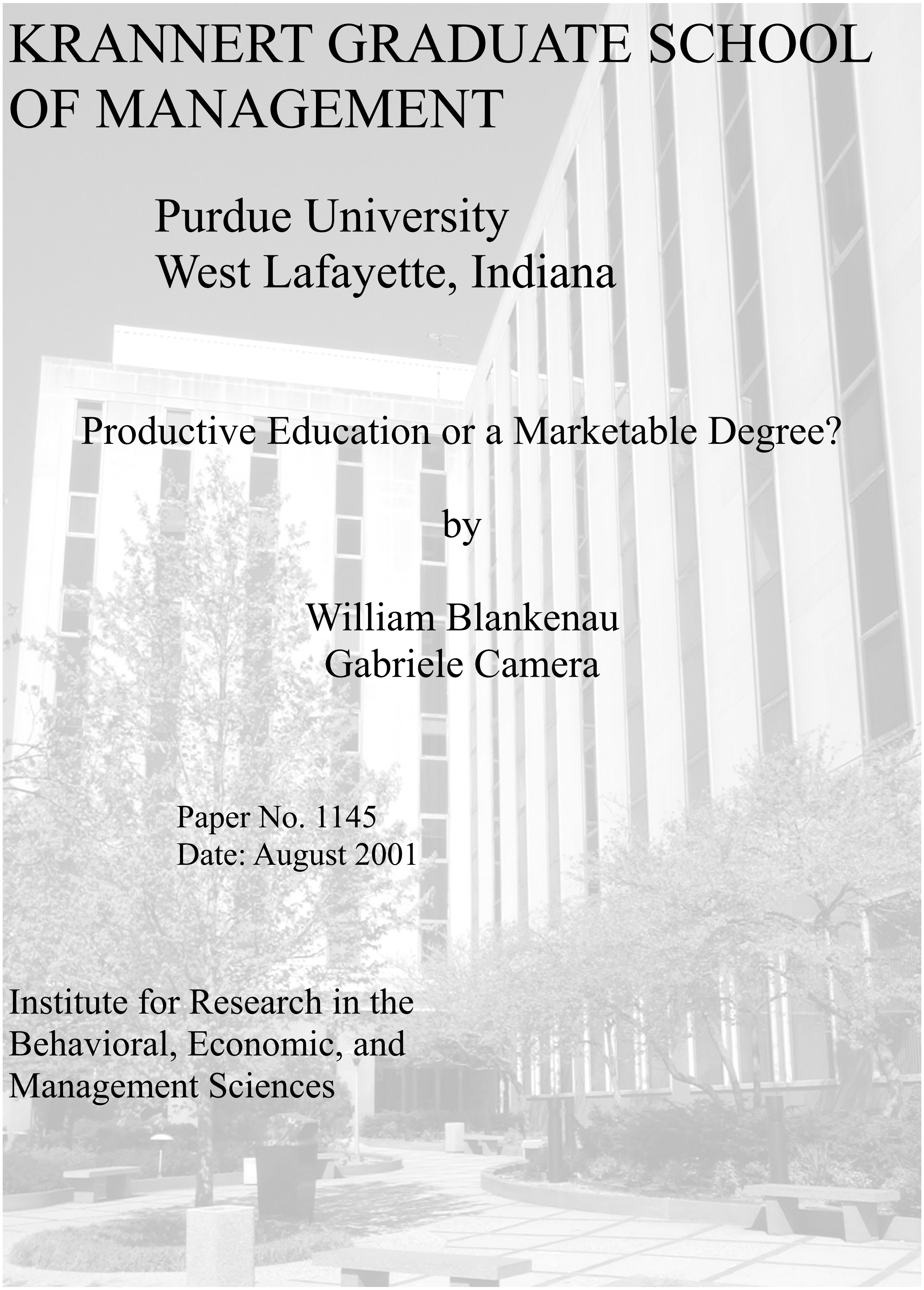

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Productive Education or a Marketable Degree?

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Productive Education or a Marketable Degree?[1]

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Abstract

Using a search-theoretic model where education's productive role is endogenous, we study the theoretical ramifications of separating human capital accumulation from educational investment decisions. Equilibria exist with ex-post skill heterogeneity within an education cohort, despite ex-ante homogeneity. This represents a market failure with over-investment in education but under-investment in skill, coexisting with better outcomes due to a strategic complementarity. Two elements affect market premia to skill and incentives to exploit education's productive role: degrees imperfectly communicate productivity, and contract imperfections allow the unskilled to capture some ability rents, in the short-run. Policy implications are explored.

Keywords: Search, Skills, Human Capital, Education. JEL: D8, I2, J24

"*I have never let my schooling interfere with my education.*" – Mark Twain

1. Introduction

What is the purpose of education? The insight provided by economic theory is tied to two distinct notions. First, education has a *productive role* in augmenting human capital (Becker, 1964). Second, education has an *identification (or signaling) role* in labor markets suffering from

[1]We are indebted to Jack Barron and Beth Ingram for thoughtful comments, and wish to thank seminar participants at Purdue University, the University of Iowa, the Society for Economic Dynamics 2000 meetings, and the European Econometric Society 2001 meetings.

informational asymmetries (Arrow, 1973, Spence, 1973, and Stiglitz, 1975). If schooling marginal costs are inversely related with imperfectly observable *innate* abilities, the more able acquire more schooling to signal their pre-existing higher productivity.

A large literature has exploited these notions in trying to account for the observed wage inequality, heterogeneity in individual productivity or educational attainment.[2] Interestingly, while the theoretical models proposed often differ in their most basic assumptions, they all share a common feature. When equilibrium difference in wages or productivity hinge on the existence of skill heterogeneity, the latter is either simply assumed (e.g. Acemoglu, 1999), or it is rooted, solely or partially, on *exogenous* heterogeneity factors.[3]

This paper develops intuition for two theoretical questions that naturally arise. The first is of a positive nature. Are exogenous heterogeneity elements *necessary* to spawn equilibrium differences in educational attainment and skills? The answer, we prove, is no. The second question is normative. Should policy makers think of fostering skill accumulation as a mere problem of reducing education costs? Once again, the answer is no.

Our approach in developing this intuition is to provide simple, albeit rigorous, theoretical examples. To do so, we construct a general equilibrium search-theoretic model where education's productive role is endogenous. That is, exploitation of an educational opportunity does not passively augment productive skills. Rather, skill accumulation requires a complementary effort. The market, however, cannot always recognize skills, and contractual imperfections impede a clear discrimination between high and low productivity workers. These frictions are key in generating ex-post skill heterogeneity. The intuition is simple. Should someone invest in a degree *and* skills? Not if it is easy to match with someone more productive, and to extract some of her ability rents.

The theoretical contribution is twofold. On the positive side, we complement the theoretical literature on the determinants of skill heterogeneity. We illustrate how differences in education and skill (across identically schooled agents) may arise despite the absence of ex-ante heterogeneity

[2] Examples of surveys are Hanushek (1986), Owen (1995), and Weiss (1995).

[3] Factors can be pre-existing and payoff-relevant, as the innate abilities' heterogeneity of Arrow (1973) or Kremer and Maskin (forthcoming). They can be pre-existing but payoff-irrelevant factors, as the observable immaterial features (e.g. color of skin) of Moro and Norman's (2000) statistical discrimination model. Factors can be intrinsic to the skill acquisition process, as the random factors in Lazear and Rosen (1981). Finally, heterogeneity factors can be a mixture of the above, as in Weiss (1983).

elements, both payoff-relevant and not. This, we show, is a market failure stemming from a strategic complementarity in the private investment in skill, and the presence of informational asymmetries.

On the normative side, we exploit the theoretical analysis to develop intuition on the role that incentives to academic achievement have on individual investment not only in education but also in the acquisition of productive skills. Such intuition, in turn, generates suggestions for some aspects of education policy. First, it indicates a key role for the provision of incentives to educational achievement, both from the market but also from within the educational system itself.[4] Second, it suggests a key role for policies directed at diminishing informational asymmetries, for example by increasing education standards or the informativeness of academic certificates. Third, it suggests that an increased public effort to lower the private cost of education may be ineffective in raising the workforce's skill level, when not complemented by incentives to student performance.

Prior research has identified factors capable of generating market failures in the acquisition and provision of productive skills.[5] Our contribution is to show that in the presence of informational asymmetries, individual strategic behavior and lack of incentives to academic achievement may *also* play an important role in generating such failures, despite agents' ex-ante homogeneity. We show how, when education's productive role is endogenized, the economy may get stuck in equilibria with "too much" schooling but "not enough" skills, from a social welfare perspective. In contrast, in virtually all treatments (of which we are aware) where an individual's education is a source of externality, under-investment in education is necessarily associated to under-investment in skills.

We proceed as follows. We give a snapshot of the model in section 2, and fully describe it in section 3. Section 4 discusses the equilibrium concept, market payoffs, value functions, and strategies. Section 5 studies existence and characterization of equilibria in economies with and

[4] The need for incentives to academic achievement is prominent in the U.S. debate. The Commission on the Skills of the American Workforce (1990), pointed out that "Many employers require a high school diploma for all new hires, yet very few believe that the diploma indicates educational achievement. ... [T]he non college bound know that their performance in high school is likely to have little or no bearing on the type of employment they manage to find." The Commission noted that employers have realized long ago that it is possible to graduate from U.S. high schools and still be functionally illiterate.

[5] In sorting models of education differences in innate abilities and informational asymmetries may generate a wedge between private and social returns to skills (Weiss, 1995). The labor literature has highlighted firms' imperfect competition for labor, individuals' credit constraints, and matching externalities as factors which may lead to market failures (Booth and Snower, 1995).

without informational asymmetries. Section 6 concludes. Proofs are in Appendix.

2. A Snapshot of the Model

We find it useful to give a quick overview of the model's main features, to both compare it and differentiate it from related work.

To focus on the role of information frictions in guiding education and skill investment decisions, we consider an environment where anonymous workers can form short-lived productive matches, but cannot enter long term contracts. For this reason we choose to work with a search-theoretic model. Education has a productive role: only through it can an individual acquire, and then market, productivity-enhancing skills.[6] Education, however, does not have a signaling role because agents are assumed ex-ante homogeneous. They make uncoordinated education decisions prior to entering a labor market characterized by information frictions. By investing in the educational opportunity the agent earns a perfectly recognizable but intrinsically useless degree. Additional effort is required to gain imperfectly recognizable skills. Thus, in contrast to the sorting models of education literature, the degree cannot signal innate abilities but only certifies the educational opportunity has been undertaken.[7] Realizing that not all those certified may have *chosen* to augment their skills, the market forms expectations on the probability any schooled agent has done so; it identifies as unskilled all the others.

To give focus to our study, we concentrate most of our analysis on economies where the acquisition of skills is essential *only* in expanding market allocations (i.e., the acquisition of skills cannot generate surplus, under autarky). Agents can produce in autarky or attempt to enhance earnings by marketing their labor to firms. Doing so is costly due to search frictions in the tradition of Diamond (1982), Mortensen (1982), or Pissarides (1987). Firms are temporary two-agent partnerships in the production of a homogenous good, where surplus is generated only if *some* skills are present, due to production complementarities. The acquisition of skill thus generates a

[6] This is a venerable notion: Adam Smith recognized the role of "habit, custom, and education" in generating the "difference of talents" so crucial to the division of labor. The standard view is that both cognitive achievement (e.g. competence in reading, problem solving) and socialization (e.g. learning to work with others) increase a student's productivity. For example, Bishop (1989) argues that, absent the general intellectual achievement test score decline between 1967 and 1980, labor quality would have been 2.9 percent higher in 1987, and GNP $86 billion higher.

[7] These basic ideas motivate the discussion contained in Blankenau (1997).

positive externality. Imperfections in the contracting process, however, affect the short-run market remuneration of skills: in undetected mismatched partnerships, the less productive agent captures some of her partner's ability rents.[8] This causes adverse selection in that while everyone prefers to team up with the most productive workers, the unskilled do not sort themselves out of the market.

Due to its simplicity, the model offers a straightforward intuition for the existence of ex-post skill heterogeneity. The limited effectiveness of degrees in communicating skills creates informational asymmetries which can be exploited due to the contracting imperfections. Thus, agents may engage in strategic behavior, investing in a degree but not skills, in order to mimic skilled workers and capture some of their ability rents, in the short-run. The extent of these imperfections affects the market premium to skill, agents' decisions, and the aggregate outcome. In particular, for an unskilled agent, the value of a degree hinges on how easily its possession allows him to match with a skilled worker, and free-ride off her productivity.

Free-riding behavior, however, not only diminishes aggregate productivity, but it also generates imperfect correlation between education and skill. This creates a negative externality which works its way though market expectations, since the more productive workers may refuse to match with someone whose skills aren't apparent and are likely to be absent. This reduces the marketability of degrees, skills, and aggregate activity. Due to a strategic complementarity in skill investment decisions, this market failure may coexist with Pareto-superior outcomes. In turn, existence of socially preferred equilibria depends not only on information frictions and relative market remuneration to skill, but also on the investment required to get a degree, relative to the cost of acquiring skills. Because lowering the cost of education increases the net gain from getting a degree without earning skills, an equilibrium with lower skill accumulation may emerge.

3. Environment

Time is discrete and continues forever. There is a constant population comprised of a measure one continuum of finitely-lived ex-ante identical *unskilled* agents. At every date the agent faces probability $1-\pi$ of leaving the economy at the beginning of the following period. Those who exit are replaced by new entrants. There is an educational opportunity which allows the new agents

[8] Skilled agents, however, have the largest lifetime return, in equilibrium. This is meant to capture the feature that remuneration schemes do not appear to sufficiently reward educational achievement and greater productivity in the short run, but do so in the long-run (e.g. Bishop, 1987, 1991, Lazear, 1977).

to enhance their skills, at a cost. Upon entering the economy agents must choose whether to earn a costly *degree*, and, contingent on that, whether to costly acquire productivity-enhancing *skills.* For simplicity it is assumed that, although separate and complementary, these decisions must be made simultaneously and may take place only in the first period of life.[9] Once the choice is made, the acquisition of a degree or skills is instantaneous. To earn a degree, a process we call *schooling*, an unskilled agent has to pay a one-time utility cost $c_d \geq 0$.[10] Degrees are payoff irrelevant and additional resources must be expended in order to increase own productivity. Choosing to earn skills generates an additional utility cost $c_s > 0$, by which we recognize the existence of a quantifiable level of disutility from supplying effort while in school.

To limit the dimensionality of the state space, it is assumed that a skilled agent cannot further augment her skill level by repeated use of the educational opportunity, or by other means (say, via learning by doing). Thus, the support of the skill distribution has only two elements. An agent can be unskilled, with low-productivity, or skilled, with high-productivity. The degree cannot be transferred, and cannot be privately produced. We denote the agents' possession of skill, degree, or lack of both, using the subscript $i = s, d, n$. Specifically, n denotes the absence of a degree; d identifies someone with a degree but no skills; s identifies someone with a degree and skills, whom we call a *skilled* agent.

Following this initial choice the agent enters a market where she can promote her productive abilities. At each date t she is randomly and anonymously matched with exactly one agent. We refer to matches between two skilled as *self-matches* in contrast to *cross-matches*, where agents have different productivity. Once matched, the partners independently and simultaneously choose whether to costlessly jointly produce a homogenous, non-storable, and perfectly divisible good. The

[9] Obviously, innate productivity differentials may exist, and schooling may enhance them even with minimal individual effort. We set aside these issues, for clarity and focus, adopting Adam Smith's homogeneity view: "When they came into the world, and for the first six or eight years of their existence, they were perhaps very much alike, and neither their parents nor playfellows could perceive any remarkable difference."

[10] A natural interpretation of c_d is the value of forgone wages (identical due to identical innate abilities). Modeling the educational process as time-consuming complicates the exposition, providing little additional insight. The assumption of instantaneous acquisition is common. For example, in Lazear and Rosen (1981) workers (who may differ in abilities) choose to invest in costly productivity-enhancing and unobservable skills prior to entering the market. Costrell's (1994) heterogenous students choose to increase their productivity prior to labor market entry, by instantaneously acquiring cognitive and social skills.

output generated is shared according to a rule which both parties take as given (described later). If both propose joint production, they set up a temporary firm, an activity we call *market production.*[11] Firms are short-lived (they terminate after one period). If the proposals are inconsistent, each agent costlessly produces in autarky, and waits until the next period to be matched again. Production is instantaneous, can only take place once per period, and output is consumed immediately after production.

The period utility from consumption, u, is linear and future utility is discounted by $\beta \in (0,1)$. The assumed risk neutrality allows us to discuss the result of productive activities in terms of u and not output quantities. Education's productive function makes skilled agents more productive in both autarky and market production. Let u_i be the utility associated with autarkic consumption by an agent i, and let u_{ik} be the utility associated with consumption of the *entire* market output produced by agents $i, k \in \{n, d, s\}$. Since degrees are payoff-irrelevant $u_{di} = u_{ni}$, $u_d = u_n$, and we assume $u_s > u_n$. There are complementarities in market production and increasing returns to the match's skill level: $u_{ik} \geq u_i + u_k$, holding with equality only if $i, k \in n, d$, and $u_{ss} > 2u_s > u_{sn} > u_{nn} = 2u_n$. Thus, only skills can generate market surplus.[12]

There are information frictions. Histories of past matches are unobservable, skills are imperfectly observable, while possession of a degree and joint output are observable in the match. Contingent on a match with a schooled individual, an agent can observe her possession of skills with probability $\gamma \in [0,1]$, independent across agents and matches.[13] Thus one, both, or none of the parties may be informed about the other's productive abilities. However, an agent cannot directly observe whether his partner is informed or not.

4. Symmetric Stationary Equilibria.

We focus on symmetric stationary rational expectations equilibria, where individuals adopt

[11] This is a natural way of interpreting a firm (e.g. Kremer and Maskin, forthcoming), and a simple yet effective way to capture the influence that an individual's productivity has on the productivity of others.

[12] One interpretation is that market production can be better organized (relative to autarky) if skills are present. For example, complementarities stem from the benefits of specialization, and the skilled can carry out specialized tasks more efficiently.

[13] This is a standard way of modeling informational asymmetries in bilateral matches (e.g. Williamson and Wright, 1995), and γ can be interpreted as a noisy signal. In our context, it may be taken to capture the efficiency of a publicly observable testing procedure used to ascertain the productivity of those schooled.

symmetric Nash strategies taking market payoffs and strategies of others as given. When market production takes place, the individual payoff is determined by a non-discriminatory rule which specifies a division of output, independent of the type of match. This is adopted for tractability, and may be thought of as implementing a solution to a more structured bargaining procedure. In equilibrium, decisions are individually optimal, time-invariant, and identical for individuals of identical type. All actions are based on the correct evaluation of the gains associated with each possible match, strategies of others and the distributions. That is, agents have rational expectations.

To prove existence we start by conjecturing a candidate equilibrium strategy vector. Subsequently, we characterize the outcome in terms of the endogenous distribution of agents' types, value functions (defined over types), and market payoffs. Then we show that the proposed strategy vector is individually optimal, by providing conditions for existence of the equilibrium in terms of the parameters of the model.

4.1 Strategies and the Determination of Market Surpluses.

The educational choices of the representative agent are described by her strategies δ and σ. In a stationary equilibrium, $\delta \in [0, 1]$ defines the probability that an agent chooses to acquire a degree in her first period of life; $\sigma \in [0, 1]$ denotes the conditional probability that she chooses to acquire skills, contingent on having chosen to acquire a degree. Denote by $\omega \in [0, 1]$ the probability that a representative skilled agent proposes joint production to her partner, contingent on a match with someone whose skills are unobserved. Agents have symmetric beliefs over σ, δ, and ω; denote by δ', σ' and ω' the steady state strategies of an individual when she takes as given the strategies of others.

We focus on an economy where the contracting process, which cannot be based on past performance or the actions taken in the match, is imperfect and incapable of inducing truthful revelation of own productivity. We choose to be agnostic about the contracting procedure itself. The only requirement is that it must be capable of generating ex-post surplus gains to anyone matched with a skilled partner, and losses to *some* type when their teammate is unskilled.[14] In particular, joint production occurs if the expected payoffs satisfy the interim participation constraint of both

[14] This is for tractability. It is the outcome, not the procedure, that matters for equilibrium skill heterogeneity. Formalization of some bargaining procedure that not always allows differentiation between productivity types (e.g. Kennan and Wilson, 1993) would complicate the exposition unnecessarily, with little gains in intuition.

agents, but not necessarily the ex-post participation constraint. Thus, there is potential for adverse selection.

Depending on the relative size of the u_{ik} parameters, several output sharing rules can be considered (contingent, for example, on the output level, or the absence of a degree). For clarity, we carry out the analysis considering a non-discriminatory rule which assigns an equal share of output to each partner, irrespective of their schooling. Since agents can always consume in autarky, we let $G_i(k)$ denote the market surplus (G for "gain") to agent i when she is matched with agent k. By retaining this framework, we can characterize equilibria by focusing only on three market surpluses:

$$G_s(s) = \frac{u_{ss}}{2} - u_s, \;\; G_s(d) = \frac{u_{sn}}{2} - u_s, \;\; G_d(s) = \frac{u_{sn}}{2} - u_n.$$

The first and the second are the surpluses a skilled agent may receive from marketing her abilities. Self-matches generate surplus $G_s(s)$, i.e. the utility received from consumption of her share of market output minus her utility in autarky. Because of described complementarities in market production, $G_s(s) > 0$, hence both skilled agents improve over autarky. Thus, a skilled always proposes joint production when she is aware of being in a self-match. When putting her abilities to use in cross-matches the skilled obtains $G_s(d)$ surplus (d indicates her partner has a degree but no skills). Similar considerations can be made for $G_d(s)$, the surplus to a schooled agent in a cross-match. Recall that a cross-match generates a positive total surplus since $u_{sn} - u_s - u_n > 0$. It follows that $G_d(s) > 0$, while the sign of $G_s(d)$ depends on u_s/u_{sn}. Since $2u_s > u_{sn}$, then $G_s(d) < 0$.

Thus, contract imperfections allow the unskilled to capture some of the ability rents of her skilled partner. Agents without skills never sort out of the market, and choose to participate in all matches with someone schooled. Production between two unskilled is not strictly beneficial, $u_{nn} = 2u_n$, hence we assume it won't be undertaken (a small transaction cost would endogenize this in equilibrium). The skilled won't *knowingly* participate in cross-matches. When abilities are unobserved, however, a skilled *may* still choose to take the risk to occasionally share her ability rents with someone schooled but lacking skills (setting $\omega' > 0$).

The virtue of this specification is that it allows us to generate the simplest possible theoretical environment with the following key features. First, since $G_s(s) > 0$, there are incentives to earn skills if there is possibility to engage in high-return market production. Second, there are positive external effects from skill acquisition (skills generate surplus in *any* market match). This generates incentives to free-ride and underinvest in skills, when going through the educational process. Since

$G_d(s) > 0$, it may be worthwhile to undertake the educational opportunity without exploiting its productive function as a way to falsely signal possession of skills. Market participants recognize this possibility and form expectations on whether someone who has a degree is also skilled (the probability σ). Based on such expectations, the skilled might limit participation in unrecognized matches to reduce the risk of a surplus loss, since $G_s(d) < 0$. This behavior has perverse macroeconomic consequences: it reduces the extent to which skills are marketable, the value of education, and the potential social gains.[15]

4.2 Value Functions

Let $P_s = \delta\sigma$ denote the proportion of skilled population, and $P_d = \delta(1-\sigma)$ be the proportion of schooled but unskilled population; $P_d + P_s = \delta$ is the educated population proportion, and the remainder is the proportion of uneducated agents.

In a stationary equilibrium denote by V_n, V_d, and V_s the expected lifetime utility of, respectively, an agent with no degree, with a degree but unskilled, and with skills. Using strategies and distribution of skills/degrees, we define conditional probabilities of joint production for those who have undertaken the educational opportunity. A skilled agent faces a probability $P_s[\gamma + (1-\gamma)\omega]$ of being matched with a skilled agent willing to jointly produce, while P_d is the probability of meeting someone with a degree but no skills (who is always willing to jointly produce). An unskilled but educated agent faces a probability $(1-\gamma)P_s\omega$ of jointly producing with a more productive agent who did not detect her lack of skills. Letting $r = 1 - \beta\pi$, the value functions must satisfy:

$$rV_s = u_s + \gamma P_s[\gamma + (1-\gamma)\omega]G_s(s) + (1-\gamma)\max_{\omega' \in [0,1]} \omega' \{P_s[\gamma + (1-\gamma)\omega]G_s(s) + P_d G_s(d)\} \quad (1)$$

$$rV_d = u_n + (1-\gamma)P_s\omega G_d(s) \quad (2)$$

$$rV_n = u_n. \quad (3)$$

For example, (1) indicates that the lifetime flow return to a skilled individual is determined by two main components. She can produce autarkically and enjoy temporary utility u_s, or she may earn surplus from marketing her skills. Due to the loss generated by the contractual imperfections,

[15] It can be proved that if $G_s(s) > G_s(d) > 0$ the incentive to not exploit education's productive function remains as long as *some* ability rents are lost in cross-matches. We prefer to work with $G_s(d) < 0$, in showing how ex-post skill heterogeneity can arise, only to simplify the proofs of existence, and to more sharply differentiate the value of self- from cross-matches.

she rejects production with someone *known* to be unskilled. When she observes her partner's productivity (with probability γ) she proposes joint production. The expected value of these matches is $\gamma P_s [\gamma + (1-\gamma)\omega] G_s(s)$, proportional to the frequency of encounters with skilled agents willing to jointly produce. She may also obtain surplus from matching with a partner who has a degree but is of unobserved productivity (with probability $1-\gamma$). Because undetected mismatched partnerships entail surplus losses for the skilled, she proposes joint production, with probability $\omega' > 0$, only if her expected surplus is non-negative. The expected value attached to these matches is proportional to the sum of the surplus lost if 'mismatched', with probability P_d, and gained otherwise.

We emphasize that the value of skills rises with $P_s [\gamma + (1-\gamma)\omega]$. This term can be thought as gauging the 'marketability' of skills, i.e. the ex-ante probability that a skilled agent is able to earn market surplus, in a period. There are two components to it. The first is P_s, the probability of meeting a skilled partner; the second is $\gamma + (1-\gamma)\omega$, the probability that, contingent on the match, the partner undertakes joint production.

The other expressions are interpreted similarly. Comparing (2) and (3), someone stands to gain from earning a degree *only if* skills can be sometimes undetected ($\gamma < 1$), if there are some skilled agents, and if they are willing to take the risk to join an unobserved match, $P_s\omega > 0$.

4.3 Equilibrium Strategies

The representative agent chooses her optimal strategy taking as given strategies of all others $\{\delta, \sigma, \omega\}$, value functions $\{V_n, V_d, V_s\}$, and correctly evaluating the surplus in all possible matches.

Consider the actions which can be taken in the first period of life. Because the choice of education and skill accumulation are intertwined, for exposition we break up the agent's problem in two parts, moving backward. That is, contingent on having decided to undertake the educational opportunity, we first discuss her choice of skill acquisition. Given that decision, she acquires skill if it improves her expected lifetime utility. Her optimal choice of skill must satisfy

$$\sigma' \begin{cases} = 1 & \text{if } V_s - c_s > V_d \\ \in [0,1] & \text{if } V_s - c_s = V_d \\ = 0 & \text{if } V_s - c_s < V_d \end{cases} \tag{4}$$

Moving one step back, the educational opportunity is undertaken if it improves the agent's expected lifetime utility, i.e. her optimal choice of schooling must satisfy

$$\delta' = \begin{cases} 1 & \text{if } V_n < \max\{V_d, V_s - c_s\} - c_d \\ \in [0,1] & \text{if } V_n = \max\{V_d, V_s - c_s\} - c_d \\ 0 & \text{if } V_n > \max\{V_d, V_s - c_s\} - c_d \end{cases} \tag{5}$$

Next, we discuss the choice of joint production. An unskilled agent obtains positive expected surplus in all cross-matches because $G_d(s) > 0$. Thus, she always proposes joint production to someone who has a degree, even if her skills are unobserved. Since $G_s(s) > 0$, a skilled proposes production when her partner's skills are observed. Because $G_s(d) < 0$, she chooses autarky when her partner is recognized as unskilled, but when skills are unobserved she may still find it worthwhile to propose market production. Using (1), in equilibrium her optimal choice must satisfy

$$\omega' \begin{cases} 1 & \text{if } P_s[\gamma + (1-\gamma)\omega]\, G_s(s) + P_d G_s(d) > 0 \\ \in [0,1] & \text{if } P_s[\gamma + (1-\gamma)\omega]\, G_s(s) + P_d G_s(d) = 0 \\ 0 & \text{if } P_s[\gamma + (1-\gamma)\omega]\, G_s(s) + P_d G_s(d) < 0 \end{cases} \tag{6}$$

Given the output-sharing rule, a skilled agent proposes joint production if her expected surplus satisfies an interim participation constraint: it must be non-negative. Ex-post her gain may be negative.[16] Finally, aggregate consistency in equilibrium requires

$$\delta' = \delta, \;\; \sigma' = \sigma, \;\; \omega' = \omega. \tag{7}$$

To sum up, in equilibrium schooling, skill accumulation, and production decisions are individually optimal given correctly perceived strategies and distributions. Market production decisions must be based on the correct evaluation of all possible market gains (rational expectations). Equilibrium strategies must be time-invariant and identical for individuals of identical type.

Definition. *A symmetric stationary equilibrium is a list of educational strategies $\{\delta, \sigma\}$, production decisions, ω, and value functions $\mathbf{V} \equiv \{V_n, V_d, V_s\}$ such that (i) individuals maximize their expected lifetime utilities using symmetric Nash strategies, i.e. given $\{\delta, \sigma, \omega\}$, $\mathbf{V}$ must satisfy (1) though (3), and given $\mathbf{V}$, then $\{\delta', \sigma', \omega'\}$ must satisfy the best response functions (5)-(6), and (ii) strategies are stationary and identical across identical agents, i.e. (7) holds.*

[16]Since costs of schooling are homogenous across agents, and because $V_s > V_d$ in equilibrium, the participation constraint of an unskilled individual is slacker. Thus there is no possibility of signaling on part of the skilled.

5. Existence and Characterization of Equilibria

To start, we define *feasibility* of skill accumulation. Expression (5) underscores that a necessary (but not sufficient) condition for existence of *some* skill accumulation is $c_d \leq \max(V_s) - c_s - V_n$. The cost of schooling cannot exceed the largest expected gain from skill. The latter is represented by the largest expected net return to a skilled agent, $\max(V_s) - c_s$, minus the return to an unskilled, V_n. As (1) indicates, V_s is a maximum when $\gamma = P_s = 1$, in which case $r(V_s - c_s - V_n) = G_s(s) - [u_n - (u_s - rc_s)]$. Thus, a necessary condition for skill accumulation to be feasible is

$$c_d \leq c_H \equiv \frac{G_s(s) - [u_n - (u_s - rc_s)]}{r} \tag{8}$$

and since c_d can be positive, then

$$G_s(s) > u_n - (u_s - rc_s)\,. \tag{9}$$

In the ensuing discussion we consider *only* those cases where (8) and (9) hold and provide existence conditions by partitioning the parameter space $\gamma \times c_d$ in different regions. For clarity of exposition the set of equilibria is classified based on P_s and P_d, using the following nomenclature. There is a subset of equilibria with *degenerate* distribution of skills: with no skill accumulation, $P_s = 0$ ($\sigma = 0$), or with skill accumulation, $P_s = 1$ ($\delta = \sigma = 1$). There is a subset of equilibria with *heterogenous* distribution of skill, $P_s = P_s^* \in (0,1)$; that is, either someone doesn't have a degree, $0 < \delta < 1$, or education is *imperfectly correlated* with skill, $0 < \sigma < 1$, or both. Thus, if $P_s + P_d = 1$ everyone has a degree but its possession is imperfectly correlated with skill ($0 < \sigma < \delta = 1$). If $P_s + P_d \in (0,1)$ not everyone has a degree but its possession may or may not be imperfectly correlated with skill ($0 < \sigma \leq 1$); if $P_d = 0$ skills and schooling are *perfectly correlated*.

5.1 Equilibria with Full Observability

Here we study the case $\gamma = 1$ to identify the sources of incentives to education in the absence of the externalities due to informational frictions. With full observability cross matches never occur since $G_s(d) < 0$. Thus, investing in education always implies investment in skills. Incentives to undertake the educational opportunity exist whenever the market remuneration of skills satisfies (8)-(9). Earning skills is individually advantageous only if these are sufficiently marketable. Because of the uncoordinated nature of educational choices, skills' marketability is subject to strategic uncertainty. A strategic complementarity supports coexistence of multiple equilibria, some of which are market failures. Due to their self-fulfilling nature, however, selection of the socially preferred outcome is independent of the cost of education.

We formalize these considerations by looking at the individual best responses (4) and (5). Conditional on having undertaken the educational opportunity, (4) indicates that an agent weakly prefers earning skills, $\sigma' \geq 0$, if

$$P_s G_s(s) \geq u_n - (u_s - rc_s) \tag{10}$$

i.e. if the expected market surplus, $P_s G_s(s)$, is at least as large as its opportunity cost. The latter is the net gain to not earning skills while holding a payoff irrelevant degree in autarky, $u_n - (u_s - rc_s)$.

In a similar manner, (5) implies that undertaking the educational opportunity *and* earning skills is individually rational, $\delta' \geq 0$, if

$$P_s G_s(s) \geq u_n - (u_s - rc_s - rc_d) \tag{11}$$

i.e. if the expected market surplus is weakly larger than the net gain to remaining unskilled in autarky, $u_n - (u_s - rc_s - rc_d)$.[17] In (10) and (11) the left hand side measures the market incentive to earn skills. The easier it is to promote or market own skills (larger P_s), and the greater is the market surplus $G_s(s)$, the bigger is the incentive to earn them. The right hand side measures the incentives provided by mere autarkic production.

Two features stand out. If $\delta \geq 0$ (10) never binds if $c_d > 0$, thus $\sigma = 1$ and $P_s > P_d = 0$. That is, the productive role of education is always exploited, so that a ownership of degree is perfectly correlated with skills. Education, obviously, cannot be unproductive because the market *only* remunerates skills. Second, the market is an *irrelevant* source of incentives, in general, if skills generate surplus even in autarky, $u_n < u_s - rc_s$. In that case $\sigma = 1$, always, and $\delta > 0$ if education is not too costly, $rc_d < u_s - rc_s - u_n$. The consequence is that the choice of skill accumulation, σ, is independent of marketability and market remuneration of skills. The set of all possible equilibria and conditions sufficient and necessary for their existence conditions are summarized next.

Lemma 1. *Let $\gamma = 1$ and suppose that (9) holds. Define $P_s^* = \frac{u_n - (u_s - rc_s) + rc_d}{G_s(s)}$. The equilibrium set is such that $P_d = 0$ whenever $c_d > 0$, and*

[17] When $\gamma = 1$ then $V_n \geq V_d - c_d$. Thus, (5) indicates that $\delta' \geq 0$ if and only if $V_s - c_s \geq V_d$, i.e. $\sigma \geq 0$.

a) when $u_n \geq u_s - rc_s$, then (i) $P_s = 0$ always (where $P_d \in [0,1]$ only if $c_d = 0$), (ii) $P_s = P_s^*$, if $0 < c_d < c_H$ (where $P_d \in (0, 1 - P_s^*)$ only if $c_d = 0$), and (iii) $P_s = 1$ if $0 \leq c_d \leq c_H$.

b) when $u_n < u_s - rc_s$, then (i) $P_s \in \{0,1\}$, if $-[u_n - (u_s - rc_s)]\, r^{-1} \leq c_d \leq c_H$, (ii) $P_s = P_s^*$ if $-[u_n - (u_s - rc_s)]\, r^{-1} < c_d < c_H$, but also (iii) $P_s = 1$, if $0 \leq c_d < -[u_n - (u_s - rc_s)]\, r^{-1}$.

Figure 1 plots the equilibrium P_s (dark lines) against c_d. The case $u_n = u_s - rc_s$ is in panel (a). In this situation, contingent on choosing to earn a degree, autarkic production is not a source of bias in favor or against the acquisition of skills. Thus, the extent of skill heterogeneity depends *only* on the incentives provided by the market, for a given cost of education. If all workers are expected to be skilled, $P_s = 1$, everyone acquires skills since their cost is less than the expected market surplus they generate. As P_s, falls, so does the expected frequency of market production, hence the incentive to earning skills falls. Below the threshold P_s^* the expected market surplus is insufficient to recoup the cost of education, which is thus not undertaken. When $P_s = P_s^*$ agents randomize. Contingent on having chosen schooling, however, skills are always acquired, i.e. education's productive role is always exploited. As c_d shrinks (or as the market surplus grows) only a smaller P_s^* preserves indifference, hence its positive slope. Finally, because $V_n > V_s - c_s - c_d$ if $P_s = 0$, there is always the (self-fulfilling) possibility of a coordination failure with no skill accumulation.[18]

When $u_n < u_s - rc_s$ the equilibrium types are identical to those just described (panel (b)). Differences exist only if education is very cheap, in which case the choice of acquiring skills is trivially optimal, *independent* of the expected market remuneration to skill. This makes it a less compelling specification for the purposes of our study. When $u_n > u_s - rc_s$, on the contrary, the model is biased *against* the acquisition of skills (panel (c)), since skills generate a loss of surplus in autarky. The equilibrium types, however, are as in the case $u_n = u_s - rc_s$. One difference is a more stringent upper bound on c_d, due to larger disutility from earning skill; education is worthwhile only for a greater frequency of market production. Thus, even if $c_d = 0$ skill accumulation may not occur unless the market believes a sufficiently large segment of the population undertakes the educational opportunity (the positive lower bound for P_s^* in panel (c)).

This analysis shows that, in general, the educational choice of others has implications for an

[18] $c_d = 0$ also supports uninteresting equilibria with no skills and indifference to education, $P_d \geq P_s = 0$.

individual's decisions if market production is a relevant source of incentives, i.e. $u_n \geq u_s - rc_s$. This is not so when $u_n < u_s - rc_s$ and c_d is small. In particular, there is a strategic complementarity in skill decisions for *any* feasible c_d only if $u_n \geq u_s - rc_s$, in which case the three types of equilibrium P_s $(0, P_s^*$ and $1)$ always coexist and $P_s = 1$ is the Pareto optimum.

Proposition 1. *Let skills be observable. If market production is a relevant source of incentives to skill acquisition, equilibria with and without skill heterogeneity coexist; thus, market failures may occur. When education is undertaken its productive role is always exploited, hence education and skills are perfectly correlated.*

Define ex-ante welfare as

$$rW(P_s) = rP_s(V_s - c_s - c_d) + rP_d(V_d - c_d) + r(1 - P_s - P_d)V_n,$$

the weighted sum of flow returns to all types of agents in the economy. It is straightforward that $rW(1) = G_s(s) + u_s - rc_s - rc_d$ and $rW(P_s^*) = rW(0) = u_n$; (9) implies that $rW(1)$ is the largest. If $u_n \geq u_s - rc_s$ more and less desirable equilibria coexist for any feasible c_d. It follows that, from a steady state point of view, a policy of lump-sum education subsidies cannot be used as a tool for equilibrium selection. If anything, larger education costs can only be beneficial to the process of skill accumulation, because P_s^* is increasing in c_d.[19]

5.2 Equilibria with Imperfect Observability

We now set $\gamma < 1$ to study how information frictions affect the incentives to education and skill accumulation. Some may choose to "free ride" by earning a degree but not exploiting education's productive role, as long as they can earn some market surplus. The extent of this behavior is reflected in the equilibrium proportion of schooled but unskilled individuals, P_d. The key factors influencing it are the relative market remuneration of skills, captured by the ratio $G_s(s)/G_d(s)$, and the magnitude of information frictions, γ. This is underscored by examination of the individual best responses (4) and (5).

Conditional on undertaking the educational opportunity, (4) indicates that an agent weakly

[19] Equilibria $P_s = P_s^*$, however, are not stable to small perturbations of c_d. Perturbations such as a small drop in c_d would increase the incentives to skills, since $P_s^* G_s(s) = rc_d$. This would lead to $P_s = 1$.

prefers earning skills, $\sigma' \geq 0$, if

$$\begin{aligned}&\gamma P_s\left[\gamma+(1-\gamma)\,\omega\right]G_s(s)+(1-\gamma)\omega\left\{P_s\left[\gamma+(1-\gamma)\,\omega\right]G_s(s)+P_dG_s(d)\right\}\\&-(1-\gamma)P_s\omega G_d(s)\geq u_n-(u_s-rc_s).\end{aligned} \tag{12}$$

Its LHS measures the expected *market premium* to skills, a difference between two expected surpluses: the one earned by marketing skills (positive in equilibrium–see (6)), minus the surplus earned by marketing an unproductive degree, $(1-\gamma)P_s\omega G_d(s)$.

Given that the market expects that some skill accumulation takes place, $P_s > 0$, (5) indicates that an agent weakly prefers to undertake the educational opportunity, $\delta' \geq 0$, if

$$\begin{aligned}&\gamma P_s\left[\gamma+(1-\gamma)\,\omega\right]G_s(s)+(1-\gamma)\omega\left\{P_s\left[\gamma+(1-\gamma)\,\omega\right]G_s(s)+P_dG_s(d)\right\}\\&\geq u_n-(u_s-rc_s)+rc_d\end{aligned} \tag{13}$$

whose LHS, the expected market surplus to skills, differs from (11) due to $\gamma < 1$. Unlike their counterparts (10)-(11), inequality (12) need not be strict when (13) holds and $c_d > 0$.[20] When educational opportunities are undertaken there could be indifference towards skills, in which case their equilibrium correlation with education is imperfect.

As for $\gamma = 1$, market production is a relevant source of incentives to skills only if skills are inessential under autarky, i.e. $u_n \geq u_s - rc_s$. In fact, as u_n falls below $u_s - rc_s$, the productivity of others becomes strategically irrelevant for an agent's choice; skill accumulation takes place, when feasible, even in the absence of market production. Thus, as for $\gamma = 1$, the sign of $u_n - (u_s - rc_s)$ is inconsequential qualitatively: it affects the size of P_s but not the equilibrium set.

We exploit this feature by focusing on the case $u_n = u_s - rc_s$: skills, while necessary to generate market surplus, cannot generate surplus under autarky. By retaining this assumption, we construct economies where skills are *essential* in expanding market allocations, but are *inessential* under autarky. The implication is that individuals will invest in a degree, and possibly in skills, *only if* there is the possibility of marketing them. Doing so allows us to give focus to the analysis, by removing any productivity bias due to mere autarky. This also simplifies the exposition of the most interesting market outcomes, those with equilibrium heterogeneity in skill and educational choices.[21]

[20] (12) must hold as a weak inequality when $c_d > 0$. Since degrees are payoff-irrelevant $\delta' = 0$ if $P_s = 0$.

[21] When $\gamma < 1$ more parameters influence market incentives; this creates a steeper trade-off between amount of detail and transparency of results. A generalization to $u_n \neq (u_s - rc_s)$ and $G_s(d) > 0$ is contained in a technical appendix available from the authors.

The equilibrium set, and the conditions necessary and sufficient to support them, is as follows.

Lemma 2. *Let $\gamma < 1$ and $u_n = (u_s - rc_s)$. Then, $P_s = 0$ is always an equilibrium (where $P_d \in [0,1]$ only if $c_d = 0$). Furthermore,*

(a) If $0 < c_d < c_L(\gamma)$ and $\gamma < \gamma_H < 1$, there exist two equilibria such that $P_s = P_s^*$, $P_d > 0$, and $\omega = \omega^*(\gamma) \in (0,1)$. Specifically, either (i) $P_s^* = \sigma_\omega(\gamma) \in (0,1)$ and $P_d + P_s = 1$ (this also exists if $c_d = 0$), or (ii) $P_s^* = \frac{rc_d}{\omega(1-\gamma)G_d(s)} < \sigma_\omega(\gamma)$ and $P_d + P_s = \frac{rc_d}{\sigma_\omega \omega^*(1-\gamma)G_d(s)} < 1$.

(b) If $0 < c_d < c_M(\gamma)$ and $\gamma \in (\gamma_L, \gamma_H) \neq \emptyset$, there exist two equilibria such that $P_s = P_s^*$, $P_d > 0$, and $\omega = 1$. Specifically, either (i) $P_s^* = \sigma_1(\gamma) \in (0,1)$ and $P_d + P_s = 1$ (this also exists if $c_d = 0$), or (ii) $P_s^* = \frac{rc_d}{(1-\gamma)G_d(s)} < \sigma_1(\gamma)$ and $P_d + P_s = \frac{rc_d}{\sigma_1(1-\gamma)G_d(s)} < 1$.

(c) If $0 < c_d < c_H$ and $\gamma > \gamma_L > 0$, there exist two equilibria such that $P_s \in \{P_s^*, 1\}$, $P_d = 0$, and $\omega = 1$. Specifically, either (i) $P_s = P_s^* = \frac{rc_d}{G_s(s)}$, or (ii) $P_s = 1$ (which includes the bounds, $0 \leq c_d \leq c_H$).

Figure 2 illustrates the set of equilibria across γ, for feasible c_d and $G_s(s) < G_d(s)$.[22] No skill accumulation is an equilibrium which coexists with any other outcome (2 through 5). Unlike the case $\gamma = 1$, it is the *unique* equilibrium if information frictions and education's costs are both substantial (area 1) because the market penalizes skilled agents with low relative surplus, $G_s(s) < G_d(s)$. As the surplus disparity vanishes, $G_s(s)/G_d(s) \to 1$, the incentives to earn skills increase, the bound on frictions vanishes, $\gamma_L \to 0$, and uniqueness of $P_s = 0$ is lost. Regions 2 through 5 support several different equilibria with skill accumulation, with or without heterogeneity, which sometimes coexist. $P_s = 1$ may arise only if information frictions are limited, $\gamma > \gamma_L$ (3 through 5). If information frictions are severe *and* education costs are small (region 2) skills can be heterogeneously distributed and imperfectly correlated with education. Moreover, the skilled randomize over production in unrecognized matches, with ω^* gauging their degree of participation in market production.

[22] The equilibria in Lemma 2 correspond to the numbered regions as follows: $P_s = 0$ is an equilibrium everywhere; the equilibria in (a) exist in 2 and 3; the equilibria in (b) exist in 3 and 4; the equilibria in (c) exist in 3, 4 and 5.

There is a multiplicity of equilibria with skill heterogeneity, $P_s = P_s^*$. In some the endogenous correlation between education and skills is imperfect, $P_d > 0$ (in 2, 3 and 4), while in others it is not, $P_d = 0$ (in 5). The probability ω may also differ, depending on the size of c_d. Unobservability is generally not an impediment to market production when education is expensive and skills easily recognizable ($\omega = 1$, in 3, 4 and 5), while it is otherwise ($\omega = \omega^*$ in 2,3).[23] Finally, education may or may not be strictly preferred ($P_s + P_d = 1$ versus $P_s + P_d < 1$), two outcomes which generally coexist.

All possible equilibria coexist when education is inexpensive, $c_d < c_L$, and information frictions moderate, $\gamma_L < \gamma < \gamma_H$ (region 3). Due to the retained structure of autarkic payoffs, there is a strategic complementarity in that skills may enhance individual earnings only if they are profitably employed. This requires sufficient skill accumulation in the economy. The larger is the proportion of the unskilled, the lower is the individual's ability to profitably market her skills and the incentive to earn them. The larger the proportion of skilled, the bigger the market premium to skills. Thus, if $P_s > P_s^*$ everyone finds it optimal to become skilled and there is ex-post homogeneity, $P_s = 1$. Conversely, if $P_s < P_s^*$, own skills are expected to be infrequently put to gainful use in the market. The resulting low expected return from earning skill leads to a coordination failure, $P_s = 0$.[24] Thus, equilibria with skill heterogeneity, $P_s = P_s^*$, are knife-edge cases.

Proposition 2. *Let skills be imperfectly observable. There are two types of equilibria with degenerate skill distribution: an equilibrium where everyone is unskilled always exists, whereas an outcome where everyone is skilled exists only for limited information frictions. There are multiple equilibria with skill heterogeneity across schooled individuals only if information frictions are severe. Several types of equilibria, sometimes all, coexist if education is sufficiently inexpensive and information frictions are not excessive.*

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[23] $\omega = 0$ cannot be an equilibrium with skill accumulation. This is obvious if there is no skill heterogeneity, or if there is skill heterogeneity but $P_d = 0$. In this case $\omega = 1$. If there is skill heterogeneity and $P_d > 0$, $\omega = 0$ is inconsistent with equilibrium behavior; those schooled but unskilled cannot exploit information frictions to earn rents on the market.

[24] Snower (1996) refers to "low-skill, bad-job traps" whereby in countries in which few good jobs are available workers have little incentive to acquire skills. This behavior feeds back on the ability of firms to provide good jobs.

Equilibrium heterogeneity may occur when the expected market premium to skill is zero. Consider the simple case where unobservability is not an obstacle to market production, $\omega = 1$, and where skills do not command a larger market surplus, $G_s(s) = G_d(s)$. Earning skills is individually optimal if the agent can raise her expected lifetime utility relative to someone who only has an unproductive degree. Having skills benefits her because it increases her frequency of market production, in those matches where her skills are observed.[25] It penalizes her, however, because she expects to cede some of her ability rents in *some* unrecognized matches, $P_d G_s(d) < 0$. Thus, by acquiring skills she confers benefits to those who have undertaken education but left its productive role unexploited. This positive externality generates incentives to free-ride by investing in a degree but not skills. If the incentives are strong enough this may lead to equilibrium skill heterogeneity with imperfect correlation between education and skill.

Figure 2 shows that skill heterogeneity may result when academic certificates are quite uninformative, $\gamma < \gamma_H$, and inexpensive, $c_d < c_M$, (regions 2, 3 and 4). If education is very cheap, $c_d < c_L$, incentives to free-ride are very strong; thus, heterogeneity can be an equilibrium only if the skilled reduce their exposure to losses setting $\omega = \omega^*$. All else equal, as c_d grows ($c_L < c_d < c_M$) incentives to free-ride fall; thus, heterogeneity is consistent with $\omega = 1$ as long as information frictions are not extreme, $\gamma_L < \gamma < \gamma_H$ (region 4). When $c_M < c_d < c_H$ the incentives to free-ride are weak, hence the productive role of education is always exploited, $P_d = 0$. This is still not sufficient to eliminate ex-post heterogeneity since, as in the case $\gamma = 1$, some may choose to remain unskilled (the equilibria in region 5 are identical to those when $\gamma = 1$).

Interestingly, equilibria without skill heterogeneity may exist even if skills are almost never observable, $\gamma \approx 0$. What impedes free-riding in this case? Suppose $G_s(s) \approx G_d(s)$, in which case $\gamma_L \approx 0$. Suppose $P_s = P_s^*$ and $\omega = \omega^*$ (an equilibrium for $\gamma > \gamma_L$ in region 3), i.e. indifference to exploiting the productive role of education. A free rider sustains lower initial costs, earns market surplus similar to a skilled in self-matches, but foregoes some matches since $\omega^* < 1$. If $P_s > P_s^*$ more good matches are expected, but a proportion ω^* of these extra matches is unavailable to the free rider. This breaks the indifference balance and leads to skill homogeneity, $P_s = 1$.

[25] When $\omega = 1$ having skills does not increase her chance to produce if her skills are unrecognized. She also has no short-term payoff advantages by being on the market since $G_s(s) = G_d(s)$. Furthermore, we have removed any productivity bias due to autarky, since $u_n = u_s - rc_s$.

Corollary 1. *If information frictions are substantial, inexpensive education supports equilibria with free-riding over the provision of skills of others. Substantial education costs or low information frictions are sufficient to stave-off free-riding behavior, and support only equilibria where education and skills are perfectly correlated.*

There is a trade off between education costs and information frictions, in eliminating free-riding behavior (c_M is negatively sloped in figure 2). A sufficient, but not necessary, condition is $c_d > c_M$. Large costs pose a barrier to those who do not intend to exploit education's productive role; this barrier is greater as the informativeness of academic certificates increases, thus c_M falls as γ rises. There is also a trade-off between information frictions and relative market surpluses. As $G_s(s)/G_d(s)$ increases so does the relative market remuneration of skills. This places more weight on unobservability as an incentive to free-ride, and is reflected in a lower γ_H (above which free-riding is not supported). In the appendix we prove that $\gamma_H \to 0$ as $G_s(s)/G_d(s) \to \infty$, and $\gamma_H, \gamma_L \to 1$ as $G_s(s)/G_d(s) \to 0$. Thus, given γ, free riding always (never) takes place if the relative market surplus to skill is sufficiently small (large).

The relative market surplus $G_s(s)/G_d(s)$ is also important in determining the effect that a reduction in c_d may have on the distribution of skills.

Corollary 2. *If $G_s(s) > G_d(s)$, a reduction in the cost of education may support greater skill accumulation, in those equilibria with skill heterogeneity. If $G_s(s) < G_d(s)$ this is not generally the case. Furthermore, the marketability of skills may be reduced by lower education costs.*

Figure 3 illustrates the first part of this corollary by plotting P_s across c_d when $\gamma_L < \gamma < \gamma_H$ and $G_s(s) > G_d(s)$. In this case $P_s = 0$, $P_s = 1$ and $P_s = P_s^*$ all exist (when feasible). The first two are represented by horizontal lines at 0 and 1, while the third is represented by the upward sloping line spanning 0 to c_H, denoted by $P_s^*(H)$. The latter is the only equilibrium with skill heterogeneity when $c_d > c_M$. Costs between c_L and c_M support two other such equilibria, denoted by $P_s^*(M)$. In one everyone has a degree, $P_S + P_d = 1$ (the horizontal component of $P_s^*(L)$), and in the other someone doesn't, $P_S + P_d < 1$ (the upward sloping segment). Two more such equilibria arise below c_L, denoted by $P_s^*(L)$.[26] Comparing P_s^* across these equilibria, it is apparent that if $G_s(s) > G_d(s)$ then $P_s^*(L) > P_s^*(M) > P_s^*(H)$ whenever the equilibria coexist. Thus, a reduction in c_d which brings about existence of $P_s^* = P_s^*(L)$, supports a local maximum for P_s^*.

To build intuition, suppose agents are indifferent to becoming skilled or remaining uneducated, $P_s + P_d < 1$. When $P_s = P_s^*(H)$ education's productive role is always exploited, thus ability rents are never lost to less productive partners. This is *not* the case if $P_s = P_s^*(M)$, since skills and education are imperfectly correlated; thus, $P_s^*(M) > P_s^*(H)$ is necessary to preserve indifference. The frequency of skilled matches must be even higher when there is skill heterogeneity across those schooled *and* degrees are not always marketable ($\omega = \omega^*$). This explains $P_s^*(L) > P_s^*(M)$. The proof of the corollary shows that $\gamma > \gamma_L$ is sufficient for $P_s^*(L) > P_s^*(M) > P_s^*(H)$ if we limit the comparison only to those equilibria where some choose to remain uneducated ($P_s + P_d < 1$). This is not so if everyone undertakes the educational opportunity ($P_S + P_d = 1$), in which case $G_s(s) > G_d(s)$ is necessary for $P_s^*(L) > P_s^*(M) > P_s^*(H)$. This is because when a degree is not sufficient to guarantee a successful market match, $\omega = \omega^*$, *every* holder of a degree foregoes gainful matches. When $G_s(s) > G_d(s)$ this loss is relatively larger for the skilled, and indifference is preserved by an increase in P_s, the (more) productive population.[27]

Lower education costs do not necessarily imply greater aggregate surplus. The corollary underlines a feature of those equilibria where, there is skill heterogeneity despite everyone being schooled, i.e. $P_s + P_d = 1$ with $P_s \in \{P_s^*(L), P_s^*(M)\}$. When $c_d < c_L$ P_s^* can be high or low. However, skills are less marketable when $P_s = P_s^*(L)$, compared to $P_s = P_s^*(M)$ when $P_s\left[\gamma + (1-\gamma)\omega\right]$ is larger. That is to say, in an economy where everyone undertakes the educational opportunity, reducing its cost may lower the marketability of skills. This has immediate implications for social welfare.

Proposition 3. *Let skills be imperfectly observable. Lowering the cost of schooling may reduce welfare.*

In our economy $G_s(d) < 0$ reflects a fundamental inability to screen out bad matches by means

[26] $P_s^*(L) \in \left\{\sigma_\omega, \frac{rc_d}{\omega^*(1-\gamma)G_d(s)}\right\}$, in which case $\omega = \omega^*$; $P_s^*(M) \in \left\{\sigma_1, \frac{rc_d}{(1-\gamma)G_d(s)}\right\}$, in which case $\omega = 1$.

[27] As for $\gamma = 1$, larger c_d must be matched by more frequent skilled matches to preserve indifference (between earning skills or remaining unskilled). Thus, P_s^* is upward sloping in Figure 3 when $P_s + P_d < 1$. When $P_s + P_d = 1$ everyone has a degree, and P_s^* does not respond to *marginal* changes in c_d (see the horizontal lines in Figure 3).

of appropriate contracts. Thus, informational asymmetries create incentives to earn a degree but not skills, as a way to falsely signal their possession. The incentives increase with lower c_d. Skilled agents can reduce the risk of losses by limiting their participation in unrecognized matches, choosing $\omega = \omega^*$. Doing so, however, impedes valuable matches and reduces the extent to which skills are marketable. As information frictions increase skilled agents more frequently walk away from unrecognized matches, i.e. ω^* falls as γ drops. This impairs a skilled agent's ability to participate in profitable market production, reduces the gains from investing in a productive education, and lowers the economy's welfare.

More specifically, recall that $P_s = 1$ is the Pareto optimum and $rW(1) = u_s + G_s(s) - r(c_d + c_s)$. Welfare is at its lowest in the absence of skills, $rW(0) = u_n$. Consider separately the two cases with skill heterogeneity, $P_s + P_d = 1$ and $P_s + P_d < 1$. When agents are indifferent between being skilled and remaining unskilled, either $\delta, \sigma \in (0,1)$ or $0 < \delta < \sigma = 1$, hence $V_n = V_s - c_d - c_s \geq V_d - c_d$. Thus, $rW(P_s^*) = rW(0)$ when $P_s + P_d < 1$. If $P_s + P_d = 1$, however, welfare is not as low since $rW(P_s^*) = r(V_d - c_d) > rV_n = rW(0)$. In equilibrium, $rW(P_s^*) = u_n + (1-\gamma)P_s^*\omega G_d(s) - rc_d$.

The proposition states that $W(P_s^*(L)) < W(P_s^*(M)) < W(1)$, where $W(P_s^*(L)) < W(P_s^*(M))$ follows from Corollary 2. Consider equilibria where everyone earns a degree but there is skill heterogeneity. If costs are not too high, $c_L < c_d < c_M$, the skilled participate in all matches, $\omega = 1$. However, if costs are very low, $c_d < c_L$, the skilled might choose to not do so, and select ω^*. Hence, welfare can only fall when $c_d < c_L$, i.e. $W(P_s^*(L)) < W(P_s^*(M)$. Obviously $W(P_s^*(M)) < W(1)$ because if $P_s = 1$ each match generates the largest surplus.

The proposition suggests that *sole* reliance on subsidization of private costs of schooling may be ineffective in raising the average skill level. In fact, it may be counterproductive if such a tool is used in isolation within the context of an economy where short-term market incentives for academic achievement (i.e. skill accumulation) and informativeness of degrees are both limited, two preeminent features of the U.S. experience according to several observers (Owen, 1995).

6. Concluding Remarks

We have built a model where education's productive role is endogenous, and shown the theoretical ramifications of separating human capital accumulation from educational investment decisions. By treating them as complementary choices, we have demonstrated the existence of equilibria with ex-post skill heterogeneity within an education cohort, despite ex-ante homogeneity. The endogenous imperfect correlation between education and skill represents a market failure characterized by over-investment in education but under-investment in skill. Two features of our economy provide incentives to earning a degree while "under-investing" in skill. First, degrees cannot perfectly communicate the productivity of their owners, but only certify the undertaking of the educational opportunity. Second, contract imperfections allow the unskilled to capture some ability rents, in the short-run. The extent of these market imperfections affects the market premium to skill. Together with the relative cost of undertaking the educational opportunity, they influence the effectiveness of education in increasing the economy's skill level.

To the extent that the frictions present in our model economy are relevant features of naturally occurring economies (and there is reason to believe they are[28]), our study has several implications. With respect to education policy, the intuition we have developed suggests a key role for a greater provision of incentives to educational achievement, both from the market but also the educational system. In particular, the analysis suggests that an increased public effort to lower the private cost of education may be ineffective in improving the workforce's skills when not complemented by incentives to student performance. Second, it suggests a key role for policies directed at diminishing informational asymmetries, for example by increasing education standards or the informativeness of academic certificates.[29] The study leads also to interesting parallels about the possible role of technological change favoring skilled workers, in explaining the increase in wage inequality experienced in the U.S. (e.g. Bound and Johnson, 1992, Katz and Murphy, 1992). Our model suggests this may be viewed as the rational response of a market which, by increasing the relative remuneration to skill, has attempted to bypass the educational sector's inability to provide sufficient incentives to fully exploit its productive function.

Because of the great deal of abstraction, ours is clearly not meant to be a comprehensive study of education's role in promoting human capital accumulation. We do think, however, that the

[28] Owen (1995) discusses contributions from economics and other social sciences, devoting attention to the relationship between cognitive achievement and labor market productivity, incentives to achievement, and public policy. Hanushek (1986) surveys analyses of the educational process and their policy implications.

[29] Both are important themes of the U.S. education debate. For example, there is evidence that employers pay little attention to grades, perhaps because of their small and decreasing information content (Owen, 1995). Recent work has discussed the impact of education standards on social welfare (Costrell, 1994, Betts, 1998).

approach adopted can provide a useful conceptual framework in developing intuition about the ramifications of endogenizing education's productive role. A natural next step is to formally model a private education sector where institutions arise endogenously and choose their services' quality to maximize their profits. By endogenizing the quality of education, this exercise could help us identify factors which encourage skill accumulation.

Appendix

Proof of Lemma 1. In this and all following proofs let $a \equiv u_n - (u_s - rc_s)$, and denote strictly mixed strategies by a star superscript, i.e. $\sigma^*, \omega^*, \delta^* \in (0,1)$. From (4) it follows that

$$\sigma' \begin{cases} = 1 & \text{if } \delta\sigma G_s(s) > a \\ \in [0,1] & \text{if } \delta\sigma G_s(s) = a \\ = 0 & \text{if } \delta\sigma G_s(s) < a \end{cases}$$

<u>Case $\sigma = 0$</u>. Given $\sigma = 0$, then only if $a \geq 0$ is $\sigma' = 0$ a symmetric equilibrium. When $a < 0$, it is also an equilibrium if $c_d > -ar^{-1}$. Using (5) it is easy to verify that there is a continuum of equilibria in which agents may or may not acquire skills, depending on c_d :

$$\delta \begin{cases} \in [0,1] & \text{if } \quad c_d = 0 \\ = 0 & \text{if } \quad c_d > 0. \end{cases}$$

Thus, the following are equilibria: (i) $P_s = P_d = 0$ (i.e. $\sigma = 0,\ \delta = 0$) always, (ii) $P_s = 0$ and $P_d \in [0,1]$ (i.e. $\sigma = 0,\ \delta \in \{0, \delta^*, 1\}$) if $c_d = 0$.

<u>Case $\sigma = 1$</u>. Given $\sigma = 1$, $\sigma' = 1$ if $\delta G_s(s) > a$, hence only $\delta > 0$ may be an equilibrium. Using (5), then $\delta = 1$ only if $G_s(s) > a + rc_d$. Thus, there is an equilibrium $\delta = \sigma = 1$ if $0 < c_d < \frac{G_s(s) - a}{r}$. Next, given $\sigma = 1$, $\delta = \delta^* = \frac{a + rc_d}{G_s(s)} \in (0,1)$ is an equilibrium iff, $G_s(s) > a + rc_d > 0$. Note that $\delta^* = 1$ when $G_s(s) = a + rc_d > 0$. It follows that there is also another equilibrium

$$\left\{ \sigma = 1, \delta = \delta^* = \frac{a + rc_d}{G_s(s)} \right\} \text{ if } G_s(s) > a + rc_d > 0.$$

Thus, the following are equilibria: (i) $0 < P_s \leq 1$ and $P_d = 0$ (i.e. $\sigma = 1$ and $\delta = \delta^*, 1$) if $0 < c_d \leq (G_s(s) - a)/r$, (ii) $P_s = 1$ and $P_d = 0$ (i.e. $\sigma = 1,\ \delta = 1$) if $0 < c_d \leq (G_s(s) - a)/r$, (iii) $0 < P_s < 1$ with $P_d = 0$ (i.e. $\sigma = 1,\ \delta = \delta^*$) if $c_d > -a/r > 0$.

Case $\sigma = \sigma^*$. Conjecture $\sigma = \sigma^*$ for some δ. Using (13) $\sigma' \in [0,1]$ when $\delta\sigma^* G_s(s) = a$. Thus, $a > 0$ is necessary and $\sigma^* = \frac{a}{\delta G_s(s)} \in (0,1)$ if $\delta > a/G_s(s)$. When $\sigma = \sigma^*$, using (5)

$$\delta \begin{cases} \in [0,1] & \text{if } c_d = 0 \\ = 0 & \text{if } c_d > 0. \end{cases}$$

There cannot be an equilibrium with $c_d > 0$ since in that case $\delta = 0$. When $c_d = 0$, if $G_s(s) > a$, then there is a continuum of equilibria such that $\delta \in (\delta^*, 1)$ and $\sigma = \sigma^*$. Therefore the following is an equilibrium: $P_s = P_s^*$ and $P_d + P_s \in [0,1]$ (i.e. $\sigma = \sigma^*$, $\delta \in (\delta^*, 1)$) if $c_d = 0$.■

Proof of Proposition 1. It follows from lemma 1.■

We set the stage for Lemma 2 by discussing functions of γ used in proving existence of equilibria.

Lemma A. *Define the functions*

$$c_L(\gamma) = \frac{-\gamma^2 G_d(s) G_s(d) G_s(s)}{r[-G_s(d)(G_d(s) - \gamma G_s(s)) + \gamma G_s(s) G_d(s)]}, \quad c_M(\gamma) = \frac{-G_d(s) G_s(d)(1-\gamma)^2}{r[G_s(s) - (1-\gamma)(G_s(d) + G_d(s))]}$$
$$\sigma_\omega(\gamma) = \frac{-G_s(d)(G_d(s) - \gamma G_s(s))}{-G_s(d)(G_d(s) - \gamma G_s(s)) + \gamma G_s(s) G_d(s)}, \quad \sigma_1(\gamma) = \frac{-G_s(d)(1-\gamma)}{G_s(s) - (1-\gamma)(G_d(s) + G_s(d))}$$
$$\omega^*(\gamma) = \frac{\gamma^2 G_s(s)}{(1-\gamma)(G_d(s) - \gamma G_s(s))}$$

omitting the argument, when understood, and the constants

$$\gamma_L \equiv 1 - \frac{G_s(s)}{G_d(s)}, \quad \gamma_H \equiv \frac{1}{1 + G_s(s)/G_d(s)}, \quad c_H = G_s(s) r^{-1}$$

Then: $c_H > c_M > c_L$ *whenever (i)* $G_s(s) \geq G_d(s)$ *and* $\gamma < \gamma_H$, *or (ii)* $G_s(s) < G_d(s)$ *and* $\gamma_L < \gamma < \gamma_H$. *If* $\sigma_\omega, \sigma_1 \in (0,1)$, *then* $\sigma_\omega \geq \sigma_1$ *if and only if* $\gamma < \gamma_H$, *and* $G_s(s) \geq G_d(s)$. *Furthermore,* σ_ω *and* σ_1 *are both decreasing in* γ, *whereas, if* $\gamma < \gamma_H$, *then* ω^* *is increasing in* γ.

Proof of Lemma A. Note that γ_L and γ_H are decreasing in $G_s(s)/G_d(s)$, and $\gamma_L < \gamma_H < 1$.

$c_H > c_M > c_L$. Let $\gamma < \gamma_H$. It is a matter of algebra to show that $c_L = c_M$ if $\gamma = \gamma_H$ and $c_L < c_M$ if $\gamma < \gamma_H$. Now consider $c_H - c_M$. It is a strictly increasing function in γ, and such that $c_H - c_M > 0$ for $\gamma = 1$. Also, $c_H - c_M \geq 0$ for $\gamma = 0$ whenever $G_s(s) \geq G_d(s)$. Conversely, if $G_s(s) < G_d(s)$ then $c_H - c_M \geq 0$ only if $\gamma \geq \gamma_L$. Note that $\gamma_H > \gamma_L$. We conclude that $c_H > c_M > c_L$ if (i) $G_s(s) \geq G_d(s)$ and $\gamma < \gamma_H$, or if (ii) $G_s(s) < G_d(s)$ and $\gamma_L \leq \gamma < \gamma_H$.

$\underline{\sigma_\omega \geq \sigma_1}$. Consider the case where $\sigma_\omega, \sigma_1 > 0$ (which must hold if they correspond to equilibrium strategies). Rearrange $\sigma_\omega < \sigma_1$ as $\gamma\left(G_d(s) - G_s(s)\right) < \gamma_H\left(G_d(s) - G_s(s)\right)$ which for $\gamma < \gamma_H$ is satisfied when $G_s(s) < G_d(s)$, whereas $\sigma_\omega \geq \sigma_1$ when $G_s(s) \geq G_d(s)$ and $\gamma < \gamma_H$.

It can be shown that σ_ω and σ_1 are decreasing in γ, and ω^* is increasing in γ when $\gamma < \gamma_H$.■

Proof of Lemma 2. Let $a = 0$.

Case $\sigma = 0$: Under the conjecture $\sigma = 0$ then $P_s = 0$, which in turn implies $\omega = 0$ (from (6)). It follows from (12) that $\sigma' = \sigma = 0$ is a symmetric equilibrium. $\delta > 0$ can be an equilibrium only if $c_d \leq 0$, while $\delta = 0$ otherwise. Therefore, when $a = 0$, then $P_s = 0$ with $P_d = 0$ if $c_d > 0$ (i.e. $\sigma = \delta = 0$ and $w = 0$) and $P_d \in [0,1]$ if $c_d = 0$ (i.e. $\sigma = 0$, $\delta \in [0,1]$ and $w = 0$).

Case $\sigma = 1$. Under the conjecture $\sigma = 1$ then $P_d = 0$, hence $\omega = 1$ (from(6)), and $P_s = \delta$. From (12), $\sigma' = 1$ is individually optimal *only if* $\delta\left[G_s(s) - (1-\gamma)G_d(s)\right] > 0$, which *may* hold only if

$$\gamma > \gamma_L \equiv 1 - G_s(s)/G_d(s)$$

Since $\delta \in (0,1]$ it follows that

$$G_s(s) \geq (1-\gamma)G_d(s) \tag{14}$$

is a necessary condition for $\sigma = 1$. From (13), $\delta > 0$ is individually optimal if it satisfies

$$\delta G_s(s) - rc_d \geq 0. \tag{15}$$

The following are equilibria when $\sigma = 1: \delta = 1$ if $G_s(s) > rc_d$ (which satisfies (15)), and $G_s(s) \geq (1-\gamma)G_d(s)$ (which satisfies (14)); $\delta = \delta^*$ if $G_s(s) \geq rc_d$ and $rc_d\left[G_s(s) - (1-\gamma)G_d(s)\right] > 0$ (which satisfies (14)), where

$$\delta^* \equiv \frac{rc_d}{G_s(s)} \in (0,1]$$

satisfies (15) with equality. It follows that, when $a = 0$, the following are equilibria: $P_s = 1$ with $P_d = 0$, if $c_d < G_s(s)r^{-1}$ and $\gamma > \gamma_L$ (i.e. $\sigma = \delta = 1$ and $\omega = 1$); $P_s = P_s^* = rc_d/G_s(s)$ with $P_d = 0$, if $c_d < c_H = G_s(s)r^{-1}$and $\gamma > \gamma_L$ (i.e. $\sigma = 1$, $\delta = rc_d/G_s(s)$ and $\omega = 1$)

Case $\sigma = \sigma^*$. From (12), $\sigma' \in [0,1]$ is individually optimal only if

$$\frac{\gamma}{1-\gamma}\delta\sigma\left[\gamma + \omega(1-\gamma)\right]G_s(s) + \omega\left\{\delta\sigma\left[\gamma + \omega(1-\gamma)\right]G_s(s) + \delta(1-\sigma)G_s(d)\right\} = \delta\sigma\omega G_d(s) \tag{16}$$

It is immediate that $\delta > 0$ is necessary for $\sigma = \sigma^*$. Because $\sigma = \sigma^*$ only if $V_d = V_s - c_s$, using (13)

$$\delta\sigma\omega(1-\gamma)G_d(s) \geq rc_d \tag{17}$$

must hold as a strict inequality when $\delta = 1$ is a symmetric equilibrium, and as an equality when $\delta \in [0,1]$. Using (6),

$$\sigma\left[\gamma + (1-\gamma)\omega\right]G_s(s) \geq -(1-\sigma)G_s(d) \tag{18}$$

must hold as a strict inequality when $\omega = 1$ is a symmetric equilibrium, as an equality when $\omega \in [0,1]$, and must be violated when $\omega = 0$ is an equilibrium. Given $\sigma = \sigma^*$, we have to consider five different combinations of the remaining variables:

Case $\omega = \omega^*$, $\delta = \delta^*$: (17) and (18) must hold with equality. Solving the system of equations (16), (17), and (18) we obtain:

$$\omega = \omega^* \equiv \frac{\gamma^2 G_s(s)}{(1-\gamma)\left(G_d(s) - \gamma G_s(s)\right)}, \quad \sigma = \sigma_\omega \equiv \frac{-G_s(d)\left(G_d(s) - \gamma G_s(s)\right)}{-G_s(d)\left(G_d(s) - \gamma G_s(s)\right) + \gamma G_s(s)G_d(s)}$$

$$\delta = \delta^* \equiv \frac{rc_d}{\omega^*\sigma^*(1-\gamma)G_d(s)}.$$

Clearly, $\sigma \in (0,1)$ always, and $\omega \leq 1$ if $\gamma \leq \gamma_H \equiv \frac{G_d(s)}{G_d(s)+G_s(s)}$. Hence $\gamma < \gamma_H$ guarantees $\omega \in (0,1)$ (the denominator of ω is positive if $\gamma < \gamma_H$). Next, $\delta > 0$ always and $\delta \leq 1$ if $\gamma \leq 1 - \frac{rc_d}{\omega\sigma G_d(s)}$, which is easily seen to hold for some pair $c_d > 0$ small, by continuity. $\delta \leq 1$ if

$$0 < c_d < c_L \equiv \frac{-\gamma^2 G_d(s)G_s(d)G_s(s)}{r\left[-G_s(d)\left(G_d(s) - \gamma G_s(s)\right) + \gamma G_s(s)G_d(s)\right]},$$

and since $\gamma < \gamma_H$,then $G_d(s) - \gamma G_s(s) > 0$ so that the denominator of c_L is positive. It follows that, when $a = 0$, the following is an equilibrium: $P_s = P_s^* = \sigma_\omega\delta^*$ and $\omega = \omega^*$ with $P_d + P_s = \delta^*$, if $0 < c_d < c_L$ and $\gamma < \gamma_H$ (i.e. $\sigma = \sigma_\omega$, $\delta = \delta^*$ and $\omega = \omega^*$)

Case $\omega = \omega^*$, $\delta = 1$: (17) must hold with a strict inequality, and (18) as an equality. Solving the system of equations (16) and (18) we obtain $\sigma = \sigma_\omega$ and

$$\omega = \frac{-G_s(d) + \sigma(G_s(d) - \gamma G_s(s))}{\sigma\left(1-\gamma\right)G_s(s)}.$$

When $\gamma < \frac{G_d(s)}{G_s(s)}$ the denominator and numerator of σ are both positive. It follows that $0 < \gamma < \frac{G_d(s)}{G_s(s)}$ is sufficient for $\sigma \in (0,1)$. Given $0 < \gamma < \frac{G_d(s)}{G_s(s)}$, then $\omega > 0$ iff $\sigma < \frac{-G_s(d)}{-G_s(d)+\gamma G_s(s)}$, i.e. $0 < \frac{-G_s(d)\gamma^2 G_s(s)}{\gamma G_s(s) - G_s(d)}$, which always holds. Similarly, $\omega < 1$ iff $\sigma > \frac{-G_s(d)}{-G_s(d)+G_s(s)}$, which holds if $\gamma < \gamma_H$.

Because $\gamma_H < \frac{G_d(s)}{G_s(s)}$ then $0 < \gamma < \gamma_H$ is sufficient for $\sigma, \omega \in (0,1)$. Finally, $\delta = 1$ if (17) holds as a strict inequality, satisfied by some $c_d > 0$. In particular $0 \leq c_d < c_L$ is necessary for $\delta = 1$. Note that, for a given σ, there is a unique ω that solves (18) with equality. Thus, since $\sigma = \sigma_\omega$, then it follows that $\omega = \omega^* \equiv \frac{\gamma^2 G_s(s)}{(1-\gamma)(G_d(s)-\gamma G_s(s))}$. It follows that, when $a = 0$, the following is an equilibrium if $0 \leq c_d < c_L$ and $\gamma < \gamma_H$: $P_s = P_s^* = \sigma_\omega$ and $\omega = \omega^*$ with $P_d + P_s = 1$ (i.e. $\sigma = \sigma_\omega$, $\delta = 1$ and $\omega = \omega^*$)

<u>Case $\omega = 0,\ \delta > 0$:</u> If $\omega = 0$, (13) implies $\delta = 0$. It follows from (16) that $\sigma = 0$. Thus, this is not an equilibrium when $\sigma = \sigma^*$.

<u>Case $\omega = 1,\ \delta = \delta^*$:</u> When $\delta = \delta^*$ (17) must hold with equality. The solution to (16) and (17) is

$$\sigma = \sigma_1 \equiv \frac{-G_s(d)(1-\gamma)}{G_s(s) - (1-\gamma)(G_d(s) + G_s(d))}, \quad \delta = \frac{rc_d\left[G_s(s) - (1-\gamma)(G_d(s) + G_s(d))\right]}{-G_s(d)(1-\gamma)^2 G_d(s)},.$$

Clearly $\delta > 0$ and, if $G_d(s) > -G_s(d)$, then $\gamma > 1 - \frac{G_s(s)}{G_s(d)+G_d(s)}$ (if $G_d(s) \leq -G_s(d)$, any γ satisfies it). Next, $\delta < 1$ if $c_d > 0$ small. When $\delta \in (0,1)$, then $\sigma \in (0,1)$ whenever $\gamma > \gamma_L$.When $\omega = 1$, (18) must hold as a strict inequality, i.e. $\sigma > \frac{-G_s(d)}{-G_s(d)+G_s(s)}$, which as seen earlier requires $\gamma < \gamma_H$. Note that $\gamma_H > \gamma_L > 1 - \frac{G_s(s)}{G_s(d)+G_d(s)}$. Thus, for some $c_d > 0$ small, then $\gamma_L < \gamma < \gamma_H$ is sufficient for existence of this equilibrium. In particular, $\delta < 1$ if

$$0 < c_d < c_M \equiv \frac{-G_d(s)G_s(d)\,(1-\gamma)^2}{r\left[G_s(s) - (1-\gamma)\,(G_s(d) + G_d(s))\right]},$$

and note that the denominator of c_M is positive when $\gamma < \gamma_H$. It follows that, when $a = 0$, the following is an equilibrium if $0 < c_d < c_M$ and $\gamma_L < \gamma < \gamma_H$: $P_s = P_s^* = \sigma_1\delta^* = \frac{rc_d}{(1-\gamma)G_d(s)}$ and $\omega = 1$ with $P_d + P_s = \delta^*$ (i.e. $\sigma = \sigma_1$, $\delta = \delta^*$ and $\omega = 1$)

<u>Case $\omega = 1,\ \delta = 1$:</u> both (17) and (18) must hold as strict inequalities. Using (16), $\sigma = \sigma_1$, hence $\sigma \in (0,1)$ if $\gamma > \gamma_L$. Next, (18) holds as a strict inequality if $\sigma > \frac{-G_s(d)}{-G_s(d)+G_s(s)}$. Then $\gamma < \gamma_H$ is necessary. Finally, (17) is strict if $\sigma > rc_d/(1-\gamma)G_d(s)$, which holds for $c_d > 0$ small. In particular, $\sigma > rc_d/(1-\gamma)G_d(s)$ whenever $0 \leq c_d < c_M$, in which case $\gamma_L < \gamma < \gamma_H$ is sufficient for existence. It follows that, when $a = 0$, the following is an equilibrium if $0 \leq c_d < c_M$ and $\gamma_L < \gamma < \gamma_H$: $P_s = P_s^* = \sigma_1$ and $\omega = 1$ with $P_d + P_s = 1$ (i.e. $\sigma = \sigma_1$, $\delta = 1$ and $\omega = 1$).

Proof of Proposition 2. Existence of the different equilibria follows from Lemma 2. From Lemma A, note that $c_H > c_M > c_L$ when $\gamma_L < \gamma < \gamma_H$. From Lemma 2, if $0 < c_d < c_L$, then $\gamma_L < \gamma < \gamma_H$

satisfies the existence condition for all of all equilibria described in it. Hence coexistence of all equilibria occurs when $c_d < c_L$ and $\gamma_L < \gamma < \gamma_H$. ■

Proof of Corollary 1. Lemma 2 implies $P_s = P_s^*$, $P_d > 0$, and $\omega \in \{\omega^*, 1\}$ only if $0 < c_d < c_L$ and $\gamma < \gamma_H$, or $0 < c_d < c_M$ and $\gamma_L < \gamma < \gamma_H$. Since $c_L < c_M$ when $\gamma < \gamma_H$, then $c_d < c_L$ and $\gamma < \gamma_H$ are sufficient to support $P_d > 0$.

Lemma 2 implies that $P_s \in \{P_s^*, 1\}$, $P_d = 0$, and $\omega = 1$ if $0 < c_d < c_H$ and $\gamma > \gamma_L$. Hence, $c_M < c_d < c_H$ is sufficient to rule out an equilibrium with $P_d > 0$. When that is the case $\gamma > \gamma_L$ is sufficient to guarantee existence of an equilibrium with $P_s \in \{P_s^*, 1\}$ and $P_d = 0$. ■

Proof of Corollary 2. Let $\gamma_L < \gamma < \gamma_H$, and $c_d \leq c_H$.

Consider equilibria where $P_s > 0$ and $P_s + P_d = 1$. Let $P_s^*(L) = \sigma_\omega$, and $P_s^*(M) = \sigma_1$, both decreasing in γ. From Lemma A, $\sigma_\omega \geq \sigma_1$ when $G_s(s) \geq G_d(s)$, hence $P_s^*(L) \geq P_s^*(M)$. The opposite is true if $G_s(s) < G_d(s)$. From Lemma 2, $P_s = 1$ is an equilibrium for all c_d. Now, consider equilibria where $P_s > 0$ and $P_s + P_d < 1$. Let $P_s^*(L) = \frac{rc_d}{\omega^*(1-\gamma)G_d(s)}$, $P_s^*(M) = \frac{rc_d}{(1-\gamma)G_d(s)}$, and $P_s^*(H) = \frac{rc_d}{G_s(s)}$. Note that $\frac{rc_d}{(1-\gamma)G_d(s)} > \frac{rc_d}{G_s(s)}$ holds if $\gamma > \gamma_L$, and that $\frac{rc_d}{\omega^*(1-\gamma)G_d(s)} > \frac{rc_d}{(1-\gamma)G_d(s)}$ since $\omega^* < 1$. Thus $P_s^*(L) > P_s^*(M) > P_s^*(H)$. Clearly, $P_s^*(M)$ increases in γ, but $P_s^*(L)$ decreases in γ since $\omega^*(1-\gamma)$ increases in γ. Hence, if education is strictly preferred lower c_d can lead to higher P_s^* only if $G_s(s) \geq G_d(s)$.

Let $P_s\,[\gamma + (1-\gamma)\omega]$ gauge the marketability of skills. For the case where $P_d + P_s = 1$, compare marketability in the equilibrium $P_s^* = P_s^*(L) = \sigma_\omega$ and $\omega = \omega^*$, to the equilibrium $P_s^* = P_s^*(L) = \sigma_1$ and $\omega = 1$. $P_s^*(L)\,[\gamma + (1-\gamma)\omega^*] \leq P_s^*(M)$ can be reduced to

$$\gamma G_d(s)\,[\gamma G_s(s) - (1-\gamma)(G_d(s) + G_s(d))] \leq -G_s(d)(1-\gamma)(G_d(s) - \gamma G_s(s)).$$

The inequality holds strictly for $\gamma = 0$, and does not for $\gamma = 1$. The RHS, which is positive, falls in γ. The LHS, which may be positive, decreases in γ, for $\gamma < \frac{G_d(s)+G_s(d)}{2(G_d(s)+G_s(d)+G_s(s))}$ (where $G_d(s) + G_s(d) + G_s(s) > 0$ because $u_{ij} > u_i + u_j$) and increases beyond that point. Because at $\gamma = 0$ ($\gamma = 1$) the LHS is smaller (larger) than the RHS, and because both sides are quadratic in γ, it follows that they are equal at exactly one point, $\gamma \in (0,1)$. Evaluating the inequality at $\gamma = \gamma_H$, shows that this point is γ_H (note that $G_d(s) - \gamma_H(G_d(s) + G_s(s)) = 0$). It follows that the inequality holds strictly for all $\gamma < \gamma_H$. It can be easily shown that when $P_d + P_s < 1$ the opposite result is true, i.e. $P_s^*(L)\left[\gamma + (1-\gamma)\omega^*\right] > P_s^*(M)$.■

Proof of Proposition 3. Let $P_s^*(L) = \sigma_\omega$, $P_s^*(L) = \sigma_1$. From the proof of corollary 2 recall that if $P_s = P_s^*$ and $P_s + P_d = 1$, then $P_s^*(L)\left[\gamma + (1-\gamma)\omega^*\right] \leq P_s^*(M)$, whenever $\gamma < \gamma_H$ (necessary for existence of each equilibrium). In these equilibria agents strictly prefer to undertake the educational opportunity but they are indifferent between acquiring skills or a degree. Hence

$$rW(P_s^*) = r(V_d - c_d) \equiv u_n + (1-\gamma)P_s^*\omega G_d(s) - rc_d.$$

Note that $W(P_s^*(L)) < W(P_s^*(M))$ whenever $P_s^*(L)\omega^* < P_s^*(M)$. This latter inequality follows from $P_s^*(L)\left[\gamma + (1-\gamma)\omega^*\right] \leq P_s^*(M)$ since $\gamma + (1-\gamma)\omega^* > \omega^*$. The inequality $W(P_s^*(M)) < W(1)$ follows from $u_n + (1-\gamma)P_s^*\omega G_d(s) - rc_d < u_s + G_s(s) - r\left(c_d + c_s\right)$.■

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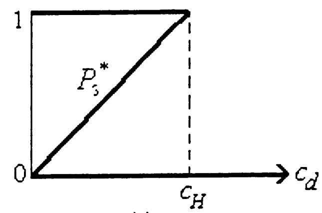

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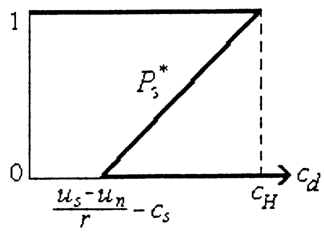

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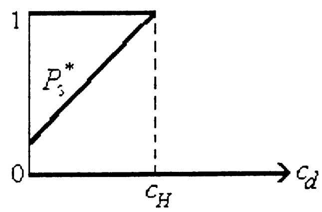

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Figure 1

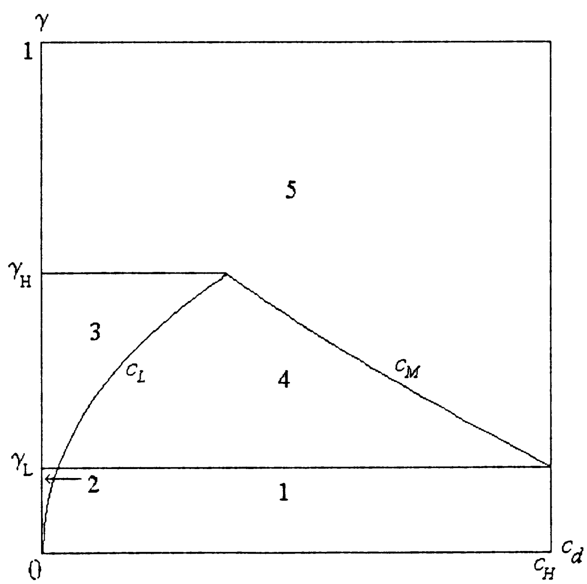
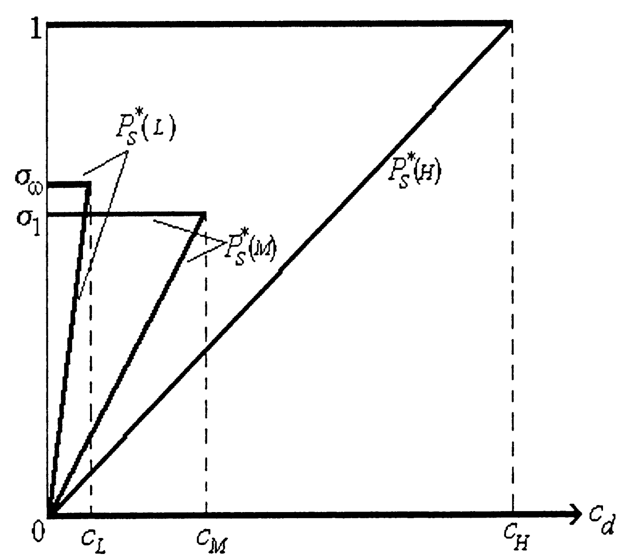


Figure 2



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