of the inventions are deemed of low quality. It is immediately apparent that partners are more likely to join inventors with high quality inventions, as shown in Table 1B. In particular, partnerships are twice more likely to have high quality inventions than solo-entrepreneurs. Stated differently, 38 percent of inventions rated as high quality were eventually joined by a partner, while only 19% of inventions with low quality were joined by a partner. We have also classified the quality of the inventions using the inventor's own research and development (R&D) expenditures prior to the CIC assessment and partnership formation.[14] We consider that R&D expenditures are positively correlated with the unobserved quality of the initial idea of the inventor. We found that partners were more likely to join inventors with higher R&D expenditures. The average R&D expenditures by the inventors that were eventually joined by partners was $95,209; the solo-entrepreneurs spent on average $5,500. Furthermore, inventors' R&D expenditures were positively correlated with positive CIC assessments. To control for varying capital requirements by technology and for varying costs of capital we include industry and year dummies in a regression of the probability of partnership formation on invention quality. (These controls are included in all future regressions.) Estimates survive the inclusion of these industry and year controls (see Table 3).

[14] We separate between the idea creation and commercialization phase by the date of the CIC assessment.

Table 2: Probability of Commercialization and Commercialization Revenues

The sample consists of 761 inventions from inventors that had asked the Canadian Innovation Center (CIC) to evaluate their inventions between 1994 and 2001. The table summarizes the rate of commercialization and the mean characteristics of inventions for all inventions, and depending on whether they were commercialized in a partnership (any partnership; and partnership with human capital; social capital; and financial capital) or commercialized by inventors on their own (solo-entrepreneurship). The table is divided into three parts. Panel A presents the probability of commercialization. Panel B presents the percentage of inventions with a positive CIC assessment, and the means of commercialization investment, and the commercialization revenues among all inventions. Panel C presents the same information as in Panel B among inventions that were commercialized. All data is in Cdn 2003 dollars.

	All	Partnership				Solo-
		Any partnership	Humcap	Soccap	Fincap	entrepreneur
A. Rate of commercialization						
Probability of commercialization (%)	11.0	30.4	30.2	33.3	25.9	6.0
B. Invention quality, commerc. investment, and revenues unconditional on commercialization						
Percentage with positive CIC assessment	23.4	40.2	40.2	40.8	34.5	19.4
Mean commercialization investment ($)	22,350	58,494	72,754	59,781	40,959	12,895
Mean commercialization revenues ($)	68,415	235,829	269,768	161,008	170,595	24,549
C. Invention quality, commerc. investment, and revenues conditional on commercialization						
Percentage with positive CIC assessment	49.9	56.0	62.5	49.4	47.8	42.1
Mean commercialization investment ($)	92,136	130,365	174,790	98,090	78,172	41,165
Mean commercialization revenues ($)	619,811	776,270	893,607	483,025	659,117	411,198

Table 3: Probit regression analysis of partnership

The sample consists of 761 inventions from inventors that had asked the Canadian Innovation Center (CIC) to evaluate their inventions between 1994 and 2001. The dependent variable is partnership, a dummy variable taking the value 1 if an innovation was commercialized as a partnership, 0 otherwise. The independent variables are "Positive", a dummy variable taking the value 1 if the CIC assesment was positive, 0 otherwise; and "R and D expenditures", the natural logarithm of R and D expenditures. All data are in Cdn 2003 dollars. All regressions include dummy variables controlling for the project's industry, and the year the invention was assessed by the CIC. Standard errors in parenthesis. ***, ** or * mean the coefficient is significant at the 1 percent, 5 percent, or 10 percent level, respectively.

Marginal increase in probability			
Positive	0.114***		0.065*
	(0.035)		(0.037)
R&D expenditures		0.020***	0.017***
		(0.004)	(0.005)
Pseudo $R^2(\%)$	0.06	0.08	0.08

Selection on demand for financing An additional reason for why partners join inventors is to provide external financing. The model provides two predictions concerning the interplay of external financing and partnership formation. This first prediction is that the probability to form a partnership to obtain financing increases with invention quality. This is because inventors with higher quality inventions – whom are more likely to be liquidity constrained – are more likely to seek partners for financing. Using the same quality indicators and controls as before as predictors, Table 4 presents Probit regressions with a dummy = 1 if a partnerships was formed to obtain financing, and zero otherwise. The table shows support for this prediction. It appears that most of the invention quality variation that determines partnership financing is best captured with pre-partnership R&D expenditures.

The second prediction refers to the invention quality where partners provide both ability and financing versus the quality where partners provide only ability. The theoretical result is that partnerships with both ability and financing can have lower average invention quality than partnerships with only ability only if the proportion of inventors with low assets is high. This is because for lower levels of invention quality, the only partnerships that may be profitable are partnerships where partners provide both ability and financing. An analysis of the data shows that partnerships with both ability and finacing have lower proportion of positive CIC assessments (37%) and mean pre-partnership R&D expentitures (Cdn $33,619) than partnerships with only ability (43% and Cdn $176,388, respectively). The differences are however not statistically

Table 4: Probit regression analysis of partnership with financing

The sample consists of 761 inventions from inventors that had asked the Canadian Innovation Center (CIC) to evaluate their inventions between 1994 and 2001. The dependent variable is partnership with financing; a dummy variable taking the value 1 if an innovation was commercialized by a partnership with financing, 0 otherwise. The independent variables are Positive; a dummy variable taking the value 1 if the CIC assesment was positive, 0 otherwise; and the natural logarithm of R and D expenditures. All data are in Cdn 2003 dollars. All regressions include dummy variables controlling for the project's industry, and the year the invention was assessed by the CIC. Standard errors in parenthesis. ***, ** or * mean the coefficient is significant at the 1 percent, 5 percent, or 10 percent level, respectively.

Marginal increase in probability			
Positive	0.02		-0.01
	(0.029)		(0.027)
R&D expenditures		0.010***	0.011***
		(0.003)	(0.003)
Pseudo $R^2(\%)$	0.04	0.06	0.06

significant (t-tests of differences in proportions and means are 1.22 and 0.71, respectively.) This result suggests that the proportion of inventors with low assets may be large. It implies that selection on demand for financing may be less since the demand for financing may be primarily from lower quality inventions.

5 The value added of partners' ability

To study the contribution of partner's ability in the commercialization of innovations we adopt the following econometric specification:

$$y_i^* = \left\{ \begin{array}{lll} y_i & \text{if} & y_i^* > 0 \\ 0 & \text{if} & y_i^* \leq 0 \end{array} \right\}$$

with y_i^* as a latent variable indicating commercialization success

$$y_i^* = \alpha q_i + \beta d_i + \delta X_i + \mu_j + \tau_t + e_i$$

where y_i is the log of commercialization revenues; q_i is invention quality; d_i is a dummy that equals one if a partnership was formed to commercialize invention i; X_i represents components that vary with observations, and e_i is a normally distributed zero mean residual component. The terms μ_j and τ_t correspond to industry and CIC application year effects as implemented by a set of dummy variables, and β captures the effect of the ability of partners on commercialization revenues not explained by the control variables.

Table 5 reports the marginal effect of forming a partnership on the probability of commercialization and on the log of revenues. We use a Tobit model as there are a large number of inventions that are never commercialized and have zero revenues.[15] For each Tobit model we decompose coefficient estimates into two components per variable: Panel A presents the marginal effect on the probability of commercialization; Panel B presents the marginal effect on log revenues conditional on commercialization, both effects estimated at sample means. The first column (Model 1) shows the unconditional effects of partnership formation where β is positive and significant. The size of β implies that an invention project run as partnership has a 0.226 greater probability of commercialization and 2.9 times greater log of revenues than a solo-entrepreneur project.

The positive correlation between commercialization success and partnership formation has to be interpreted with caution. We previously showed that partners were more likely to join inventions of higher quality and that the demand for financing depended on invention quality and thus also determined partnership formation. Both findings indicate that the partnership coefficient in Column 1 is endogeneously determined and likely upwards biased.

To account for selection into partnerships based on invention quality and demand for financing we add two proxies of invention quality: the CIC assessment and the log of R&D expenditures (pre-partnership). The second column in Table 5 (Model 2) shows that the effect of partnership formation on P(comm.) then decreases from 0.226 to 0.156, a 33 percent reduction, while the effect on revenues is reduced by 34 percent at sample mean. However, the partnership dummy still remains significant and large.

Two additional mechanisms may explain the remaining partnership effect — the role of commercialization investments and external financing. Our theory suggests that optimal commercialization investments should increase whenever the partner's ability increases the productivity of capital. If partner's ability increase the productivity of capital, controlling for the commercialization investment should account for the part of the partnership effect that causes an increase in the optimal investment level. In addition, the external financing provided by partners should capture the partnership effect on revenues from relaxing liquidity constraints. Unfortunately, due to survey structure we cannot simultaneously identify these two effects.[16] We therefore run two

[15] We also experimented with a Heckman selection specification, but we could not find a variable that could be reasonably assumed to affect the probability to commercialize but not revenues conditional on commercialization. Without an exclusion restriction estimations were very unstable or did not converge.

[16] The survey enquired: 1. First, we would like to know how much money was spent on developing XX. Include all

regressions where we first analyze the impact of commercialization investments and then analyze the impact of external financing.

In Model 3 of Table 5 we analyze the effects of commercialization investments. The third column includes the natural logarithm of pre-partnership R&D investments and the natural logarithm of post-partnership commercialization investments; the second measure being the sum of all cash provided both by the inventor and external financiers to commercialize the invention after the formation of a partnership. The results show that the commercialization investment is affected by partners contributing ability. But while the effect of the commercialization investment is statistically and economically important, and while its introduction reduces the coefficient for the partnership dummy considerably, the partnership effect remains positive and statistically significant. Another noteworthy results is that both the quality indicators diminshes in size and significance once we control for commercialization investment. The reason is that the commercialization investment is also endogenous to project quality: optimal investments increases with quality.

To account for external financing, in Table 6 we instead separate between the natural logarithm of the inventor's cash contribution and the natural logarithm of the sum of all cash contributions by all external financiers.[17] The size of the coefficient for external financing is almost four times lower than the coefficient for internal financing. The result is consistent with the idea that inventors are capital constrained. If they were not constrained the coefficients for internal and external financing should be equal.[18] External financing is also positively correlated with the partnership effect, but not very much. Quantitatively, the effect of partnership on P(comm.) is reduced from 0.129 (in model 2) to 0.114 (in model 3), a reduction of the original partnership coefficient by 7%. The partnership effect on revenues drops from 1.65 to 1.46, a reduction of the original partnership coefficient by 6%.

Whatever remains of the partnership coefficient after accounting for selection on quality, commercialization investment, and external financing can be attributed to the partner's ability, inventor characteristics and measurement error of invention quality. The remaining effect is on

costs for product development, marketing research, making of prototypes, etc. How much did you spend before you contacted the CIC for an evaluation? 2. How much did you spend after you contacted the CIC for an evaluation? 3. I will now read a list of sources of funds that you may have used to pay for the costs of developing your invention. Please tell me for each source whether you have actually used it or not. 4. Consider the total amount of money you have spent on this invention so far. How large a proportion of this amount was your own money? These data allow us to identify either the effect of commercialization investment (using question 2) or external financing (using question 4).

[17] All others may be for example banks, family, friends, business partners, universities as well the government. Due to survey structure we could not separate the investments between these external suppliers of capital.

[18] This result is consistent with the finding that smaller and younger firms have higher growth-cash flow sensitivities than larger and more mature firms (see e.g. Fazzari, Hubbard, and Petersen, 2000).

the order of 40% of the original partnership coefficient in Table 5 and approximately 50% of the original partnership coefficient in Table 6. This remaining effect is economically meaningful. For example, the partnership formation doubles the mean P(comm.) from 0.11 to 0.22 in Table 6. In the remainder of this section we try to control for selection on inventor-invention characteristics, selection on unobservables and measurement error of invention quality to isolate the value added effect of partner abililty on commercialization success.

5.1 Accounting for selection on observables

We start by controlling for selection into partnerships on observable inventor characteristics using a propensity-score weighted model described by Hirano, Imbens, and Ridder, 2003. Woolridge discuss a related approach (Woolridge, 2007), but Hirano et al.'s method may produce more efficient estimates. We estimate the propensity to form a partnership with logistic regression using as predictors the previously used variables Positive, pre-team R&D expenditures, industry and year dummies, as well as a range of additional pre-determined pre-team inventor and invention characteristics to calibrate the propensity to form a partnership with as much precision as possible.[19] The range of inventor and invention characteristics is quite large. Matching partnership observations to non-partnership observations with similar propensity scores we can behave as if there was random assignment to partnerships on inventor and invention characteristics, under the condition that there is ample partnership and non-partnership observations for each score. We examined this requirement and deleted 27 observations where there was no common support, leaving 734 observations for subsequent analysis. The region of common support for the score is [.02, .91], capturing the 1st to the 99th percentile. Because there is considerable overlap in the score distributions between partnership and non-partnership observations between the 1st to the 99th percentile the so-called balance property is satisified and we can safely rely on the scores to provide reasonable matching. Results of the inverse propensity-score weighted Tobit are provided in Model 4 of Table 5 and Model 3 of Table 6. As seen, both estimates of the partnership dummy are again significantly reduced, indicating that there is also selection on observable inventor and invention characteristics. For example, the marginal effect of partnership formation on P(comm.) decreases from 0.087 to 0.061 in Table 5 and from 0.114 to 0.111 in Table 6, both evaluated at the mean of the sample. The marginal effect on revenue conditional on commercialization drop

[19] We included inventor gender, marital status, age, education, work experience, managerial experience, business experience, family business experience, years experience inventing, number of inventions developed, invention developed at work, invention stimulated at work, full-time, part-time, un- or self-employed when inventing. We also included the following invention characteristics: positive, pre-team R&D expenditures, industry dummies, year dummies, and whether the fee paid to the CIC for the review was partly subsidized by a third party.

Table 5: Marginal Effects on the Probability of Commercialization and Commercialization Revenues

This Table presents results from Tobit regressions. The dependent variable is the natural logarithm of commercialization revenues. The independent variables are; partnership: a dummy variable =1 if an inventor formed a partnership to commercialize the innovation and 0 otherwise; partner with ability is a dummy =1 if the inventor formed a partnership and the partner contributed human and/or social capital and 0 otherwise; partner without ability but with financing is a dummy variable =1 if the inventor formed a partnership and the partner contribute financing but did not contribute neither human nor social capital; Positive, is a dummy variable =1 if the CIC assesment was positive, 0 otherwise; and R and D expenditures, and commercialization investment are the natural logarithms of R and D expenditures and commercialization,investment respectively. All data are in Cdn 2003 dollars. All regressions include dummy variables controlling for the project's industry, and the year the invention was assessed by the CIC. Standard errors in parenthesis. ***, ** or * mean the coefficient is significant at the 1 percent, 5 percent or 10 percent level, respectively. Coefficient estimates are decomposed into marginal effects on probability of commercialization and marginal effects on commercialization revenues conditional on commercialization.

	Model 1	Model 2	Model 3	Model 4	Model 5
	Tobit	Tobit	Tobit	Propensity Score Weighted Tobit	Tobit
A. Marginal Effects on the Probability of Commercialization					
Partnership	0.226***	0.156***	0.087***	0.061***	
	(0.023)	(0.018)	(0.014)	(0.010)	
Partner with ability					0.094***
					(0.015)
Partner without ability but with financing					0.086***
					(0.027)
Positive evaluation		0.050***	0.026*	0.018*	0.026*
		(0.018)	(0.015)	(0.010)	(0.015)
R&D expenditures		0.016***	0.006**	0.000	0.006**
		(0.003)	(0.002)	(0.001)	(0.002)
Commercialization investment			0.012***	0.009***	0.012***
			(0.002)	(0.001)	(0.002)
B. Marginal Effects on the Commercialization Revenues.					
Partnership	2.89***	1.94***	1.17***	0.80***	
	(0.36)	(0.29)	(0.24)	(0.21)	
Partner with ability					1.22***
					(0.25)
Partner without ability but with financing					1.07**
					(0.47)
Positive evaluation		0.71***	0.41	0.32	0.40*
		(0.29)	(0.26)	(0.21)	(0.25)
R&D expenditures		0.27***	0.10**	-0.02	0.10***
		(0.05)	(0.04)	(0.03)	(0.04)
Commercialization investment			0.20***	0.19***	0.20***
			(0.03)	(0.03)	(0.03)
Pseudo R^2(%)	0.09	0.15	0.19	0.15	0.19
N	761	761	761	734	761

from 1.17 to 0.80 in Table 5 and drop from 1.46 to 1.27 in Table 6. These results represent a decrease of the original partnership coefficients by an additional 11.5% and 1.3%, in Tables 5 and 6 respectively. However, after controlling for these selection effects, the partnership dummy still remains significant and large. For example, at the sample mean it increases revenues of commercialized inventions by either 80% or 127%, depending on the estimate, a non-trivial impact. The size of this effect is 28% and 44% of the original partnership coefficient, respectively.

Another result to note is that once we control for inventor and invention characteristics prior to collaboration, the coefficient for own financing ceases to be significant. This may be the case because our propensity score method uses observables that are correlated with the borrowing capacity of the inventor. In addition, the effect of the inventor's pre-team R&D expenditures on commercialization success also ceases to be significant. The effect of the initial R&D on commercialization success is apparently strongly correlated with the invention characteristics determining partnership formation. Indeed, rather surprisingly, this result shows that all of the effect of invention quality is through its effect on partnership formation and none is through its direct impact on commercialization success.[20]

5.2 Accounting for selection on unobservables

Finally, we address the possibility that there is inventor-invention unobserved heterogeneity and measurement error of our identified selection effects. Here we utilize the information on whether the realized partners, in the opinion of the inventor, provided human or social or financial capital and the fact that some partners only provided financial capital. We decompose the partnership effect as follows: Partnership = partner with ability [P(a)] + partner without ability but with financing [P(not_a_fin)]. A result of our theoretical model is that the financial contribution of partners exclusively affect commercialization investment by relaxing liquidity constraints. An implication of this identifying restriction is that once we control for invention quality and commercialization investment, a partner that exclusively provides financing should not affect revenues in any other way, i.e., the coefficient for P(not_a_fin) should be zero ($\gamma = 0$). If the estimated coefficient for P(not_a_fin) is zero, $\widehat{\gamma} = 0$, then the coefficient for P(a) (label this $\widehat{\beta}$) should represent the partner's estimated value added of ability. Alternatively, if $\widehat{\gamma}$ is positive, the there

[20] In a second attempt to endogenize partnership formation we estimated an IV model with "the invention was stimulated at work" as exogenous predictor of partnership. It seems reasonable to presume that if the stimulus for the invention was at work it may make it easier for the inventor to find partners, but should not necessarily directly affect returns. The variable indeed was a significant predictor of partnership (t=2.94, p<0.01) and the J-test confirmed that it was not correlated with the error term of the outcome regression (Chi-2=0.09 and 0.06, p>0.10.) . Although the instrument is valid and reliable the results were not stable. This is a situation where the instrument simply is too weakly identified.

Table 6: Estimates of Productivity of Inventor's and Other's Capital

This table presents results from Tobit regressions. The dependent variable is the natural logarithm of commercialization revenues. The independent variables are partnership, a dummy variable =1 if an inventor formed a partnership to commercialize the innovation and 0 otherwise; partner with ability is a dummy variable =1 if the inventor formed a partnership and the partner contributed human and/or social capital and 0 othewise; partner ability but with financing is a dummy variable =1 if the inventor formed without a partnership and the partner contribute financing but did not contribute neither human nor social capital; Positive, which is a dummy variable =1 if the CIC assesment was positive, 0 otherwise; and own financing and other financing are the natural logarithms of the total R and D expenditures and the total commercialization investment from the inventor and the partner, respectively. All data are in Cdn 2003 dollars. All regressions include dummy variables controlling for the project's industry, and the year the invention was assessed by the CIC. Standard errors in parenthesis. ***, ** or * mean the coefficient is significant at the 1 percent, 5 percent, or 10 percent level, respectively. Coefficient estimates are decomposed into marginal effects on probability of commercialization and marginal effects on commercialization revenues conditional on commercialization.

	Model 1	Model 2	Model 3	Model 4	Model 5
	Tobit	Tobit	Tobit	Propensity Score Weighted Tobit	Tobit
A. Marginal effects of partnership on the probability of commercialization					
Partnership		0.129***	0.114***	0.111***	
		(0.017)	(0.017)	(0.013)	
Partner with ability					0.127***
					(0.018)
Partner without ability					0.089***
but with financing					(0.032)
Positive evaluation		0.049**	0.041**	0.044***	0.040**
		(0.016)	(0.017)	(0.013)	(0.017)
own financing		0.017***	0.016***	0.002	0.015***
		(0.003)	(0.003)	(0.002)	(0.003)
external financing			0.004**	0.005***	0.004**
			(0.002)	(0.001)	(0.002)
B. Marginal effects of partnership on commercialization revenues					
Partnership		1.65***	1.46***	1.27***	
		(0.28)	(0.28)	(0.24)	
Partner with ability					1.573***
					(0.288)
Partner without ability					1.103**
but with financing					(0.515)
Positive evaluation		0.70***	0.59**	0.63***	0.573**
		(0.27)	(0.27)	(0.24)	(0.269)
own financing		0.27***	0.25***	0.04	0.247***
		(0.05)	(0.05)	(0.03)	(0.047)
external financing			0.06**	0.09***	0.063**
			(0.03)	(0.03)	(0.029)
Pseudo R^2(%)		0.16	0.16	0.09	0.16
N		761	761	734	761

will likely be selection on unobservables and therefore $\widehat{\beta}$ may be have an upward bias.

Model 5 (Model 4) in Tables 5 (6) replaces Partnership with dummies for P(a) and P(not_a_fin). In Table 5, where we control for R&D expenditures and commercialization investment, we find that $\widehat{\beta} = 8.10$ ($p < 0.01$), and $\widehat{\gamma} = 6.92$ ($p < 0.05$).[21] In Table 6, where we control for the inventor's expenditures and the partner's investment, we find that $\widehat{\beta} = 9.64$ ($p < 0.01$) and $\widehat{\gamma} = 6.80$ ($p = 0.06$). Therefore, it appers that $\widehat{\beta}$ is upwards biased due to selection on unobservables.

We proceed to separately identify the contribution of the partner's ability from selection on unobservables. Rather than imposing further parametric restrictions to obtain point identification, we construct a lower bound for $\widehat{\beta}$. The effect of selection on unobservables may differ between partners who provide abilities and partners who only provide financing. Indeed, Figure 1 shows that conditional on inventor's assets the partnerships that receive only financing ($A = 1$) have on average higher quality inventions than the rest of the partnerships. An implication of this result is that the higher the quality of an invention, the more likely is that a partnership with only financing will be formed. This is equivalent to that $cov(P\_a, Q) < cov(P\_not\_a\_fin, Q)$. The sign of this inequality allows us to calculate a lower bound of the partner's ability: $\beta^L = \widehat{\beta} - 0.23\widehat{\gamma}$.[22] Evaluating the right hand side of the bound at the estimated $\widehat{\beta}$ and $\widehat{\gamma}$, we obtain $\beta^L = 6.50$ (std. err. $1.91, p < 0.00$) for the estimation presented in Table 5. Because we can safely assume that an upper bound for β is $\widehat{\beta}$, the best estimate of partner's ability must lie in the range $\beta \in (6.50, 8.10)$. The lower bound represents a partnership coefficient that is lowered from 7.91 in Model 3 to 6.50 in Model 5 of Table 4. With these inclusions the lower bound effect of partner ability on P(comm.) is 0.075 and the effect of partner ability on revenues is 0.98.[23] These lower bounds on the value added of partner's ability remain economically significant. For example, the mean probability of commercialization increases from 0.11 to 0.18 at the estimated lower bound value added.

[21] In the text we report coefficient estimates rather than marginal effects. The Table displays marginal effects.

[22] Define $bias(\widehat{\beta}) = \frac{cov(P\_a,Q)}{Var(P\_a)}$ and $bias(\widehat{\gamma}) = \frac{cov(P\_not\_a\_fin,Q)}{Var(P\_a)}$. $bias(\widehat{\gamma}) = \widehat{\gamma}$ since our theoretical model implies that the true value of γ is 0, while $bias(\widehat{\beta}) = \widehat{\beta} - \beta$. Rearranging and using that $Cov(P\_a, Q) < Cov(P\_not\_a\_fin, Q)$, the lower bound β^L for $\widehat{\beta}$, is $\beta^L = \widehat{\beta} - \widehat{\gamma}(\frac{Var(P\_a,Q)}{Var(P\_a)}) = \widehat{\beta} - 0.23\widehat{\gamma}$. We have replaced $Var(P\_a, Q)$ and $Var(P\_a)$ with their sample counterparts.

[23] The respective figures for estimations presented in Table 5 are: $\beta^L = 8.08$, std. err. 2.02. The best estimate of partner's value added thus lies in the range $\beta \in (8.08, 9.64)$. In the regression of Table 6 the lower bound represents an additional reduction of the partnership coefficient from 9.19 in Model 3 to 8.08. With these inclusions the lower bound marginal effect of human and social capital on P(comm.) drops from 0.114 to 0.107 and the marginal effect of value added on revenues drops from 1.463 to 1.318, both significant reductions.

6 Conclusion

We investigated the value of informal capital for invention commercialization through business partnership formation. Partnerships are defined as when an inventor partners with someone to obtain human capital, social capital and/or financing in order to commercialize an invention. Our characterization of potential partners reflects high net worth individuals, typically with some prior business and/or entrepreneurial experience. We impose no restrictions on their social relations to the original founder.

We develop a model of invention commercialization with partnership formation which reveals three selection effecs. We show that partners are more likely to join inventor-inventions of high quality because these inventions allow them to obtain a higher return as compensation for their effort. A second insight is that among all potential partners the better partners are more likely to join inventors. Lastly, inventors with high quality inventions are more likely to be liquidity constrained and consequently more likely to seek partners for financing.

Raw data reveal that the effect of partnerships on project outcomes is considerable. The rate of commercialization of inventions run by partnerships is five times larger than those run by solo entrepreneurs and revenues are almost ten times as large for partnerships as for solo entrepreneurs. The data reveal selection into partnerships based on invention quality: 39% of inventions rated as high quality were eventually joined by a partner, while only 19% of inventions with low quality were joined by a partner. To examine selection on financing we note that the model predicts that the marginal investment return should drop once a partner provides financing and that the probability of a partner bringing financing should increase with pre-team project quality. Both predictions are supported in empirical analysis.

The model further predicts that the value added of partner qualities must be interpreted as a treatment-on-the-treated effect. Once implementing this specification in Tobit analysis and controlling for selection on invention quality and external financing, the remaining effect of partnership formation must be due to the partner ability value added or unobserved heterogeneity. We try to isolate the effect of value added in two ways and find that it represents an increase in the probability of commercialization between 0.06 and 0.10 in a propensity-score-weighted specification, and between 0.08 and 0.11 in an unobserved-heterogeneity specification. These are economically meaningful results as the mean probability of commercialization is 0.11. The estimated effect of value added on revenues is also large approximately representing eaither an 80% or a 127% increase in revenues for commercialized inventions, depending on the specification.

Our paper relates to the growing work in finance which tries to estimate the value added of venture capital to entrepreneurs. This effect has been hard to isolate because VCs select on project quality, they probably release credit constraints, and may also provide various forms of value added. The three effects appear simultaneously when projects are financed by VCs. In a recent paper Kerr, Lerner, and Schoar, 2010 compare the impact of obtaining and not obtaining informal venture capital for those just above and below a funding cut-off, thereby eliminating much of explanations based on selection on unobservables and sorting. We take a different approach than Kerr et al., in that we try to separately estimate both the sorting and added value effects, and we also try to disentagle the effect of releasing liquidity constraints from value added.

Our setting is admittedly unique. We likely examine a domain where good business partners' human and social capital are considerably more useful than in standard start-ups such as the mom-and-pop corner store. In this respect our sample is probably more similar to that in Kerr's et al. study, while at the same time our sample does not contain many of the high-flying projects that receive VC funding.[24] Nevertheless, our model and empirical methodology is with ease portable to other related domains of investigation. Our data further exhibited some limitations such as not linking the type of external investors with the amounts they provide, not counting the number of partners, not collecting contractual information (we doubt there exist much), and not including the characteristics of realized as well as potential partners. These limitations provides opportunities for future research.

The policy implications that one may draw from these estimations must be very tentative given the first-of-a-kind nature of this work. Nevertheless, if the results hold up in future work, it would suggest that for inventive projects, the major policy leverage to increase commercialization rates and revenues is to lubricate the market for finding skilled partners. Furthemore, the analysis echoes the sentiments by angel investors that they have a tough time finding sufficient investment opportunities (Mason, 2009) In this study the few projects with high initial quality had many times higher participation rates by business partners than those with mediocre quality.

Finally, our work contributes to the literature on entrepreneurial choice. Lazear (Lazear, 2005) develop a theory of entrepreneurs as jacks-of-all-trades where he assumes that the entrepreneur must perform all tasks. The model we propose differs from Lazear's in that we allow individuals with insufficient skills to form partnerships to obtain the required skills rather than having to invest in own skill development. Our model also addresses project financing on which Lazear is silent.

[24] The fraction which received VC financing was 0.8%, too small to be analyzeable in our study.

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7 Appendix: Inventor's maximization problem

Let $V(Q,Z,A)$ define the expected value of an invention of quality Q with a potential partner with ability A evaluated at the profit maximizing capital investment as

$$V(Q,Z,A) = \max_{a \in \{0,1\}} \{V^a(Q,Z,A)\}$$

where

$$V^a(Q,Z,A) = (1 + aA(\beta))Q{K^*}^\alpha + r(Z - K^*) - a\tau$$

where $\alpha \in (0,1)$, the indicator $a_i \in \{0,1\}$ illustrates whether a project is run as a solo-entrepreneur or partnership, and K^* is the optimal commercialization investment, which may be constrained if $a = 0$. The capital investment that maximizes the inventor's profits from commercializing the invention on her own is

$$K_e^* = \begin{Bmatrix} \left(\frac{\alpha Q}{r}\right)^{1/(1-\alpha)} & \text{if} \quad Q \leq \frac{r}{\alpha}(\lambda Z)^{1-\alpha} \\ \lambda Z & \text{if} \quad Q > \frac{r}{\alpha}(\lambda Z)^{1-\alpha} \end{Bmatrix}$$

and the capital investment that maximizes the partnership's profits from commercializing the invention is

$$K_t^* = \left(\frac{\alpha A(\beta)Q}{r}\right)^{1/(1-\alpha)}$$

8 Appendix Proofs

Proposition 1. There exist two cut-off rules, $\widehat{Q}^P(Z, A(\beta))$ and $\widehat{Q}^C(Z, A(\beta))$, that describes three potential choices that an inventor (Z, Q) that meets a potential partner with ability $A(\beta)$ can make: no partnership; partnership with financing; and partnership with no financing.

Proof.

We start by showing that there exist a level of Q such that for a fixed Z an inventor is liquidity constrained. Consider two cases: the inventor meets a partner, or she does not. If the inventor does not meet a partner, the constrained investment level is $K^* = \lambda Z$ for $Q > \frac{r}{\alpha}(\lambda Z)^{1-\alpha} = \widehat{Q}^C(Z, p)$. If the inventor meets a partner, we have $K^* = \lambda Z$ for $Q > \frac{r}{\alpha A(\beta)}(\lambda Z)^{1-\alpha} = \widehat{Q}^C(Z, A(\beta))$, where $A(\beta)$ is the partner's ability.

The second cutoff rule $\widehat{Q}^P(Z, A(\beta))$ is the level of invention quality that makes an inventor indifferent between forming a partnership and commercializing the invention solo. Let $V^a(Q, Z, A(\beta)) = (1 + aA(\beta))QK^{*\alpha} + r(Z - K^*) - a\tau$ be the value of an invention commercialized through partnership ($a = 1$) or solo ($a = 0$). $\widehat{Q}^P(Z, A(\beta))$ is the invention quality such that $V^1(\widehat{Q}^P, Z, A(\beta)) = V^0(\widehat{Q}^P, Z, A(\beta))$. There exists a unique cutoff $\widehat{Q}^P(Z, A(\beta))$. For that to follow, it must be the case that $\widetilde{V}(Q) = V^1(Q, Z, p) - V^0(Q, Z, p)$ is strictly increasing with Q and that the value of $\widetilde{V}(Q)$ is positive for some Q (e.g., a Q sufficiently high) and negative for another Q (e.g., $Q = 0$). We will then focus our analysis on showing that $\widetilde{V}(Q)$ is increasing in Q. Let us first consider a Q such that the inventor is liquidity constrained, i.e., $K = \lambda Z$. Then, as Q increases, the value of V^1 increases at a faster pace than V^0. Next consider the inventor not liquidity constrained. Here V^1 increases at a faster pace than V^0 with Q because a marginal change in Q in a partnership is amplified through the partner's ability $A(\beta)$. This is because $A(\beta)$ and Q enters multiplicatively in the revenue of an innovation. Therefore, we can conclude that, for a fixed Z and $A(\beta)$, there exist an invention quality level $\widehat{Q}^P(Z, A(\beta))$ that makes an inventor indifferent between forming a partnership or working solo.

Proposition 2. For a fixed wealth Z, the cutoff rule $\widehat{Q}^P(Z, A(\beta))$ is decreasing with the partner's ability $A(\beta)$. Therefore, the probability of forming a partnership increases with the quality of the invention Q.

Proof: We would like to show that the liquidity cutoff $\widehat{Q}^C(Z, A(\beta))$ and the partnership cutoff $\widehat{Q}^P(Z, A(\beta))$ are decreasing functions with the partner's ability $A(\beta)$. That $\widehat{Q}^C(Z, A(\beta))$ is decreasing with $A(\beta)$ for a fixed Z is straigthforward because $\widehat{Q}^C(Z, A(\beta)) = \frac{r}{\alpha A(\beta)}(\lambda Z)^{1-\alpha}$. Showing that $\widehat{Q}^P(Z, A(\beta))$ decreases with $A(\beta)$ is somewhat more involved. For a fixed Q, the higher $A(\beta)$ is, the higher is the the capital investment, and so is the value of partnership V^1. The value of *solo-entrepreneurship V^0 does not change with $A(\beta)$, so the difference between partnership and entrepreneurship increases with $A(\beta)$. Now we have to show that the higher Q is, the lower is the different between V^1 and V^0. For a fixed $A(\beta)$, the lower Q is, the lower is the capital investment and so is the value of partnership and the value of solo-entrepreneurship. However, because $A(\beta)$and Q enter multiplicatively in the revenue function, the value of partnership will drop more than the value of solo-entrepreneurship. Therefore, we conclude that the higher is the partner's ability $A(\beta)$, the lower is the cutoff $\widehat{Q}^P(Z, A(\beta))$.*

Proposition 3. Inventors who are liquidity constrained are more likely than unconstrained inventors to form partnerships.

Proof: To prove this result we must show that for a fixed inventor's wealth Z, the probability to form a partnership is higher for an invention with quality $Q > \widehat{Q}^C(Z, A(\beta))$ than for the rest of the inventions $Q \leq \widehat{Q}^C(Z, A(\beta))$. The probability to form a partnership is the probability to meet a partner with ability $A(\beta)$ such that $Q > \widehat{Q}^P(Z, A(\beta))$. Let us start with inventions where an inventor is not liquidity constrained, i.e., the quality level is such that $Q \leq \widehat{Q}^C(Z, A(\beta))$. Here the benefit of partnership is exclusively given by the partner's ability $A(\beta)$ and partnerships will only be formed for inventions with invention quality above $\widehat{Q}^P(Z, p)$ (see proposition 2). This implies that when $Q \leq \widehat{Q}^C(Z, A(\beta))$ the probability of partnership will tend to be low. Alternatively, if an inventor is liquidity constrained (i.e., $Q > \widehat{Q}^C(Z, A(\beta))$), the benefit to form a partnership is due to both the partner's ability $A(\beta)$ as well as the increase in the level of capital investment from the constrained level λZ to the unconstrained one $K^* = \left(\frac{\alpha A(\beta) Q}{r}\right)^{1/(1-\alpha)}$. The two effects together are associated with a lower cutoff to form a partnership $\widehat{Q}^P(Z, A(\beta))$ than for inventions held by inventors that were not liquidity constrained, i.e., $Q \leq \widehat{Q}^C(Z, A(\beta))$. Therefore, the probability to form a partnership is higher when the inventor is liquidity constrained than for the rest of inventions.

Proposition 4. Conditional on a partnership being formed, the average ability of a partner is strictly higher than the ability of the average potential partner.

Proof: Recall that $A(\beta)$ is the realization of a stochastic random variable that determines the partner's ability. Before meeting a partner, the ability of a potential partner is $E[A(\beta)]$. For a fixed invention quality Q and inventor's wealth Z, the probability of partnership is the probability a partner $A(\beta)$ meets a inventor with $Q > \widehat{Q}^t(Z, A(\beta))$. Since the function $\widehat{Q}^t(Z, A(\beta))$ is strictly monotone with $A(\beta)$, for a fixed invention quality Q, we can define the probability of partnership $Pr(A(\beta) > \widehat{Q}^{t[-1]}(Z, Q))$, where $\widehat{Q}^{t[-1]}$ is the inverse of the function $\widehat{Q}^t$. We want to show that conditional on a partnership being formed, the ability of the average partner is higher than the *expected ability of a partner, i.e.,* $E[A(\beta)|A(\beta) \geq \widehat{Q}^{t[-1]}(Z,Q)]] > E[A(\beta)]$*. This inequality holds for all* Q *in a partnership because* $A(\beta) \geq 1$*. Therefore, the ability of the average partner that formed a partnership is higher than the average potential partner.*