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Essays on Search and Informational Asymmetry in Labor
and Credit Markets

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Foreword

Timo Vesala's doctoral dissertation applies a search-theoretic approach to analyze labour and credit market issues. The first essay re-examines the question of whether the signalling motive could lead to overinvestment in education and thereby induce efficiency losses when employers cannot observe the true productivity before hiring. It is shown that the signalling motive does not always lead to excessive investment in education. This results from modelling wage formation as a decentralized bargaining game where the private return from schooling is generally lower than the social return. The second essay studies the efficiency of loan contracts between financiers and entrepreneurs in a credit market with asymmetric information, search frictions and decentralized trading. It is shown that efficient resource allocation can take place only under sufficiently 'liquid' market conditions, where the number of financiers is large enough compared to the number of loan applicants. Here the matching technique is applied in an elegant way to generate various division rules for the surplus. The third essay develops a theory of wage formation in a continuous-time search model with heterogeneous labour and establishes a non-linear relationship between equilibrium wage differentials and the distribution of skills. High-skilled workers earn a strictly larger fraction of the matching surplus than workers belonging to low-skilled groups because the 'wait and continue to search' option is more valuable for the high-skilled worker. To conclude, this thesis contributes to the search theoretic approach. Overall, the dissertation presents a unified view of how search models can be applied in a variety of circumstances.

This study is part of the research agenda carried out by the Research Unit of Economic Structures and Growth (RUESG). The aim of RUESG is to conduct theoretical and empirical research with respect to important issues in industrial economics, real option theory, game theory, organization theory, theory of financial systems as well as problems in labour markets, natural resources, taxation and econometrics.

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Timo Vesala

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Chapter I

Introduction

1 Background

Search (and matching) theory consists of a family of models that can be seen to fill the 'gap' between the traditional Walrasian general equilibrium theory and isolated partial equilibrium models that use game-theoretic analysis. A Walrasian competitive equilibrium model implicitly assumes trading via centralized auctioneer in a setting where all prices are publicly known to everyone and each agent has an instant and frictionless access to any of the trading opportunities in the market. Strategic interactions between agents are practically absent in that model - buyers and sellers only interact through the price system, which they cannot influence. However, in many markets, e.g. in labor and credit markets, there is no centralized auctioneer but the prices are determined and transactions concluded in private meetings between buyers and sellers. Moreover, agents typically have a limited, or at least costly, access to other trading opportunities outside their current meeting.

Search-theoretic models are designed to incorporate these aspects. The assumption of decentralized trading enables a more satisfactory characterization of strategic interactions between trading partners than is possible in Walrasian context. Most notably, it is possible to have proper micro-foundations for the price formation process. In models with bilateral trading, some sort of bargaining game (or posted prices) is a typical mode of price determination. In models where multiple simultaneous meetings are possible, one can also utilize auction theory. Compared to purely game-theoretic settings, search models remove the isolation of the analysis by providing the traders with an option to break up the current meeting and start searching for other partners.

Option to quit creates competitive pressure that affects the outcome obtained in the private meeting.

When one introduces a matching function that governs the overall meeting rates and postulates market entry conditions, search models can be closed into general equilibrium. Indeed, when search frictions become infinitesimal, these models typically produce Walrasian outcome as a limiting case.

1.1 A brief history of the economics of search

According to commonly held view the economics of search primarily began with Stigler's (1961) famous work on "The Economics of Information", although some other authors, e.g., Simon (1955), had discussed related problems already earlier. Stigler's article was inspired by the observation that in most markets prices tends to change with varying frequency, even though the selling goods were seemingly homogeneous. Unless the market is completely centralized, no buyer will know all the prices various sellers quote. Therefore a buyer who wishes to find out the most favorable price has to overcome this informational shortage by conducting *search*. Stigler then developed a theory of how consumers should 'canvass' various sellers when search is costly and only the distribution of prices is common knowledge. Stigler's analysis was not really dynamic, as he asserted that consumers ought to visit a fixed number of stores and then buy from the seller with the lowest price. McCall (1965, 1970), Mortensen (1970), Nelson (1970) and Gronau (1971) pointed out that Stigler's decision rule is not optimal and that the best practice would be to visit stores sequentially. Utilizing the theory of optimal stopping rules, these authors developed the concept of reservation price. The optimal sequential decision rule was such that the buyer should continue searching if the lowest price observed up to that point exceeded the reservation price. Another powerful criticism of Stigler's theory was spelled out by Rothchild (1973), who asserted that it is a "partial partial-equilibrium theory". The 'double partial' refers to the fact that only one market is considered at a time and the analysis is restricted to only one side of this market. Rothchild writes: "Although it [Stigler's model] explains how customers should react to variability in price, it does not explain where this variability comes from or what, if anything, preserves it." Hence, the punchline of Rothchild's critique was that as long as the behavior of price setters is unexplained, it

cannot be affected by consumers' choices and Stigler's model is a completely isolated environment without any strategic considerations.

Rothchild's critique - which was widely recognized already a bit earlier than Rothchild's famous survey was published - triggered a considerable wave of research trying to add the missing elements into Stigler's analysis. A great number of authors tried to construct a model where price dispersion would arise endogenously. However, Diamond (1971), Rothchild (1973) and Butters (1977b) showed that price dispersion tends to disappear when the pricing strategies are implemented in a simple market setting. Diamond's seminal paper concluded that when consumers employ sequential search strategy and search costs are strictly positive, the only unique equilibrium strategy for sellers is to ask monopoly prices. Monopoly pricing would hold regardless of the number of sellers in the market and however small the search costs would be. This result became known as Diamond Paradox.

Butters (1977a) noted that some deviation of the "simplest model" - wherein identical consumers with unitary demand search sequentially, at a fixed search cost, over homogenous consumption goods - is required to obtain a non-degenerate price dispersion. Butters (1977a) himself proposed such a deviation by allowing multiple simultaneous meetings (a setting which became known as the 'urn-ball' model). Reinganum (1979) demonstrated that a non-degenerate price distribution could be obtained if one relaxed the assumptions of unitary demand and producer's homogenous cost structure. Burdett and Judd (1983) introduced a notion of noisy search, while Stahl (1996) allowed a possibility that some consumers face zero search costs and thereby visit all stores. In a more recent contribution, Arbatskaya (2004) argues that price dispersion is obtained if the assumption of random search is replaced by 'ordered search'. The literature that avoids the Diamond Paradox by assuming some sort of heterogeneity in the selling goods is immense. Anderson and Renault (1999) provide an excellent discussion on this topic.

An intuitively very appealing explanation for equilibrium price (wage) dispersion is provided by Julien, Kennes and King (2000), who develop a "competing-auction" theoretic setting to model wage formation. In their model, each unemployed worker announces a reserve wage (the lowest wage that would be acceptable for him) to attract employers to trade with him. If only one employer approaches the worker, then trading takes place at the reserve wage. If there will be more than one interested employer,

then the worker sells his labor services to the highest bidder. This kind of structure gives rise to wage dispersion even with completely homogeneous sellers (workers).

1.2 Popular application fields of search theory

Search theory has probably been most successful in labor economics. This is quite natural, because labor markets are typically characterized by decentralized trading, search frictions and various kinds of matching problems. The early contributions in this tradition were Alchian (1969), Phelps (1968) and Mortensen (1970) - which were collected with some other articles in the same spirit in the "Phelps volume" (Phelps et al., 1970) - as well as McCall (1970) and Gronau (1971). The early theory of job search suffered from the same criticism as Stigler's model: the market was characterized by an exogenous distribution of wage offers and unemployment emerged as an equilibrium phenomenon because workers rejected too low offers. Lucas and Prescott (1974) were the first to develop an equilibrium model that met Rothchild's (1973) criticism of search models being "partial partial-equilibrium" analysis. Their model, however, overlooked workers' option to search for alternative jobs and they did not consider the market's matching patterns that would directly relate unemployment to vacancies and hirings. The first applications that introduced the concept of the 'matching function' in order to bypass the need to model reservation wages as the driving force behind unemployment were due Hall (1979), Pissarides (1979), and Bowden (1980). Finally, Pissarides (1979, 1984a) introduced a 'free-entry' condition for new jobs, leading to a general equilibrium model with endogenous labor demand.

In recent years, the search and matching model, which is usually called the Mortensen-Pissarides model, has become the standard theory of equilibrium unemployment. The success of the Mortensen-Pissarides framework is due to its tractability and its potential to tackle a wide array of relevant policy issues, such as unemployment insurance, taxation, minimum wages etc. Mortensen and Pissarides (1999a,b) and Rogerson, Shimer and Wright (2004) provide extensive surveys on the recent developments of this convention. Also Pissarides' (2000) textbook is widely used as an encyclopedic reference. The first (Chapter II) and the third essay (Chapter IV) in this dissertation are related to the trade in the labor market.

Search theory has also been employed to rationalize the use of money as a medium

of exchange. In a frictionless world where complete contracts were possible, money would not be needed because economic agents could agree on who produces what and how the resulting outputs are shared. In a world with incomplete contracts and limited access to potential trading opportunities, however, a trader does not necessarily find a partner with whom to exchange goods. The search models of money include, for example, Diamond (1984), Kiyotaki and Wright (1991), Shi (1997) and Kocherlakota (1998).

Pairwise trading is a typical mode of transaction also in certain segments of financial markets, most notably in venture capital markets and, to some extent, in credit markets. However, applying search theory to model financial matching is a relatively new area with only a handful of contributions (e.g. Becsi, Li and Wang, 2000, Wasmer and Weil, 2000, Michelacci and Suarez, 2002, and Inderst and Müller, 2004). The second essay (Chapter III) in this dissertation considers financial matching in the credit market context.

1.3 Some currently active areas of research

One of the current areas of interest is how the price determination process should be modeled. In the early applications of search theory, price formation was typically modeled as monopolistic price-setting by sellers (e.g. Mortensen, 1970, and Diamond, 1971). The Nash bargaining solution was first introduced in this context by Diamond (1982). The Mortensen-Pissarides model also utilizes Nash wage equation as a price formation mechanism. This practice has been justified by the observation (derived by Binmore, Rubinstein and Wolinsky, 1986) that the outcome of Rubinstein's (1982) strategic bargaining game (the "alternating offers' game") approaches the sharing rule generated by the axiomatic, generalized Nash bargaining, if the time-interval between sequential offers approaches zero. Moreover, in search context, generalized Nash bargaining is equivalent of having the trading partners making 'take-it-or-leave-it-offers' to their opponents with probabilities that are equal to the exogenous 'bargaining powers' in the Nash solution. However, using Nash bargaining is not completely satisfactory because the choice of the exogenous bargaining powers is arbitrary and it is usually quite hard to identify proper micro-foundations that would support any particular choice. A nice feature of bargaining models in general equilibrium search context is

that the outside option (i.e., the option to leave the current meeting and start searching for another partner) is endogenous. But even though the disagreement point in Nash bargaining is indeed based on some economic fundamentals, the rule by which the remaining surplus is divided is arbitrary.

The dominant role of Nash solution in the main stream search and matching literature is somewhat bothersome because search models would typically allow a more detailed price formation mechanism with proper micro-foundations. In recent years, some authors have developed alternative ways to determine prices in search context. For example, in models where multiple meetings are possible, one can utilize auction theory, as is done by Kultti (1999) and Julien et al. (2000). In these models, there will be several different prices at which trading takes place, depending on the number of agents that meet each other. Kultti and Virrankoski (2004), in turn, postulate a setting where competitive auctions are only an 'off-equilibrium-path' scenario, leading to a unique price in the market.

These new openings are welcome because the conventional Mortensen-Pissarides model has proved to generate some clearly counterfactual predictions - the main source of which is the Nash bargaining used in wage determination. A major critique is spelled out by Shimer (2004b) who argues that the Mortensen-Pissarides model is incapable of explaining the cyclical behavior of its two central elements, namely unemployment and vacancies. According to Shimer, this failure is mainly due to the fact that Nash bargaining produces too little wage rigidity. Also the third essay of this dissertation (Chapter IV), which is an extension of the Kultti-Virrankoski model, shows that when workers are vertically differentiated, Nash bargaining could miss some important economic insight.

Another area that has generated interest is the attempt to reconsider the issues of economics of information in search theoretic models. The reason why search models are attractive also in this respect stems from their nature as 'intermediate cases' between competitive equilibrium theory and isolated game-theoretic models. As the first essay of this dissertation (Chapter II) exemplifies, the assumption of private meetings and search frictions can help to avoid the stability problems related to signaling models in competitive environment. On the other hand, the option to quit the current meeting and search for another trading partner adds some competitive flavor to the simplistic principal-agent -setting where the principal acts as a Stackelberg leader. Es-

say II (Chapter III), besides other things, shows that in search models it is possible to construct a bilateral trading process that avoids the complexities related to bargaining games with asymmetric information (see for example Muthoo, 1999, ch. 9.8, and Fudenberg and Tirole, 1991, ch. 10.4) but, unlike the principal-agent -models, still retains at least some market power also to the informed party. Blouin (2002), in turn, shows that the Akerlof's (1970) 'impasse' - a situation where the quality of a good is seller's private information and the presence of low quality goods drives the market price so low that sellers of high quality goods refuse to trade - does not necessarily emerge in a model with pairwise trading. Dam and Pérez-Castrillo (2003) postulate the principal-agent economy as a two sided matching game and characterize the set of stable outcomes of such market. Their main aim is to develop a framework for analyzing the principal-agent relationship not as an isolated entity but as a part of an entire market where several principals and agents interact. Also Shimer (2004a) examines moral hazard problem related to employment relationships in search equilibrium.

2 Summaries of the essays

This section provides brief summaries of the three essays in the order of their appearance.

2.1 Essay I: "Overinvestment vs. underinvestment in educational signals: A search-theoretic approach"

In his famous work, Spence (1973, 1974) asserted that employers' inability to observe workers' true productivity prior to hiring could lead to a separating equilibrium where workers with different marginal products acquire different levels of education in order to *signal* their innate and unobservable types. The first essay (Chapter II) re-examines this idea in a search-theoretic framework.

In the extreme version of Spence's theory, education *per se* did not contribute to labor productivity but could only be used as a signaling device. Since acquiring degrees in the schooling sector was thought to be costly, the signaling motive inevitably led to 'overeducation' and efficiency losses. Riley (1979) extended Spence's original model and postulated that schooling and workers' marginal products were positively

related. Riley's first observation was that a separating equilibrium defined by Spence would not exist in a Walrasian competitive equilibrium model. In order to resolve the existence issue, Riley introduced a refinement to that equilibrium concept (so called *reactive equilibrium*) and derived a unique separating equilibrium where the least able type chooses his first-best educational level while the more able workers overinvest in schooling in order to separate themselves from the less able colleagues. This result became known as the 'Riley outcome'. The 'overinvestment' result of the Riley outcome has also been verified in explicitly game-theoretic models of sequential moves, where the informed party acts as a Stackelberg leader (see Cho and Kreps, 1987).

In our search-theoretic model, the signaling motive does not always lead to overeducation. Instead, undereducation may arise at least within a subset of types. The main reason for the qualitative differences between our results and the Riley outcome is that in our case wage formation is modeled as a decentralized bargaining game; i.e., the surplus generated by a successful match in the labor market is divided among the trading partners according to the sharing rule obtained in wage bargaining. Hence, the private return for a worker from schooling is generally less than the social return. As a result, the signaling motive is not always strong enough to induce socially adequate investment in education. In Riley's 'quasi-competitive' model, in turn, employers are competitive so that workers are able to capture the whole social surplus from education. Given the congruence of the private and social returns, the signaling motive unambiguously induces overeducation.

As a theoretical contribution, we also note that search model can avoid the non-existence problem characteristic to Walrasian analysis. The main reason for the non-existence of a competitive separating equilibrium is the assumption of centralized trading where all agents have simultaneous and frictionless access to the same trading opportunities and all prices are publicly known to everyone. Under decentralized trading, however, all transactions are concluded in private between employers and workers, and moving from one trading opportunity to another entails search frictions. As a result, the possible separating equilibrium is not vulnerable to the costless rent-seeking behavior that is present in Walrasian context.

The equilibrium signaling profile derived in the essay is typically not unique but we argue that the set of equilibria can be restricted by an 'intuitive criterion'. Greater

search frictions in the labor market tend to amplify underinvestment. On the other hand, if these frictions become infinitesimal, the model produces the Riley outcome as a limiting case. A rather surprising observation is that, if overeducation is the more dominant source of inefficiency in the labor market, increasing search frictions may actually improve educational efficiency. We also find that increasing complementarity between education and innate ability tends to worsen the inefficiencies caused by undereducation among the low-skilled and overeducation among the high-skilled. If one assumes that increasing complementarity between education and ability is due to a 'skill-biased' technological change, our model predicts that such a skill-biased development would compound the inequality in both education levels and wages. Finally, we conclude that, depending on whether overeducation or undereducation is the most prominent problem, a regulator can improve efficiency by introducing either a system of income taxes or schooling subsidies.

As the model is closed into a general labor market equilibrium, we find that if the complementarity between workers' innate ability and schooling in terms of productivity is sufficiently strong, the model may exhibit multiple (two) steady state equilibria. Typically, one of the steady states is characterized by high unemployment and severe undereducation while the other steady state entails lower unemployment and better educated workers. Multiplicity of steady states implies the possibility of 'Big-Push' development á la Murphy, Shleifer and Vishny (1991); i.e., even small improvements in market infrastructure may lead to a considerable leap from a sub-optimal steady state to a unique and a more efficient steady state.

2.2 Essay II: "Asymmetric information in credit markets and entrepreneurial risk taking"

The essay (Chapter III) investigates the efficiency of loan contracts between financiers and entrepreneurs in a credit market with asymmetric information, search frictions and decentralized trading. The novel feature in the paper is that the financier can distinguish between 'risky' and 'safe' projects, but the entrepreneur's ability that governs the success probability of the risky investment is unobservable to the financier. Hence, the efficiency of trading is driven by entrepreneurs' self-selection among the business opportunities. The previous literature (e.g. Stiglitz and Weiss, 1981, and

de Meza and Webb, 1987) typically assumes that entrepreneurs are bound to uniform investment opportunities. Moreover, instead of assuming perfect competition among financiers, it is assumed that all transactions are concluded in private meetings between entrepreneurs and financiers and that movement from one trading opportunity to another is restricted by search frictions. The assumption of decentralized trading also entails a theoretical contribution that stems from the way the pairwise bargaining under asymmetric information is treated. The well-known complexities related to asymmetric information in Rubinstein's (1982) strategic bargaining game (see for example Muthoo, 1999, ch. 9.8 and Fudenberg and Tirole, 1991, ch. 10.4) are avoided by assuming that only the uninformed party, i.e. the financier, is allowed to make offers in a take-it-or-leave-it manner. However, borrowers are assumed to have an option to *continue search* meanwhile negotiating with the financier. If the borrower exercised this option and managed to locate another financier, the two competing financiers would bid for the right to finance the entrepreneur's project.

It is shown that efficient resource allocation can take place only under sufficiently 'liquid' market conditions; i.e., when the number of financiers in the credit market is large enough compared to the number of loan applicants. Better market liquidity increases the rate at which a competing financier can be located, which unambiguously improves entrepreneurs' 'bargaining power'. As a result, entrepreneurs' private return from financial matching comes closer to the available social return so that entrepreneurs face greater incentives to select projects efficiently. Under tight (i.e. illiquid) market conditions, inefficiencies in resource allocation may be due to either excessive investment in risky projects or entrepreneur's refusal to take up risky projects at all (extreme underinvestment). This result somewhat contradicts with the implications of the model by Becsi, Li and Wang (2003). Becsi et al. endogenize market entry by borrowers and conclude that greater credit market tightness discourages low-quality borrowers disproportionately, leading to higher average quality of projects. We also note that greater credit market tightness can, in a sense, be interpreted as less intense competition between financiers. According such interpretation, our result contradicts with the commonly held view that financial sector competition is likely to induce risk taking and thereby financial fragility.

Regarding the role of search frictions in the market, we find that improving matching efficiency (i.e. lower search frictions) tends to increase, *ceteris paribus*, the

probability of adverse selection. This is because greater matching rates increase the value of entrepreneurs' option to continue search and the expected utility available from risky projects increases disproportionately. As a result, risky investments become relatively more attractive than safe projects, and the likelihood of excessive investment in risky projects increases. Since lower search frictions increase the total number of matches, our model produces a trade-off between the total volume of trading and the average quality of entrepreneurial projects. As the search frictions become infinitesimal, each agent has an immediate access to any trading opportunity in the market so that a competitive equilibrium - the framework of the models by Stiglitz and Weiss (1981) and de Meza and Webb (1987) - is obtained as a limiting case. However, the general trade-off between quality and quantity along with more efficient matching does not necessarily imply that there would be adverse selection in the competitive limit. Which allocative regime is in effect depends primarily on the market tightness and on the distribution of types.

2.3 Essay III: "Non-linear wages and the distribution of skills"

The third essay (Chapter IV) constructs a theory of wage formation in a continuous-time search model with heterogeneous labor. The main purpose of the essay is to develop a pricing mechanism that produces an endogenous sharing rule arising from economic fundamentals and which establishes a theoretical linkage between equilibrium wage differentials and the distribution of skills. Neither of these features typically arise in models with one-sided heterogeneity where the transferable surplus is divided according to an exogenous sharing rule, e.g. Nash bargaining.

This essay draws from the recent contribution by Kultti and Virrankoski (2004), whose model, in turn, rests on the work by Julien, Kennes and King (2000) and Kultti (2000). The main idea in the Kultti-Virrankoski model is that if trading in a private meeting between a buyer and a seller seems unfavorable for either party, the dissatisfied partner may choose to wait for other agents to show up. Appearance of another seller triggers a Bertrand-like price competition. Instead, if another buyer is to show up, the competing buyers are driven to a bidding contest. Kultti and Virrankoski show that, if at the initial meeting either of the trading partners can propose the first offer in a 'take-it-or-leave-it' fashion, then waiting is 'off-equilibrium' event and the

agent with the first-mover advantage will propose an offer that is just good enough to prevent the opponent from exercising his waiting option. The current essay utilizes this idea in the context of labor markets where employers possess the right to propose initial wage offers. The essay also extends the Kultti-Virrankoski model by assuming heterogeneous workers.

The main finding in the essay is that the equilibrium wages are non-linear with respect to workers' skills: better skilled workers earn strictly larger fraction of the matching surplus than workers belonging to lower skill groups. This is because the 'wait-and-continue-search' option is disproportionately more valuable for the more skilled than for the less skilled worker. The disparity is the greater the larger is the fraction of workers belonging to skill groups below the more able worker. Our result contrasts with the outcome from Nash bargaining, under which wages are typically linear in the sense that the price of the productivity unit is the same for all skill groups. Moreover, under exogenous Nash sharing rule, the skill composition of the work force does not affect the shape of the wage schedule. Instead, our model predicts that a high-skilled worker is able to extract more surplus from the employer when there are only few equally able workers in the market than in the case when the market is flooded with high-skilled workers.

Non-linearity of wages implies that a mean-preserving spread in the skill distribution leads to greater wage dispersion. We also show that if the skill distribution of a country A is 'better' than that of a country B in a first-order stochastic dominance sense, then the wage structure should be narrower in country A than in country B . Moreover, non-linear wages offer a potential explanation for the puzzling trend that a substantial growth in the relative supply of skilled labor has in most industrialized economies been accompanied by increasing 'skill premium' in wages (cf. Katz and Autor, 1999, for an overview). Many previous studies (e.g. Katz et al., 1993, Katz and Autor, 1999, and Krusell et al. 2000) assert that a strong skill-biased technological change has to be the key factor explaining the phenomenon. However, our theory suggests that, if there is a common increase in labor productivity throughout the skill groups, then workers belonging to upper tail skill groups should gain disproportionately. Therefore even if the distribution of skills would be transformed to weight higher skill groups, the wage dispersion may still generally increase if the magnitude of the productivity upgrade is sufficiently large. Hence, non-linear wages mitigate the

need for strong skill-biased technological change to explain the simultaneous increase in both supply and price of skilled labor.

An increase in labor market tightness is shown to increase the lower tail wage differentials. However, we identify a Laffer-curve type relationship between market tightness and upper tail wage gaps. When the labor market is sufficiently tight initially, a marginal increase in labor demand tends to increase the upper tail wage dispersion. But when the market is 'slack' *ex ante*, increasing demand actually compresses upper tail wages. This is because a marginal increase in demand dilutes part of the high-skilled workers' comparative advantage when vacant jobs are the short side of the market.

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Chapter II

Overinvestment vs. underinvestment in educational signals: A search-theoretic approach

Abstract

We consider Spence's (1973, 1974) idea of job market signalling in a continuous time search model, where workers invest in education to accumulate human capital and to signal their privately known 'types'. We show that when wages are determined according to a decentralized bargaining game and when moving from one trading opportunity to another is restricted by search frictions, the signalling motive does not always lead to overeducation. Instead, undereducation may arise at least within a subset of types. Greater search frictions amplify undereducation. As search frictions become infinitesimal, the 'Riley outcome' holds as a limiting case; i.e. each type, except the least able worker, overinvests in education. We also find that technological development tends to worsen undereducation among the low types and compound dispersion in education levels and wages. On the market level, undereducation may give rise to multiple steady state equilibria.

1 Introduction

In his seminal work, Spence (1973, 1974) suggested that difficulties in observing the marginal product of workers prior to hiring could result in an equilibrium where employers' wage offers were based on the observable education levels; i.e., workers might be able to signal their unobservable 'types' by means of their education choices. The necessary preconditions for the existence of such a *separating regime* would be that workers with greater productivity would also face smaller marginal cost in acquiring education and that the equilibrium wage function (contingent upon the signals) would induce the workers of each type to choose different education levels.

We reconsider Spence's idea in a simple continuous-time search model where all transactions are concluded and wages determined in private meetings between employers and workers. The sequential structure of the model is as follows: Before entering the labor market, workers optimize their education choices, given the prevailing wage function conditional upon educational signals. The wage function, in turn, results from the bilateral bargaining, given the workers' optimal education choices at the *ex ante* stage. Our model incorporates both the *human capital* aspect of education as well as the *signaling hypothesis*¹; i.e., besides functioning as a signaling device, education also contributes to the marginal product of labor. Following Riley (1979), it is assumed that education and innate ability are complementary in production.

Besides Spence's path-breaking ideas, also Riley's (1979) analysis has become an important benchmark in the job market signaling literature. His main observation was that a Walrasian separating equilibrium is generally instable because under publicly known prices and free access to any trading opportunity there would always remain unexploited rents for price searching buyers². In order to resolve this problem, Riley introduced a refinement to the Walrasian equilibrium - so called *reactive equilibrium* - and concluded that only one separating regime would reach stability under the new equilibrium concept. The unique separating equilibrium entailed the Pareto-dominant³ signaling profile where the least able type chooses his first-best education level while the more able workers overinvest in schooling in order to separate themselves from the less able colleagues. This result became known as the 'Riley outcome'. The same result typically holds also in explicitly game-theoretic models, where the informed

¹The empirical literature provides a rather conflicting view on which of the two aspects is more profound. The traditional human capital literature initiated by Becker (1964) emphasizes the role of education in determining labor productivity, while evidence from so called 'sorting models' (e.g., Kang and Bishop, 1986 and Altonji, 1995) stress the signalling role of education. However, Chatterji, Seaman and Singell (2003) find quite strong evidence that workers invest in education *both* because it improves their productivity *and* because it distinguishes them from less able colleagues.

²A few years earlier, Rothschild and Stiglitz (1976) (in the context of a two class model) and Riley (1975) (with continuum of types) had already shown that an 'informationally consistent' wage function (the term *informationally consistent* pricing was used in the 1970s when the particular price function supported separating behavior) did not necessarily arise as an extension of the Walrasian price vector.

³Or *second-best*, so to say.

party acts as a Stackelberg leader⁴.

In our search-theoretic model, however, the signaling motive does not always lead to overeducation. Instead, undereducation may arise at least within a subset of types. The main reason for the qualitative differences between our results and the Riley outcome is that in our case wage formation is modeled as a decentralized bargaining game. Upon a meeting, the unemployed worker (the firm) proposes a wage demand (offer) in a 'take-it-or-leave-it' fashion with probability $\gamma(1-\gamma)$ ⁵. In the case of disagreement, trading partners separate and receive their reservation utilities^{6,7}. If $\gamma < 1$, employers earn a strictly positive fraction of the surplus generated by a successful recruitment so that the private return for a worker from schooling is less than the social return. As a result, the signaling motive may not be strong enough to induce socially adequate investment in education. In Riley's 'quasi-competitive' model, employers are always driven to their reservation utility levels so that workers are able to capture the whole social surplus from education. Overeducation then follows from the congruence of the private and social returns. We also note that our model is not vulnerable to the same rent-seeking behavior that is present in Walrasian context because all transactions are concluded in private meetings and moving from one trading opportunity to another is encumbered by search frictions.

We find that the equilibrium signaling profile is typically not unique but the set

⁴Cho and Kreps (1987) were the first to provide a complete game-theoretic analysis of the Spence's model. They concluded that only the sequential equilibrium (this equilibrium concept was originally due to Kreps and Wilson, 1982, while besides Cho and Kreps, also Banks and Sobel, 1987, introduced further refinements to it) that corresponded to the Riley outcome was 'intuitive'.

⁵This practice is simpler than Rubinstein's (1982) 'alternating offers game' in the sense that it does not allow for counteroffers. It should also be noted that this type of bargaining produces a sharing rule that coincides with the outcome from generalized Nash bargaining with exogenous 'bargaining powers' γ and $1-\gamma$.

⁶Since any rejection leads to immediate separation, the model does not allow the possibility of strategic delays for signalling purposes (e.g. Gul, Sonnenschein and Wilson, 1986, Gul and Sonnenschein, 1988, and Admati and Perry, 1987).

⁷Still, our simple bargaining mechanism does not rule out the possibility that informed agents could try to transmit information about their types by making unexpected offers, which again could potentially lead to a great multiplicity of different type of equilibria (see Muthoo, 1999, ch. 9.8 and Fudenberg and Tirole, 1991, ch. 10.4). However, these considerations are beyond the scope of the study because we are focusing on wage functions that support separating regimes where educational signals reveal all the relevant information about worker characteristics.

of 'intuitive' signaling profiles can be restricted to the set of profiles between the 'minimum signaling profile' (the MS-profile) and the profile that induces the least type to invest efficiently (the LTE-profile). It is shown that the MS-profile entails underinvestment in education at least within a subset of 'lower-tail' types. The extent of undereducation in the MS-equilibrium, or in other intuitive regimes, depends crucially on the prevailing market conditions; i.e. whether the labor market is 'tight' or 'slack', or how severe the search frictions are. Moreover, the Pareto-dominant profile (the PD-profile) is not necessarily 'intuitive' which means that sometimes not even the second-best outcome is feasible. However, as the search frictions become infinitesimal, the MS-profile, the LTE-profile and the PD-profile all coincide so that the equilibrium signaling profile is unique and the 'Riley outcome' emerges as a limiting case.

Greater search frictions in the labor market are shown to amplify underinvestment. Interestingly, if overeducation is the dominant source of inefficiency, increasing search frictions may improve efficiency in the acquisition of education. Depending on whether undereducation or overeducation is the most prominent problem, a regulator can improve efficiency by introducing either a system of income taxes or schooling subsidies. We also find that an exogenous improvement in technological development tends to worsen undereducation among the low types and lead to greater dispersion in both education levels and wages.

Underinvestment in education is a common phenomenon in pure human capital models (e.g. Laing, Palivos and Wang, 1995). In those models, undereducation arises whenever workers have to bear all the schooling costs but can only earn part of the extra surplus due additional schooling; i.e., when the private return from education is less than the social return. The possibility of inadequate education in a model with asymmetric information has previously been studied by Stiglitz (1975), who asserts that 'social return' on schooling may in some cases exceed 'private return', if the signaling somehow improves the 'match' between workers and jobs⁸. However, Stiglitz's argument implicitly assumes heterogeneity also on employers' side of the market - a feature that is not incorporated in the current model. In our case, bilateral trading and search frictions suffice to give rise to inefficiently low levels of education. Swinkels

⁸Stiglitz's argument rests on the assumption that the abilities that correlate with schooling improve productivity on some 'specialized' vacancies but not on all jobs.

(1999)⁹, in turn, modifies the basic set-up by assuming that employers can make wage offers to students already in the process of schooling and derives a unique sequential equilibrium that entails no wasteful education. He also shows that when education is productive, there is a semi-separating equilibrium in which more able workers become undereducated.

In the final section of the current paper, the model is closed into a general labor market equilibrium. A steady state analysis is carried out according to the matching framework postulated by Laing, Palivos and Wang (1995), whose model, in turn, rests on the pioneering works of Diamond (1982), Mortensen (1982) and Pissarides (1984, 2000). Reminiscent of the results derived by Laing et al. (1995), we find that the underinvestment problem may hinder job creation when the labor market is 'slack'; i.e., when the number of vacant jobs is relatively low compared to the number of unemployed in the market. This feature gives rise to a rather surprising dynamics: As improvements in workers' position reduce undereducation, market entry by firms may sometimes be stimulated by employers' lowering share of the matching surplus. Such an adverse relationship is the more likely to occur the weaker is workers' bargaining power at the wage negotiation stage. Due to this feature, multiple (two) steady state equilibria may arise. Typically, one of the steady states is a 'development trap' characterized by high unemployment and severe undereducation while the other steady state features lower unemployment and better educated workers. Along the lines of Laing et al. (1995), our model suggests that small improvements in market infrastructures may lead to a considerable leap from the development trap to a unique and a more efficient steady state. The model therefore predicts a possibility of 'Big-Push' development á la Murphy, Shleifer and Vishny (1991).

The paper is organized as follows. Section 2 presents the model setup. In Section 3, the concept of a separating equilibrium is defined and the model solved accordingly. Section 4 is devoted to analyzing the properties of the possible signaling profiles. Finally, in Section 5, the model is closed into a general equilibrium and a steady state

⁹Swinkels' model is designed to answer the critique of Weiss (1983) and Admati and Perry (1987), who point out that, as students begin education, the separation has already occurred so that overeducation could be avoided if employers were allowed to make offers as soon as students enroll classes. This extension has also been explored by Nöldeke and Van Damme (1990) whose model, contrary to Swinkels, produces the Riley outcome as a limiting case.

analysis is examined. Section 6 concludes.

2 The Model

The economy is populated by a continuum of infinitely lived and risk neutral workers and by a continuum of impersonal firms. Firms open vacancies that require a labor input of exactly one worker.

2.1 Heterogeneous labor

Workers are heterogeneous and the 'type' of a worker is denoted by $\theta \in \Theta$. This parameter serves as a measure for labor productivity so that a worker with higher θ can produce more output than a colleague with lower θ .

* *Assumption 1:* The type of a worker θ is distributed on $\Theta = [\theta_l, \theta_h]$ according to a strictly increasing function $F(\theta)$. $F(\theta)$ is common knowledge, while the actual realization of θ is each worker's private information.

2.2 Schooling

Before entering labor market, workers may devote effort in acquiring some level of schooling, $s \in S = [0, \infty)^{10}$, in education sector. For simplicity, it is assumed that schooling is a one shot investment, the cost of which, $C(\theta; s)$ depends on the chosen education level, s , and on the type of the agent, θ .

* *Assumption 2:*

$$C_s > 0, C_\theta < 0, \text{ and } C_{s\theta} < 0, C_{ss} > 0.$$

In Assumption 2, the lower indices denote partial derivatives. The third partial derivative, $C_{s\theta} < 0$, guarantees that the first necessary precondition for the existence of a separating equilibrium is satisfied; i.e., workers with greater productivity face smaller marginal cost in acquiring education. The properties of $C(\theta; s)$ are common knowledge.

¹⁰Hence, there is no upper bound for how much a single worker can choose to take education. Having an upper bound for schooling would only limit the set of feasible separating equilibria; for a detailed discussion, see Riley (1979).

After obtaining diploma from the education sector, workers are ready to enter the labor market and start searching for a job as an unemployed worker.

2.3 Search and matching output

We utilize a simple continuous-time search model where an unemployed worker locates a firm with an open vacancy at a Poisson arrival rate α and a firm locates an unemployed worker at rate β . Even though individual agents take α and β as exogenously given, they will be endogenously determined in a steady state general equilibrium. Steady state analysis is carried out in Section 5. Each economic agent discounts future income with the common discount rate, $r > 0$. Search effort itself is costless but time consuming. Therefore the size of the discount rate reflects the exogenous search frictions in the market, while the endogenous meeting rates α and β describe the steady state congestion in each side of the market.

We follow here Laing, Palivos and Wang (1995) by assuming that once an unemployed worker and an unfilled job have been matched, the trading partners establish a 'lifelong' relationship¹¹. Each successful match generates a perpetual stream of output which is determined by worker's type, θ , and his education level, s . The present value of this infinite flow of output is denoted by $V(\theta; s)$.

* *Assumption 3*:

$$V_\theta > 0, V_s > 0, V_{\theta\theta} < 0, V_{ss} < 0 \text{ and } V_{s\theta} > 0.$$

Assumption 3 states that both the worker's innate type and education contribute positively to the productivity of labor, albeit at a diminishing rate. Moreover, the cross-derivative $V_{s\theta} > 0$ implies that schooling and ability are complementary in production.

2.4 The Bellman equations

Separating regime requires that the available wage rate in the labor market must be conditional upon the observable level of schooling; i.e., $w = w(s)$. The discounted

¹¹Thus, there is no exogenous 'job destruction' and thereby no risk of falling back into the pool of unemployed workers.

value of the life-time earnings received by a worker labeled with an education level s reads as

$$W(s) = \int_t^{\infty} e^{-(\tau-t)r} w(s) d\tau.$$

Henceforth, we will work with the function $W(s)$ and it will be referred as the wage function of the labor market, even though it literally represents the present value of a perpetual income stream.

Assuming that working effort does not cause any disutility, risk-neutrality implies that the discounted value of being employed is given by

$$J^E(\theta; s) = W(s). \quad (1)$$

Since an unemployed worker locates a potential employer at rate α , the value of being unemployed obtains

$$rJ^U(\theta; s) = \alpha (J^E(\theta; s) - J^U(\theta; s)), \quad (2)$$

Regarding employers' pay-offs, the value available from a filled vacancy is

$$\pi^F(\theta; s) = V(\theta; s) - J^E(\theta; s). \quad (3)$$

Moreover, given that firms locate workers at rate β , the expected present value of having an unfilled vacancy is given by

$$r\mathbb{E}[\pi^U(\theta; s)] = \beta (\mathbb{E}[\pi^F(\theta; s)] - \mathbb{E}[\pi^U(\theta; s)]), \quad (4)$$

where

$$\mathbb{E}[\pi^j(\theta; s)] = \int_{\Theta} \pi^j(\theta; s) dF(\theta), \quad j = U, F.$$

2.5 Bargaining¹²

Upon meeting, worker and firm negotiate over the division of the surplus generated by the match. The bargaining process is modeled as a bargaining game where the unemployed worker is allowed to propose a wage demand in a 'take-it-or-leave-it' fashion

¹²As already noted above, focusing on separating regimes guarantees that the bargaining with educational signals can be treated as if there were no asymmetric information concerning workers' innate abilities. Under separating regime, the observable education level of a worker fully reveals the unobservable productivity of the particular worker.

with probability γ while the employer is in a similar position with the complementary probability $1 - \gamma$.¹³ Generally, an equilibrium strategy in the bargaining game is to demand or offer a wage that makes the trading partner indifferent between accepting the offer and continuing search. Hence, the party who *receives* the wage offer is driven to his reservation utility level. When the unemployed worker is to propose the offer, the resulting wage demand captures the net of the gross output from the match, $V(\theta; s)$, and employers' expected reservation utility, $\mathbb{E}[\pi^U(\theta; s)]$. On the other hand, when the employer makes the offer, he offers a future income stream equivalent to the value of being unemployed, $J^U(\theta; s)$. Therefore, the value of the income stream earned by a worker with education s is the weighted average of these two offers:

$$W(s) = \gamma (V(\theta; s) - \mathbb{E}[\pi^U(\theta; s)]) + (1 - \gamma) J^U(\theta; s). \quad (5)$$

3 Separating equilibrium

Definition 1 *Separating equilibrium is a wage-function $W(s)$ s.t. (i) workers of type θ choose*

$$s = g^{-1}(\theta),$$

where

$$g^{-1}(\theta) \in \arg \max_{s \in S} U(\theta, s) = \{J^U(\theta, s) - C(\theta, s)\} \quad \forall \theta,$$

and (ii) $\exists [\underline{s}, \infty) \subset S$ s.t. $g : [\underline{s}, \infty) \rightarrow \mathbb{R}_+$ is strictly and monotonically increasing with

$$\theta_l \geq g(\underline{s}),$$

and (iii) $W(s)$ results from the sharing rule expressed in (5).

Condition (i) in Definition 1 requires that the educational signals result from workers' optimization problem at the *ex ante* stage, given the prevailing wage function in the labor market. Condition (ii), in turn, requires that for each education level there is exactly one worker type who has chosen that particular signal, and that employers can infer higher schooling effort to indicate higher ability¹⁴. Finally, condition (iii)

¹³This type of bargaining produces a sharing rule that coincides with the outcome from generalized Nash bargaining.

¹⁴If this was not the case, Assumption 1 implies that it would always pay for the 'low-type' workers to imitate the 'high-types'. Therefore, a signaling profile that is decreasing along with worker's type cannot establish a stable separating equilibrium.

states that, given workers' optimal signaling strategies, the equilibrium wage schedule results from the sharing rule expressed in equation (5).

The model will be solved in the spirit of backward induction: We start with condition (iii) and determine wages as a function of the educational signals. Then, given the wage function, we proceed with condition (i) and derive worker's optimal schooling effort at the *ex ante* stage. As a final step, we need to make sure that the possible signaling profiles are consistent with condition (ii).

Step 1: Characterization of the wage function Given that workers have chosen the education levels according to the separating regime, plugging (2) and (4) into the sharing-rule in (5), and utilizing (1) and (3), we have

$$W(s) = \frac{\gamma(\alpha + r)}{\gamma\alpha + r} (V(h(s), s) - \mathbb{E}[\pi^U(h(s); s)]), \quad (6)$$

where $h(s) = \theta$.

Now, consider a schooling level $s + \Delta$. Then the corresponding wage satisfies¹⁵

$$W(s + \Delta) = \frac{\gamma(\alpha + r)}{\gamma\alpha + r} (V(h(s + \Delta), s + \Delta) - \mathbb{E}[\pi^U(h(s); s)]). \quad (7)$$

Subtracting (6) from (7), rearranging terms and dividing both sides by Δ gives the difference quotient:

$$\frac{W(s + \Delta) - W(s)}{\Delta} = \frac{\gamma(\alpha + r)}{\gamma\alpha + r} \frac{[V(h(s + \Delta), s + \Delta) - V(h(s), s)]}{\Delta}.$$

Now, letting $\Delta \rightarrow 0$, we have the first derivative of the wage function w.r.t. schooling,

$$W'(s) = \frac{\gamma(\alpha + r)}{\gamma\alpha + r} [V_\theta h'(s) + V_s], \quad (8)$$

where the lower indices again denote partial derivatives.

Step 2: Optimal investment in educational signals Workers' optimal signaling profile is determined by the following program for each type $\theta \in \Theta$:

$$\max_s J^U(\theta, W(s)) - C(\theta, s).$$

¹⁵Note that Δ does not appear at $\mathbb{E}[\pi^U(\cdot, \cdot)]$, because the employers' 'outside option' is the same upon every match.

The first-order necessary condition gives

$$\frac{\alpha}{\alpha + r} W'(s) - C_s = 0.$$

Utilizing (8), the first order condition can be rewritten as

$$\frac{\gamma\alpha}{\gamma\alpha + r} [V_\theta h'(s) + V_s] - C_s = 0, \quad (9)$$

which can be solved for $h'(s)$ to yield

$$h'(s) = \frac{\frac{\gamma\alpha+r}{\gamma\alpha} C_s - V_s}{V_\theta}. \quad (10)$$

Equation (10) is an ordinary differential equation. As noted by Riley (1979), this kind of ODE has family of solutions of type

$$\theta = h(s) = g(s; k), \quad (11)$$

where k is an integrating constant. From (11), one can solve the equilibrium signaling as a function of worker's type:

$$s = g^{-1}(\theta; k). \quad (12)$$

Equation (10) gives the slope of the function $g(\cdot, \cdot)$. Differentiating this expression second time w.r.t. s gives

$$h''(s) = \frac{\left(\frac{\gamma\alpha+r}{\gamma\alpha} C_{ss} - V_{ss}\right) V_\theta - \left(\frac{\gamma\alpha+r}{\gamma\alpha} C_s - V_s\right) V_{\theta s}}{(V_\theta)^2} \geq 0,$$

which means that the equilibrium signaling profile may exhibit both convex and concave parts in $s\theta$ -space.

Example 1 Let us specify $C(\theta; s) = \frac{2}{3}s^{\frac{3}{2}}\theta^{-\frac{1}{2}}$ and $V(\theta; s) = As^{\frac{1}{2}}\theta^{\frac{1}{2}}$, where A represents the exogenous level of technological development. Now, $C_s = s^{\frac{1}{2}}\theta^{-\frac{1}{2}}$, $V_s = \frac{A}{2}s^{-\frac{1}{2}}\theta^{\frac{1}{2}}$ and $V_\theta = \frac{A}{2}s^{\frac{1}{2}}\theta^{-\frac{1}{2}}$. Equation (10) then yields

$$h'(s) = \frac{\gamma\alpha + r}{\gamma\alpha} \frac{2}{A} - \frac{\theta}{s}.$$

Moreover, $h''(s) > 0$ so that the function $g(\cdot, \cdot)$ is convex. The solution to this ODE is

$$\theta = g(s; k) = \frac{\gamma\alpha + r}{\gamma\alpha} \frac{2}{A} s - \theta \ln s + k.$$

Solving for θ obtains

$$\theta = \frac{\frac{\gamma\alpha+r}{\gamma\alpha} \frac{2}{A} s + k}{1 + \ln s}.$$

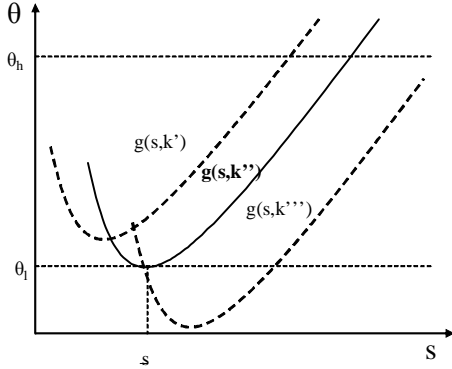


Figure 1: Three possible signaling profiles

Step 3: Verification of condition (ii) According to condition (ii) in Definition 1, we must have $h'(s) > 0$, which means that the innate type of a worker, θ , and his education choice, s , are positively related. Clearly, this necessary precondition is not automatically satisfied in (10). However, by convexity of C and concavity of V w.r.t. s we know that the numerator of (10) inevitably turns positive after some threshold \underline{s} . According to Riley (1979), it is simply a matter of choosing k such that $\theta_l \geq g(\underline{s}; k)$ (required by condition (ii)). In Figure 1, $g(s; k'')$ establishes a separating equilibrium while $g(s; k')$ does not. Note that $g(s; k'')$ is the minimum signaling profile in the sense that $\theta_l = g(\underline{s}; k)$; i.e., the least able worker chooses education level \underline{s} at which the profile $g(s; k)$ turns upward-sloping. The lowest schooling level, \underline{s} , can be found at the point where $\frac{\gamma\alpha+r}{\gamma\alpha}C_s = V_s$. Of course, also some other signaling profiles, like $g(s; k''')$, may establish separating regimes. The next section discusses which profiles are 'intuitive'.

Before that, it is instructive to derive the equilibrium wage function, given the equilibrium signaling. Plugging (10) back into (8), and using (11) and (12), we get

$$W_s(\theta, g^{-1}(\theta)) = \frac{\alpha+r}{\alpha}C_s(\theta, g^{-1}(\theta)), \quad (13)$$

so that the equilibrium wage schedule yields

$$W(g^{-1}(\theta)) = \frac{\alpha+r}{\alpha}C(\theta, g^{-1}(\theta)) + K, \quad (14)$$

where constant K can be interpreted as a base salary to be paid for each worker, regardless of his type. According to (14), the equilibrium wage function is such that,

at the time of investment in schooling, the present value of the marginal increase in wages in response to a marginal increase in education level just off-sets the marginal costs from additional schooling effort; i.e., workers' behave as Stackelberg leaders by choosing education at the level where the marginal benefit and the (personal) marginal cost from education balance.

4 Properties of the signaling profiles

4.1 A benchmark: First-best signaling profile

As a benchmark, let us start with characterizing socially optimal education levels for each type. First-best signals satisfy

$$s^{fb} = \arg \max_s \left\{ \frac{\alpha}{\alpha + r} V(\theta, s) - C(\theta, s) \right\},$$

and the first-order condition of the first-best can be written as

$$\frac{\alpha + r}{\alpha} C_s(\theta, s^{fb}) = V_s(\theta, s^{fb}), \quad (15)$$

which says that the marginal cost from schooling and the 'present value' of the marginal social gain must balance at the first-best optimum. Differentiating (15) w.r.t. s and θ gives

$$\frac{d\theta}{ds} = - \left(\frac{\frac{\alpha+r}{\alpha} C_{ss} - V_{ss}}{\frac{\alpha+r}{\alpha} C_{s\theta} - V_{s\theta}} \right) > 0,$$

so that the first-best locus in $s\theta$ -space is upward-sloping. Since the second derivative of the locus depends on third derivatives of the functions $C(\cdot, \cdot)$ and $V(\cdot, \cdot)$, the shape of the FB-locus is generally ambiguous. However, using the specifications given in Example 1, $d\theta/ds = 2(\alpha + r)/\alpha A$, in which case the FB-locus is a straight line.

4.2 Minimum signaling profile (MS-profile)

Based on the discussion provided above, we know that the separating equilibrium entailing the minimum amount of schooling requires that

$$\frac{\gamma\alpha + r}{\gamma\alpha} C_s(\theta_l, \underline{s}) = V_s(\theta_l, \underline{s}), \text{ and} \quad (16)$$

$$\frac{\gamma\alpha + r}{\gamma\alpha} C_s(\theta, s) > V_s(\theta, s) \quad \forall \theta > \theta_l. \quad (17)$$

Since the LHS of (16) is increasing with s^{16} and decreasing with γ , \underline{s} is lower than the first-best schooling level s^{fb} for the least able type if γ is strictly less than one. Obviously, this gap in education is the larger the more severe are the search frictions in the market; i.e. the greater is r . However, separating regime requires that (17) holds for rest of the types $\theta > \theta_l$ so that educational signaling may exceed the first-best schooling for types above some threshold $\bar{\theta}$ (see Figure 2, Case A). Hence,

Proposition 1 *Given that $\gamma < 1$, the minimum signaling profile (the MS-profile) entails underinvestment in education at least within a range of lower-tail types. Greater search frictions amplify undereducation.*

4.3 Signaling profile with the least type investing efficiently (LTE-profile)

Consider now a signaling profile where the least type chooses his first-best education while everyone else invests an amount that is enough to separate himself from the less able colleagues. In traditional competitive equilibrium models (e.g. Spence 1973, Riley 1979) - or in explicitly game-theoretic models (e.g. Cho-Kreps) - this kind of practice leads to overinvestment among all other types except the least able type. This result is known as the 'Riley outcome'. Instead, under decentralized trading and search frictions, such a separating regime requires

$$\begin{aligned} \frac{\alpha + r}{\alpha} C_s(\theta_l, s_l^{fb}) &= V_s(\theta_l, s_l^{fb}), \text{ but} \\ \frac{\gamma\alpha + r}{\gamma\alpha} C_s(\theta, s) &> V_s(\theta, s) \quad \forall \theta > \theta_l. \end{aligned}$$

Again we have that if γ is sufficiently low the slope of the signaling profile is steeper than the FB-locus, and the LTE-profile exhibits undereducation.

Proposition 2 *For sufficiently low γ , the LTE-profile induces underinvestment in education throughout the set Θ .*

This possibility is depicted by the Case B in Figure 2. Note that for intermediate levels of γ , also the LTE-profile may induce undereducation only within a subset of types. Whether this happens among the higher- or lower-tail types depends on the specific forms of the V and C functions.

¹⁶By the convexity of the cost function.

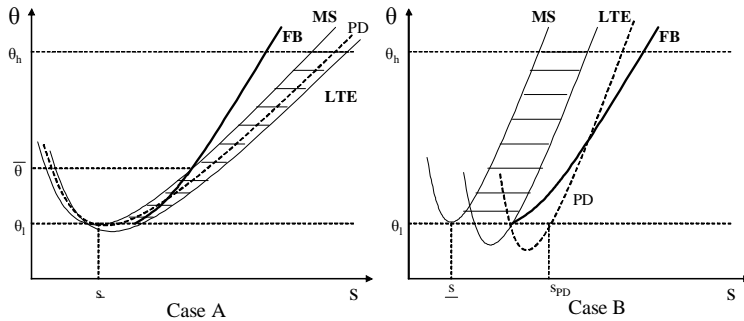


Figure 2: Set of 'intuitive' signaling profiles

4.4 The set of 'intuitive' signaling profiles

A typical result in the conventional literature is that the LTE-profile is the most 'intuitive' regime. This is because, in these models, this type of signaling pattern happens to coincide with both the MS-profile and the Pareto-dominant signaling profile (PD-profile). In our case, however, if $\gamma < 1$ and when search frictions are non-trivial, the MS-profile induces each type to invest in education strictly less than the LTE-profile does. Moreover, as we will see below, neither of these signaling profiles are necessarily Pareto-dominant.

We will argue that signaling profiles inducing more education than the LTE-profile are not 'intuitive'. Our argument draws from Cho and Krep's (1987) 'intuitive criterion' and is based on the assumption that if an employer meets a worker with an 'off-equilibrium' signal, s' , that is less than the 'more-than-efficient' signal, $s_l^* > s_l^{fb}$, chosen by the least able type in equilibrium, then the employer infers that such a worker must be of the least type. But then it would be mutually beneficial if the least able type deviated for s' because that would generate extra surplus. 'Intuitive criterion' then requires that such an opportunity will be exploited. This reasoning can be continued until the least type invests his first-best level. However, the least type's equilibrium signals below the efficient level cannot be ruled out by the same argument. This is because a downward-deviation would lead to a mutually less efficient outcome, while an upward-deviation would make the least type to imitate some higher type, which, in turn, would violate the condition for optimal schooling determined by the individual utility maximization. Therefore we have

Proposition 3 *The set of 'intuitive' signaling profiles consists of profiles in between the MS-profile and the LTE-profile.*

Figure 2 illustrates the set of 'intuitive' signaling profiles under different market conditions. Under relatively high γ and moderate search frictions (Case A), the MS-profile entails undereducation for types $\theta < \bar{\theta}$ and overeducation for $\theta > \bar{\theta}$, while the LTE-profile generates overeducation throughout the set Θ . In the opposite case, i.e., when workers' share of the matching surplus is relatively low or the search frictions in the labor market are severe (Case B), both boundary profiles induce undereducation.

The Case B in Figure 2 also depicts an example where none of the 'intuitive' profiles is Pareto-dominant; i.e., a signaling profile which minimizes the inefficiencies due under- and overinvestment in education.

Proposition 4 *If either γ is sufficiently low or the search frictions in the labor market are severe, the PD-profile does not belong to the set of 'intuitive' signaling profiles.*

Under the market conditions illustrated by the case B, the second-best signaling (the PD-profile) would induce overeducation among the lower-tail types to mitigate the undereducation problem among some of the higher types. However, in the Case A, the PD-profile is in the set of 'intuitive' signaling profiles and the second-best outcome is feasible.

4.5 'Riley outcome' as a limiting case

Riley (1979) considered signaling in a 'quasi-competitive' equilibrium model¹⁷, which can be treated as a limiting case of the current setting. Assume that search frictions in the labor market become trivial which is the case when r approaches zero. Then, equation (10) obtains

$$h'(s) = \frac{C_s - V_s}{V_\theta},$$

which is equivalent to the formula derived by Riley (1979). Social optimum now requires that each type θ chooses an education level where the marginal cost and marginal benefit from schooling balance; i.e., $C_s = V_s$. In a second-best solution, however,

¹⁷Though, he needed to introduce a refinement to conventional Walrasian equilibrium concept in order to obtain stability of the separating equilibrium. Riley's refinement was 'reactive equilibrium'.

separating equilibrium requires $C_s > V_s$. Thus, signaling profiles that establish separating equilibrium must entail too much investment in education compared to the socially efficient level. Moreover, when r approaches zero, γ does not affect the shape of the signaling profile so that the MS-profile, the LTE-profile and the PD-profile are all equal. Hence, the Riley outcome holds as a limiting case.

4.6 Discussion

It was shown above that bilateral trading and search frictions in the labor market can give rise to inefficiently low education levels at least within a subset of types. Sometimes undereducation counterbalances the inefficiencies caused by overeducation, as depicted by the Case A in Figure 2, but sometimes underinvestment in education takes place throughout the types (Case B). The latter is the more likely to happen the weaker is workers' position at the bargaining stage and the more severe are the search frictions.

Obviously, there would be room for efficiency improving policy measures. Let us first consider market conditions characterized by the Case A. Interestingly, under these circumstances increasing search frictions (i.e. higher r) would improve efficiency because the set of intuitive signaling profiles would shift counter-clockwise, leading to reduced overeducation among the high-types. As a result, the possible signaling profiles would come closer to the efficient FB-profile. This finding implies that an employment service, for example, may in some cases provide 'too efficient' coordination if that practice promotes significant overeducation. Note that an introduction of income taxes would essentially have the same effect as degenerating search frictions. Hence, a regulator may be able to improve educational efficiency by implementing a positive income tax system. On the other hand, in Case B, undereducation is the more prominent problem. Attempts to improve efficiency therefore call for schooling subsidies. The second best (the PD-profile), for example, could be implemented by introducing a schooling subsidy that guarantees free and mandatory education up to a degree s_{PD} (see the right panel of Figure 2).

Finally, let us elaborate the effect of an exogenous increase in labor productivity on equilibrium signaling. Let parameter A to represent the general level of technological development in the economy. In terms of the MS-profile, the effect of improving

technology on the schooling level obtained by the least able type is given by

$$\frac{ds}{dA} = \frac{V_{sA}}{\frac{\gamma^{\alpha+r}}{\gamma^\alpha} C_{ss} - V_{ss}},$$

which is increasing in γ if $V_{sA} > 0$. The effect of better technology on the first-best education level s^{fb} is given by the same formula with $\gamma = 1$. In other words, when $\gamma < 1$, the minimum schooling for the least able type increases less in response to a positive technological shock than in the first-best case. As a result, technological development tends to amplify undereducation among the least able types. How about rest of the types? The slope of the signaling profile is given by (10). Differentiating this expression with respect to A gives

$$\frac{\partial^2 h(s)}{\partial s \partial A} = \frac{-V_{sA} V_\theta - V_{\theta A} \left(\frac{\gamma^{\alpha+r}}{\gamma^\alpha} C_s - V_s \right)}{[V_\theta]^2},$$

which is a negative number since $V_{\theta A} > 0$ and because separating equilibrium requires $\frac{\gamma^{\alpha+r}}{\gamma^\alpha} C_s - V_s > 0$. Hence, the signaling profile becomes flatter as the general labor productivity parameter is increased. From this observation we cannot conclude, however, that overeducation among the high-types gets worse because also the first-best profile becomes flatter requiring more education for each type. Instead, we have that

Proposition 5 *An exogenous increase in technological knowledge amplifies undereducation among the low types and compounds the dispersion in education levels and wages.*

The empirically observed increase in 'skill premium' in wages has been claimed to result from 'skill-biased' technological development. Proposition 5 suggests that a similar trend can result from 'non-biased' technological change if labor markets are imperfect.

5 General equilibrium analysis

In this section we analyze general labor market equilibrium by the same token as is done in Laing, Palivos and Wang (1995), who investigate the effects of human capital accumulation on market entry and growth. The main purpose of this section is to examine how the main macroeconomic implications and their economic interpretations are modified when also the 'signaling hypothesis' is taken into consideration.

5.1 Entry and exit

It is assumed that new workers are born at an exogenously given and constant rate, η . From employers' side we assume unrestricted entry. The cost of opening a vacancy is denoted by ϕ , which can be thought to capture all the other factors of production except the worker. Firms will open new vacancies until the expected profit from a filled vacancy equals the fixed cost, ϕ . After a successful match, both the hired worker and the filled vacancy exit the market forever.

5.2 Pairwise matching

The number of unemployed workers is denoted by u while v is our measure for the number of open vacancies. The matching function, $m_0 M(u, v)$, gives the total number of matches at each point of time as a function of two inputs, u and v . Parameter m_0 describes the exogenous matching technology.

* *Assumption 4:* Matching function $M : R_+^2 \rightarrow R_+$ is strictly increasing and strictly concave, satisfies the Inada-conditions, and exhibits constant returns to scale (CRS).

In a steady state, pairwise matching requires:

$$\alpha u = \beta v. \tag{18}$$

5.3 Steady state equilibrium

Definition 2 *A steady-state equilibrium is characterized by a wage schedule $W(s, \alpha^*)$ and a corresponding signaling profile $g(s; \alpha^*)$, and a quadruple $(\alpha^*, \beta^*, u^*, v^*)$ s.t.*

- (i) $\mathbb{E}[\pi^U] = \phi$ (free entry)
- (ii) $\alpha^* u^* = \beta^* v^* = m_0 M(u^*, v^*)$, (matching condition)
- (iii) $\alpha^* u^* = \eta$ (steady-state condition).

The pairwise matching condition, together with the CRS-property of the matching function, implies that

$$\beta = m_0 M\left(\frac{\beta}{\alpha}, 1\right), \tag{19}$$

which implicitly defines the locus of the 'Beveridge-curve' (the steady state relationship between unfilled jobs and unemployment) in $\alpha\beta$ -space Utilizing the equilibrium wage schedule given in (14), the free-entry condition can be written as

$$\mathbb{E} [\pi^U] = \frac{\beta}{\beta + r} \int_{\Theta} [V(\theta, g^{-1}(\theta, \alpha)) - W(g^{-1}(\theta, \alpha))] dF(\theta) = \phi. \quad (20)$$

Now, the equations (19) and (20) determine the steady state meeting rates, α^* and β^* . Since $u^* = \eta/\alpha^*$ and $v^* = \eta/\beta^*$, the two equations solve the system completely, and a steady state equilibrium can be found at the intersection of the 'Beveridge-curve' (BC), and the free-entry curve (FE).

Following immediately from Assumption 4, the locus of the 'Beveridge-curve' is downward-sloping and convex in $\alpha\beta$ -space. In turn, the slope of the free-entry curve obtains

$$\frac{d\beta}{d\alpha} = -\frac{\int_{\Theta} [V_s - W_s] \frac{\partial g^{-1}}{\partial \alpha} dF(\theta)}{r / (\beta + r)^2}. \quad (21)$$

Lemma 1 *The FE-locus exhibits a decreasing segment in $\alpha\beta$ -space, if undereducation is the prevailing mode in education sector. Correspondingly, the FE-locus is increasing when overeducation dominates. The slope of the FE-locus is zero at the point where the inefficiencies caused by under- and overeducation balance.*

Proof. See Appendix. ■

By the analysis carried out in the previous section, we know that undereducation tend to dominate if either γ is sufficiently low or the search frictions in the labor market are severe. An example of such a situation was depicted by the Case B in Figure 2 where undereducation prevails throughout the set Θ . The level of congestion, which is the greater the smaller is the meeting rate, affects exactly as the exogenous friction r . The intuition behind the downward-sloping property of the FE-locus is that it may not pay to open new vacancies unless workers have sufficient incentives to invest in schooling. Undereducation eases off as the congestion on workers' side of the market is alleviated (i.e. α becomes larger). This happens when the labor market becomes 'tighter' (from employers' point of view) so that the ratio between vacant jobs and unemployed workers is larger. Therefore, even though tight market conditions typically discourage entry because of the congestion effect on employers' side, in some cases market tightness may actually stimulate market entry by firms

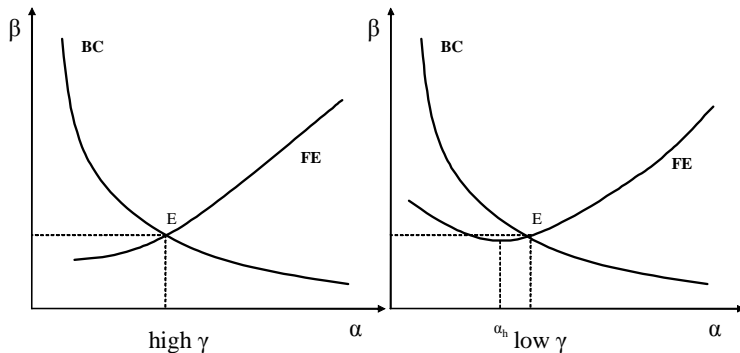


Figure 3: Unique steady states

because undereducation among workers is reduced. As a result increasing α may lead to tougher competition on labor force and higher congestion on employers' side (lower β).¹⁸ However, as $\alpha \rightarrow \infty$, it is obvious from (10) that the signaling profile approaches the 'Riley outcome' so that overeducation prevails throughout the set Θ and the FE-locus becomes monotonously increasing. Therefore, we may conclude that the FE-locus necessarily turns increasing after some threshold level for α , say α_h . If $\alpha_h > 0$, then the FE-locus exhibits a downward-sloping segment within the interval $\alpha \in [0, \alpha_h]$.

Figure 3 illustrates the two cases: Firstly, when workers' private return from schooling is relatively high, i.e., when γ is large enough, overeducation is the most dominant feature and employers' free-entry curve is monotonously increasing in $\alpha\beta$ -space (the left panel). Secondly, when γ is low, undereducation dominates under 'slack' labor market conditions and the FE-locus exhibits a decreasing segment (the right panel).

5.4 Multiple equilibria

For multiple equilibria to arise, the downward-sloping property of the free-entry locus is a necessary¹⁹ precondition. Obviously, the labor market is the more likely to exhibit multiple steady state equilibria the steeper is the decreasing segment of the FE-locus

¹⁸This is essentially the same intuition as in the model by Laing et al.'s (1995). However, they do not justify the shape of the free-entry locus analytically.

¹⁹But not sufficient, as clearly visible in Figure 3.

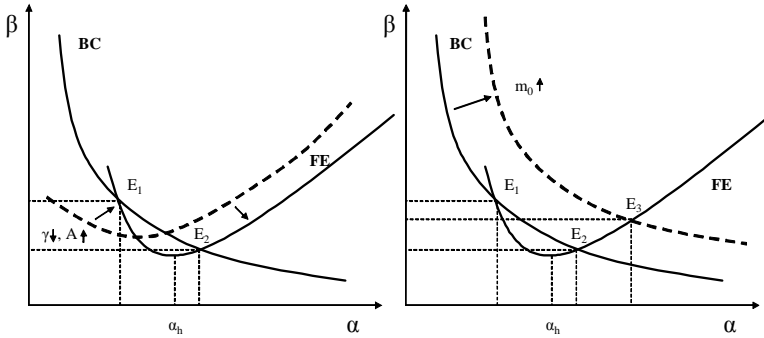


Figure 4: Multiple equilibria and escaping 'development trap'

and the higher is the threshold α_h . Since a decrease in workers' bargaining power amplifies undereducation, multiplicity of steady states may result from an exogenous drop in γ . Moreover, Proposition 5 suggests that an improvement in technological development tend to compound underinvestment in education at least among the lower-tail types. The left panel of Figure 4 provides a tentative sketch of a possible outcome from lowering γ and/or increasing A . The reason why the free-entry curve is drawn to also shift down is that lower γ enlarges employers' share of the matching surplus which encourages market entry.

Since the steady state unemployment and vacancies can be expressed as $u^* = \eta/\alpha^*$ and $v^* = \eta/\beta^*$ respectively, the first steady state, E_1 , is characterized by high equilibrium unemployment, severe undereducation, and low market entry by firms. Under steady state E_2 , in turn, there are more open vacancies, less unemployment, and better educated workers than in E_1 . Steady state E_1 can be interpreted as a development trap that can arise as a coordination failure in a decentralized economy: Workers are stuck at undereducation because private returns from educational investments remain low due scarce working opportunities in the labor market. Employers, in turn, are reluctant to open new vacancies due to poor educational level of labor force.

The policy measures proposed in Section 4.6 could be used to eliminate undereducation problem, which is the fundamental source of the potential indeterminacy of steady states. Moreover, reminiscent of the results by Laing et al. (1995), the right panel of Figure 4 suggests that even small improvements in market infrastructure, m_0 , may help the economy to escape the development trap. For example, better coordi-

nation in public employment service can initiate a considerable leap from an inferior high-unemployment steady state (E_1) to a unique steady state with lower unemployment (E_2). As noted by Laing et al., such a 'take-off' can be interpreted as an example of Murphy's et. al (1991) 'big push' development, where potentially small improvements in economic infrastructure may 'push' the economy from 'cottage'-production to industrialization.

6 Concluding remarks

According to the traditional job market signaling literature, e.g. Spence (1973, 1974) and Riley (1979), signaling motive tends to induce overinvestment in education. The current model deviates from the previous literature by considering imperfect labor markets characterized by decentralized trading and search frictions. It turns out that, as the division of the gains from trading is determined according to a bargaining game, the private return from schooling available for workers may not be high enough to guarantee sufficient investment in education. Instead, undereducation may arise at least within a subset of types. Workers' lower 'bargaining power', as well as greater search frictions, tend to amplify underinvestment. As search frictions become infinitesimal, the 'Riley outcome' with all types except the least able worker overinvesting in schooling emerges as a limiting case.

As a theoretical notice, we emphasize that our model with decentralized trading does not suffer from the instability problems characteristic to Walrasian analysis. The equilibrium signaling profile, however, is typically not unique, but the set of 'intuitive' signaling profiles can be identified. This set consists of profiles between the 'minimum signaling profile' (the MS-profile) and the profile that induces the least type to invest efficiently (the LTE-profile). We also note that the Pareto-dominant signaling profile - the profile that minimizes inefficiencies caused by under- and overinvestment - is not necessarily 'intuitive', implying that not even the second-best is always feasible. However, the regulator can improve efficiency by introducing either income taxation (if overeducation is the more prominent problem) or schooling subsidies (when undereducation dominates).

Our model also predicts that technological progress is likely to worsen undereducation among the low types and thereby compound the dispersion in both education

levels and wages. This finding suggests that widening inequality in wage structure may result from 'ordinary' technological development that is not distinctively 'skill-biased'.

On the market level, we find that underinvestment in schooling may hinder job creation when labor market is 'slack'. Even though workers' increasing likelihood to be matched generally weakens firms' position in wage negotiations, it also alleviates undereducation. Therefore, it is possible that higher contact rate on workers' side actually stimulates market entry by firms. This feature may give rise to multiple steady state equilibria. One of the steady states can be interpreted as a development trap characterized by high unemployment and severe undereducation. Reminiscent of the model by Laing et al. (1995), the model may feature a possibility of 'Big Push' development; i.e., even small improvements in labor market's matching efficiency may help the economy to escape the development trap for a unique and more efficient steady state equilibrium.

Appendix

A Proof of Lemma 1

Proof. Let us restate here the formula for the slope of the FE-curve:

$$\frac{d\beta}{d\alpha} = -\frac{\int_{\Theta} [V_s - W_s] \frac{\partial g^{-1}}{\partial \alpha} dF(\theta)}{r / (\beta + r)^2}.$$

Since the denominator is positive, the sign of $d\beta/d\alpha$ is determined by the numerator. Firstly, the partial derivative $\partial g^{-1}/\partial \alpha$ tells how the education levels react when α is increased. Since greater α means less frictions in locating potential employers, higher α should increase workers' private return from schooling both because their position in wage bargaining is improved through more valuable 'disagreement-option' and because the first contact in the labour market is more readily available. Indeed, from (10) we can conclude that $h_{s\alpha} < 0$, which in turn implies

$$\frac{\partial g(s; \cdot)}{\partial \alpha} = \int h_{s\alpha} ds < 0,$$

and $\partial g^{-1}(s; \cdot)/\partial \alpha > 0$. Secondly, $V_s - W_s$ gives the difference between the marginal effect of education on output and equilibrium wage. Equations (13) and (15) directly

imply that first-best schooling requires

$$W_s = \frac{\alpha + r}{\alpha} C_s = V_s,$$

so that $V_s - W_s = 0$ and the slope of the FE-curve is zero. Since C is convex and V concave in s ,

$$V_s > W_s,$$

implies undereducation. However, the integral over all types is positive only if undereducation holds for sufficiently large number of types. This is the case for example in Case B, where undereducation prevails throughout the set Θ . ■

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Chapter III

Asymmetric information in credit markets and entrepreneurial risk taking

Abstract

The paper constructs a search-theoretic model of credit markets with bilateral trading under asymmetric information. Borrowers' success probabilities are unobservable to the financiers, but the observable project riskiness functions as a signaling device. We find that the efficiency of perfect Bayesian equilibrium depends negatively (positively) on the credit market 'tightness' (liquidity). If greater credit market tightness is interpreted as less intense competition among financiers, the commonly held view of a negative relationship between financial competition and average project quality does not emerge in our set-up.

We also find that lower search frictions tend to increase the probability of adverse selection so that a trade-off between total volume of trading and efficient project selection may arise. This general trade-off does not, however, necessarily imply that there would be adverse selection in the competitive limit. That depends crucially on the index of credit market tightness and the distribution of types.

1 Introduction

The paper considers trading between financiers and entrepreneurs in a credit market with asymmetric information. The market's microstructure is characterized by search frictions and decentralized (pairwise) trading: loan prices are determined and transactions concluded in private meetings between entrepreneurs and financiers. Financiers are homogenous and generic; a financier can be interpreted as an individual investor, venture capitalist, or a financial institution such as bank. All entrepreneurs have access to either a 'risky' or a 'safe' investment. The characteristic of the project will be observed by the financier, but the success probability of a risky project depends on entrepreneur's unobservable ability. Entrepreneurs are of two types, high and low

ability. The sequence of moves is as follows: Entrepreneurs with hidden types first choose either a 'risky' or a 'safe' project and then, after writing up the business plan, start seeking finance for the chosen project. Efficient project selection takes place under a separating regime where the low-type chooses a safe project while the high type goes for a risky investment. Upon a meeting between an entrepreneur and a financier, the financier proposes a loan contract offer based on the project's characteristics and his beliefs on the type of the entrepreneur. Therefore, the observable project riskiness serves as a signal of the unobservable success probability¹.

Our construction differs from the conventional models of credit market with asymmetric information (e.g. Stiglitz and Weiss, 1981, and de Meza and Webb, 1987) with two important respects: Firstly, financiers can distinguish between 'risky' and 'safe' projects but not whether the entrepreneur has high or low success probability in risky investments. As a result, the efficiency of trading is driven by entrepreneurs' self-selection among the business opportunities². Secondly, price formation is decentralized and movement from one trading opportunity to another is restricted by search frictions. The model features also a theoretical contribution that stems from the way the pairwise bargaining under asymmetric information is treated³. The well-known complexities related to asymmetric information in Rubinstein's (1982) strategic bargaining game⁴ are avoided by assuming that only the uninformed party, i.e. the financier, is allowed to make offers in a take-it-or-leave-it manner. However, borrowers are assumed to have an option to *continue search* meanwhile negotiating with the financier. If the borrower exercised this option and managed to locate another financier, the two competing financiers would bid for the right to finance the entrepreneur's project.

¹In this sense, the setting resembles the models where collateral can be used as a sorting device (e.g. Wette (1983) and Bester (1985, 1987)). The set-up can also be interpreted as an *ex ante*-stage moral hazard model.

²Kanniainen and Leppämäki (2002) address the question how people with different talents get allocated to various projects under different financial institutions. Takalo and Toivanen (2003) also discuss adverse selection problem in financial markets via occupational choice between starting as an entrepreneur or a financier

³Inderst (2001) provides an interesting analysis on bargaining with asymmetric information in a bilateral matching model. However, his model is simplified by the assumption that principal's payoff is independent of the agent's type. Also Bester (1988) studies bargaining in a search model, where differences between sellers' types create price dispersions, but he does not consider adverse selection.

⁴See for example Muthoo (1999, ch. 9.8) and Fudenberg and Tirole (1991, ch. 10.4)

The proposed deviations from the standard literature seem meaningful, because pairwise trading is a common mode of interaction in credit markets and its unlikely that entrepreneurs would be bound to uniform investment opportunities. The upcoming analysis demonstrates that our setting provides new economic insight into the efficiency of resource allocation. Our search-theoretic approach also allows us to define 'taxonomy' of market conditions and discuss how these underlying conditions - like market liquidity or the frequency of financial matchmaking (which can be thought to depend on the sophistication of financial institutions) - affect allocative efficiency.

There will be four possible regimes governing the allocation of financial resources. The first one is the *separating equilibrium* (SE) where each type chooses efficiently. Another equilibrium in pure-strategies the *pooling equilibrium I* (PE_I) where both types choose a risky project so that there is adverse selection by the low-type. As an intermediate case we have the *semi-separating equilibrium* (SSE) where the high-type again selects efficiently but the low-type deviates from the efficient regime with some probability. There is also the *pooling equilibrium II* (PE_{II}) where both types stick to safe projects; i.e., there is adverse selection by the high-type. It is shown that the efficient separating equilibrium exists only under sufficiently 'liquid' market conditions which is the case when the number of financiers in the credit market is large enough compared to the number of loan applicants. Better market liquidity increases the rate at which a competing financier can be located, which unambiguously improves entrepreneurs' 'bargaining power'. As a result, entrepreneurs' private return from financial matching comes closer to the available social return so that entrepreneurs face greater incentives to select projects efficiently. Correspondingly, the regimes where the low-type chooses inefficiently can emerge only under sufficiently 'tight' (i.e. illiquid) market conditions. The gains available for 'low ability' entrepreneurs from safe investments decrease along with greater credit market tightness - which enhances financiers' market power - more rapidly than the gains available from risky investments. This is because entrepreneurs with high success probability in risky projects 'cross-subsidize' the borrowers with low success rate. Although the regime where the high-types select inefficiently, the PE_{II} , can under some parameter values exist globally, it is generally more likely to prevail only under sufficiently illiquid markets. Hence, credit market tightness may give rise to either extreme over- or underinvestment in risky projects.

Our results somewhat contradicts with those of Becsi, Li and Wang (2003) who

also develop a model of 'financial matching'⁵ with heterogeneous borrowers (they do not discuss informational asymmetries, however). Becsi et al. endogenize market entry by borrowers and conclude that greater credit market tightness discourages low-quality borrowers disproportionately, leading to higher average quality of projects. Moreover, greater credit market tightness can, in a sense, be interpreted as less intense competition on scarce financing projects. According such interpretation, our result contradicts with the commonly held view that financial sector competition is likely to induce risk taking and thereby financial fragility.^{6,7} In this branch of literature, only a few papers consider the effect of competition on adverse selection problem. Broecker (1990) analyzes this issue and concludes that intensified competition among financiers is likely to worsen adverse selection because borrowers whose loan applications have been rejected at one place can stay in the market and apply for loans from competing financiers. As a result, the average quality of loan applicants decreases along with more intense competition.⁸ However, as in our model the emphasis is shifted on the entrepreneurs'

⁵Financial matching has also been studied by Wasmer and Weil (2000) and Diamond (1990). Wasmer and Weil investigate the interaction between labor and credit market imperfections as a potential explanation why European and the US unemployment differ so greatly. Diamond, in turn, focuses on comparing lumpy and smooth credit supply in a search equilibrium.

⁶In his highly influential paper, Keeley (1990) claimed that the peak in bank failures in the US during the 1980's was caused by banking sector deregulation that spurred competition and reduced monopoly rents. The reason for excessive risk taking was that the reduction in the banks' 'charter value' magnified the agency problem between bank owners and deposit insurance fund. In the face of lower mark-ups, bank owners have greater incentive to increase upside potential via excess risk taking because limited liability and deposit insurance deaden the downside risks.

Theoretical results similar to Keeley's argument were derived by Besanko and Thakor (1993), Boot and Greenbaum (1993) and Erwards and Mishkin (1995). There are also a host of papers investigating how competition on deposits affects banks' risk taking (e.g. Nagarajan and Sealey, 1995, Matutes and Vives, 2000, Hellman, Murdock and Stiglitz, 2000, Perotti and Suarez, 2002, and Cordella and Yeyati, 2002, and Caminal and Matutes, 2002), most of which produce a trade-off between competition and excess risk taking. However, Nagarajan and Sealey (1995) and Caminal and Matutes (2002) construct examples where the converse is true.

⁷The empirical literature (e.g. Keeley, 1990, and Beck, Demirguc-Kunt and Levine, 2003) investigating the relationship between banking competition and financial stability does not offer a clear-cut evidence in either direction and the results seem highly case dependent. Carletti and Hartmann (2003) and Allen and Gale (2003) provide excellent surveys of the literature.

⁸Some authors, like Cetorelli and Peretto (2000), emphasize financiers critical role in screening entrepreneurial projects. They find that banking competition exacerbates adverse selection because

active role in project selection, higher private returns encourage efficient selection and the adverse relationship between financial competition and average project quality does not emerge.⁹

Regarding the role of search frictions in the market, we find that lower frictions tend to increase, *ceteris paribus*, the probability of adverse selection. Financiers' 'first-mover advantage' upon meetings dilutes along with greater matching rates, which increases the utility available from risky projects disproportionately. Consequently, risky investments become relatively more attractive than safe projects. Therefore, our model produces a trade-off between the total volume of trading and the average quality of investments along with lower search frictions. In Becsi et al.'s (2003) model such a trade-off arises as a result of greater market liquidity. As the search frictions become infinitesimal, each agent has an immediate access to any trading opportunity in the market so that we obtain competitive equilibrium - the framework of the models by Stiglitz and Weiss (1981) and de Meza and Webb (1987) - as a limiting case. The general trade-off between quality and quantity along with more efficient matching does not, however, necessarily imply that there would be adverse selection in the competitive limit. Which allocative regime is in effect depends primarily on the market tightness and on the distribution of types. If one considers, for example, the symmetric case where the number of entrepreneurs and financiers in the market is roughly the same, i.e., there is no excess demand nor excess supply, efficient allocation exists if the fraction of the high-type borrowers is sufficiently small. This is because higher relative number of high-types reinforces the cross-subsidization effect and the low-types are more likely to deviate in favor of less efficient project selection.

The paper is organized as follows. Section 2 introduces the model setup, defines the taxonomy of market conditions and describes the formation of loan prices. Section 3 discusses the possible regimes that govern resource allocation in credit markets. Section 4 concludes.

competitive banks face less incentive to exert costly project evaluation due potential free-riding.

⁹Koskela and Stenbacka (2000) conclude in a model with endogenous investment volumes that loan market competition reduces lending rates and generates higher investments without increasing the equilibrium bankruptcy risk of borrowers.

2 The model setup

2.1 Economic agents

There are two types of risk-neutral agents operating in the credit market: entrepreneurs and financiers. Entrepreneurs have access to investment opportunities whose implementation requires external finance. Financiers, in turn, possess access to financial resources. Without loss of generality, it is assumed that it takes exactly one entrepreneur and one financier to form a financial relationship.

Financiers are homogenous and generic: a financier can be interpreted as an individual investor or a financial institution such as bank. Entrepreneurs differ in their type $\theta \in \Theta = \{\theta_L, \theta_H\}$, which is unobservable to the financier. It is common knowledge that entrepreneur can be either 'high-type' (θ_H) or 'low-type' (θ_L) with respective probabilities $\lambda(\theta_H) = \bar{\lambda}$ and $\lambda(\theta_L) = 1 - \bar{\lambda}$.

Each entrepreneur has access to either 'risky' (ω_σ) or 'safe' (ω_s)¹⁰ project. Before meeting with a financier, entrepreneurs must commit to the business plan for which they are seeking finance. It is assumed that financiers can observe whether the chosen project is 'safe' or 'risky', and that they are able to monitor the implementation of the chosen project; i.e. there is no moral hazard in the model like for example in Holmstöm and Tirole (1997).

Regardless of the type of the entrepreneur, safe projects produce a constant and perpetual stream of output, the present value of which is denoted by W_s ; i.e.

$$W_s = \int_{\tau}^{\infty} e^{-(t-\tau)r} w_s dt = \frac{w_s}{r},$$

where w_s is the return on safe investment at every instant and r is the risk-free interest rate, which also serves as the common discount rate of the economy.

When successful, a risky project generates a perpetual flow of output w_σ normalized to one; i.e. $W_\sigma = 1/r$. However, if a risky investment fails, it produces no output. In that case, due limited liability, the financier takes the credit loss and becomes 'idle' while the entrepreneur leaves the credit market forever. Whether the risky project succeeds or fails is revealed immediately after the investment.

¹⁰The 'less risky' project is treated as 'safe' investment for simplicity.

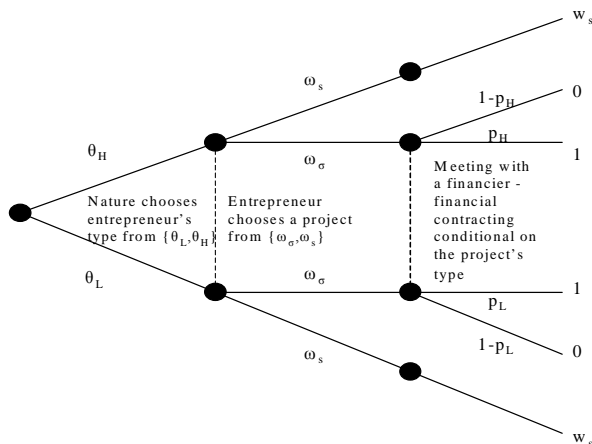


Figure 1: Sequence of events

If a high-type (low-type) entrepreneur chooses ω_σ , she will succeed with probability p_H (p_L) and fail with the complementary probability $1 - p_H$ ($1 - p_L$). Thus, the present value of the expected output from a risky project reads as p_i/r , $i = H, L$. The success probabilities p_i are common knowledge.

Any new start-up requires financial resources equal to a constant amount, K . If K units of capital were invested elsewhere in the financial markets, financiers could obtain a flow of rental earnings b , the discounted value of which is b/r .

* *Assumption 1*

- (i) $p_H > p_L$,
- (ii) $p_H > w_s > p_L$, $w_s > b$.

Hence, type- θ_H is a 'better' manager for a risky project than type- θ_L in a first-order stochastic dominance sense. Assumption 1 implies that, in a social optimum, type- θ_H should choose a risky project while type- θ_L should stick to a safe project.

Reminiscent of the models where collateral is used as a sorting device, e.g. Wette (1983) and Bester (1985, 1987), the riskiness of the chosen project can be thought to give a signal of the entrepreneur's innate type. Due to the sequential structure of the model (as depicted in Figure 1) a perfect Bayesian equilibrium (PBE) will be used as a solution concept.

2.2 Utilities from financial contracting

The general form of the financial contract is standard debt, because debt finance can be shown to be the equilibrium method of finance under Assumption 1¹¹. Therefore, the present value of the expected utility that an entrepreneur of type- θ_i gets from a risky project is given by

$$U_\sigma^i = \frac{p_i(1 - R_\sigma)}{r}, \quad (1)$$

where R_σ is the interest rate charged by the financier in the case of a risky investment. Similarly, the discounted value of the utility from starting a safe project is given by

$$U_s = \frac{w_s - R_s}{r}, \quad (2)$$

where R_s is the interest rate charged in the case of a safe project.

Correspondingly, the present value of a financier's payoff from financing a safe project yields

$$V_s = \frac{R_s - b}{r}. \quad (3)$$

However, since entrepreneurs' types are their private information, the expected present value of the profits available from financing a risky project is given by

$$V_\sigma = \frac{\xi R_\sigma - b}{r}, \quad (4)$$

where the 'average' success probability ξ , $p_L \leq \xi \leq p_H$, reflects the fact that the risky project may be managed by either a type- θ_H or a type- θ_L . Let us denote by $\mu(\omega_\sigma)$ the financier's *posterior belief* on probability that the risky project is carried out by a high-type entrepreneur. Then we have

$$\xi = \mu(\omega_\sigma)p_H + (1 - \mu(\omega_\sigma))p_L. \quad (5)$$

As in the model by de Meza and Webb (1987), there is cross-subsidization between the types. Since financiers make loan price offers for risky investments based on their posterior beliefs, type- θ_H with 'higher-than-average' success rate suffers while the type- θ_L with 'lower-than-average' success rate gains.

¹¹The formal proof can be found in de Meza and Webb (1987). The intuition behind this result is that entrepreneurs with higher success probability than the average success rate, \hat{p} , prefer to issue debt while entrepreneurs with lower than average success probability would prefer equity. Therefore, financiers cannot gain by offering to buy equity.

2.3 Search and matching

Unlike in the conventional Walrasian analysis, trading in the credit market is decentralized and carried out in an uncoordinated manner. Search for a trading partner is costless but time-consuming, which creates a friction in the functioning of the market¹². Moreover, the matching process is random in a sense that each individual has an equal chance of locating a trading partner.

Since we utilize continuous-time framework, matching rates can be represented by Poisson flow probabilities. The contact rate of an unmatched entrepreneur with a financier is denoted by α while financiers locate entrepreneurs at rate β . The number of entrepreneurs seeking finance is denoted by E and the number of financiers by F . The pairwise matching condition, $\alpha E = \beta F$, manifests the fact that exactly one entrepreneur and one financier is needed to establish a successful match. We follow Rubinstein and Wolinsky (1987) by assuming that there are exogenous and constant flows of arrival at the rates of e new entrepreneurs and e new financiers at each point of time¹³. Thus, the model will deal with a steady state situation in which the measures E and F are constant over time¹⁴.

The ratio $\varphi = E/F (= \beta/\alpha)$ measures credit market tightness. If φ is high, credit market is 'tight' since there is a large number of entrepreneurs seeking finance per each 'vacant lot' of loan capital. Equivalently, $1/\varphi$ is an index of the liquidity of the credit market¹⁵: If φ is low, there is relatively large supply of credit compared to the demand and thereby finance is more readily available. Note that the meeting rates α and β are interlinked; in steady state, $\beta = \varphi\alpha$. Therefore we may say that, if α is low the matching efficiency of the credit market is poor, while in the opposite case, search frictions are moderate and matching is relatively efficient. Figure 2 illustrates the interpretation of the $\alpha\beta$ -plane in credit market context.

¹²Having direct search costs would introduce just another friction to the matching process.

¹³These rates must be equal to ensure the existence of a steady state.

¹⁴This type of setting is a simplified version of the conventional Mortensen-Pissarides framework (Mortensen, 1982, and Pissarides, 1984, 2000) in which these numbers are typically determined by a free-entry condition and an exogenous 'matching function'.

¹⁵We follow here Wasmer and Weil (2000).

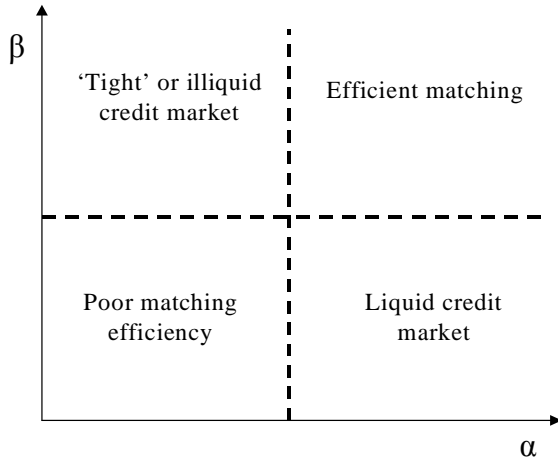


Figure 2: Taxonomy of market conditions

2.4 Price formation

Upon meeting, the financier makes a loan contract offer in a take-it-or-leave-it manner. However, before accepting or rejecting the offer, the entrepreneur has an option to continue search for another financier. If another financier shows up, the two lender candidates must engage in a Bertrand-type price competition. As a result, the competing financiers lower their credit rate offers until driven to their reservation utility levels, V_0 ¹⁶.

Thus, when there are two financiers at the meeting, the competitive loan prices are set on a level that, given the equilibrium beliefs $\mu^*(\omega_\sigma)$, produces the entrepreneur expected utility¹⁷ equal to

$$\hat{U}_\sigma^{comp} = \frac{\xi(\mu^*) - b}{r} - V_0(R_s, R_\sigma), \quad (6)$$

if the underlying project is risky, and

$$U_s^{comp} = \frac{w_s - b}{r} - V_0(R_s, R_\sigma), \quad (7)$$

when a safe project has been chosen.

¹⁶A more general treatment of this type of negotiation procedure can be found in Kultti and Virrankoski (2004).

¹⁷Again in present value terms.

Note that $\xi - b$ ($w_s - b$) represents the expected total surplus available from a risky (safe) investment. Thus, equations (6) and (7) simply state that the expected gain from trade for an entrepreneur facing two competing financiers equals the net of the expected total surplus and lenders' reservation utility, V_0 .

In order to derive the formula describing V_0 , let us denote by τ ($1 - \tau$) the probability that the 'next' project to be met is risky (safe). As financiers locate entrepreneurs at rate, V_0 can be determined by the following asset pricing formula:

$$rV_0(R_s, R_\sigma) = \beta \{(\tau V_\sigma(R_\sigma) + (1 - \tau) V_s(R_s)) - V_0(R_s, R_\sigma)\},$$

which directly implies that

$$V_0(R_s, R_\sigma) = \frac{\beta}{\beta + r} (\tau V_\sigma(R_\sigma) + (1 - \tau) V_s(R_s)). \quad (8)$$

Upon every meeting, the entrepreneur - with either a safe or a risky investment opportunity - faces an *option to continue search*. Let us denote the respective values of those options by \hat{P}_σ and P_s . Since entrepreneurs locate financiers at rate α , the asset values of the continuation options yield respectively

$$\hat{P}_\sigma = \frac{\alpha}{\alpha + r} \hat{U}_\sigma^{comp}, \text{ and } P_s = \frac{\alpha}{\alpha + r} U_s^{comp}. \quad (9)$$

Since financiers can make take-it-or-leave-it offers, a profit maximizing lender proposes an offer that just prevents the entrepreneur from exercising her continuation option¹⁸. Thus, the financier sets the loan prices in a manner that guarantees the entrepreneur with a risky project an average utility equal to

$$\hat{U}_\sigma(R_s, R_\sigma) = \hat{P}_\sigma(R_s, R_\sigma) = \frac{\alpha}{\alpha + r} \left(\frac{\xi(\mu^*) - b}{r} - V_0(R_s, R_\sigma) \right), \quad (10)$$

while the utility available for entrepreneurs with safe projects reads as

$$U_s(R_s, R_\sigma) = P_s(R_s, R_\sigma) = \frac{\alpha}{\alpha + r} \left(\frac{w_s - b}{r} - V_0(R_s, R_\sigma) \right). \quad (11)$$

In the trading process characterized by equations (6)-(11) entrepreneurs possess an option to continue search while financiers do not. This asymmetry facilitates our wish to let only the uninformed party to propose offers and, at the same time, provide

¹⁸Kultti and Virrankoski (2003) provide a rigorous proof for the fact that no continuation options are exercised in equilibrium.

some market power to the informed party as well. The assumptions needed to justify such an asymmetric structure are: 1) In order to maintain the contact with the entrepreneur, financier must propose an offer upon the meeting, 2) Once the entrepreneur has received the offer, it remains valid until she has either accepted or rejected it, and 3) All loan contract offers are enforceable; i.e. they obligate banks to provide finance at the proposed interest rate. Fortunately, these assumptions are somewhat weak and plausible.

Equations (10) and (11) implicitly define the loan prices R_σ and R_s respectively. Lemma 1 gives the explicit expressions for the pricing rule, $\{R_s, R_\sigma\}$ and the utility levels \hat{U}_σ and U_s .

Lemma 1

$$R_s = \frac{(\alpha + r)(\beta + r)w_s + \alpha(\alpha + r)b + \tau\alpha\beta(\xi - w_s)}{(\alpha + r)(\alpha + \beta + r)},$$

$$R_\sigma = \frac{(\alpha + r)(\beta + r)\xi + \alpha(\alpha + r)b - \tau\alpha\beta(\xi - w_s)}{\xi(\alpha + r)(\alpha + \beta + r)},$$

while

$$U_s = \frac{\alpha((\alpha + r)(w_s - b) - \tau\beta(\xi - w_s))}{(\alpha + r)(\alpha + \beta + r)r},$$

$$\hat{U}_\sigma = \frac{\alpha((\alpha + r)(\xi - b) + \tau\beta(\xi - w_s))}{(\alpha + r)(\alpha + \beta + r)r}.$$

Proof. Follows directly from (11) and (10). ■

Corollary 1 $U_\sigma^H = \frac{\underline{\mu}}{\underline{\xi}}\hat{U}_\sigma > \hat{U}_\sigma$ and $U_\sigma^L = \frac{\underline{\mu}}{\underline{\xi}}\hat{U}_\sigma < \hat{U}_\sigma$.

Proof. Follows after few steps from (11) and from (10), and Lemma 1. ■

The contact rates α and β affect the share of the surplus available to each trading partner. In steady state, α and $\beta = \varphi\alpha$. Substituting this fact into the loan price equations and combining terms gives

$$R_s = \frac{(\varphi\alpha + r)w_s + \alpha b + \tau\varphi\frac{\alpha}{\alpha+r}(\xi - w_s)}{\alpha + \varphi\alpha + r},$$

$$R_\sigma = \frac{(\beta + r)\xi + \alpha b - \tau\varphi\frac{\alpha^2}{\alpha+r}(\xi - w_s)}{\xi(\alpha + \beta + r)},$$

Differentiating these expressions w.r.t. the index of market tightness, φ , obtains

Lemma 2 *Greater credit market tightness leads to higher equilibrium loan prices.*

This rather obvious result stems from the fact that increased market tightness reduces the frequency at which entrepreneurs locate a competing financier, leading to an unambiguous improvement in financiers' bargaining power.

3 Equilibrium analysis

3.1 Definition of a perfect Bayesian equilibrium

A strategy for an entrepreneur of type- θ_i prescribes a probability distribution $\{1 - \eta, \eta\}$ over actions in the set $\Phi = \{\omega_s, \omega_\sigma\}$, given that financiers make loan contract offers according to the pricing rule expressed in Lemma 1. Thus, the strategy profile of type- θ_i gives the probability η ($1 - \eta$) with which a risky (safe) project, ω_σ (ω_s), is chosen. Financiers, who observe the entrepreneur's choice from the set Φ , use Bayes' rule to update their beliefs and to obtain the posterior distribution $\mu(\omega)$ over the set Θ . Formally,

Definition 1 *An perfect Bayesian equilibrium (PBE) is an entrepreneur's strategy profile $\{1 - \eta_i^*, \eta_i^*\}$, $i, j = H, L$ and financier's posterior beliefs $\mu^*(\omega)$ such that*

$$(i) \eta_i^* \in \arg \max_{\eta_i \in [0,1]} \{ (1 - \eta_i) U_s(R_\sigma(\eta_i, \eta_j^*)) + \eta_i U_\sigma^i(R_s(\eta_i, \eta_j^*)) \},$$

and (ii) financiers propose offers, $R_s(\eta_i^*, \eta_j^*)$ and $R_\sigma(\eta_i^*, \eta_j^*)$, according to Lemma 1, and

$$(iii) \mu^*(\omega) = \frac{\lambda(\theta_H) \eta_i^*(\omega)}{\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^*(\omega)}, \omega \in \Phi$$

if

$$\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^*(\omega) > 0.$$

If

$$\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^*(\omega) = 0,$$

then $\mu^*(\omega)$ is any probability distribution on Θ .

By condition (i) in Definition 1, the equilibrium strategies yield

$$\begin{aligned} \{1 - \eta_i^*, \eta_i^*\} &= \{0, 1\} \Leftrightarrow \forall \eta_j^*: U_\sigma^i(R_s(\eta_i^*, \eta_j^*)) > U_s(R_s(\eta_i^*, \eta_j^*)) \text{ and} \\ \{1 - \eta_i^*, \eta_i^*\} &= \{1, 0\} \Leftrightarrow \forall \eta_j^*: U_\sigma^i(R_s(\eta_i^*, \eta_j^*)) < U_s(R_s(\eta_i^*, \eta_j^*)). \end{aligned}$$

On the other hand, a regime where type- θ_i randomizes her choice over the set Φ , i.e. $\{1 - \eta_i^*, \eta_i^*\}$ s.t. $\eta_i^* \in (0, 1)$, is an equilibrium only if

$$U_\sigma^i(R_s(\eta_i^*, \eta_j^*)) = U_s(R_s(\eta_i^*, \eta_j^*)), \quad \forall \eta_j^*. \quad (12)$$

Condition (ii) states that the price formation is carried through the procedure described in Sections 2.4, and that financiers are actually willing to propose offers according to that pricing rule. Since any loan contract will produce the financier a payoff that at least equals his reservation value, and since this reservation value (in expected terms) can be shown to be positive under any credit market equilibria, the latter condition is automatically satisfied.

The Bayes' rule expressed in condition (iii) equals

$$\mu(\omega_\sigma) = \frac{\bar{\lambda}\eta_H^*}{\bar{\lambda}\eta_H^* + (1 - \bar{\lambda})\eta_L^*}, \quad \text{and} \quad \mu(\omega_s) = \frac{\bar{\lambda}(1 - \eta_H^*)}{\bar{\lambda}(1 - \eta_H^*) + (1 - \bar{\lambda})(1 - \eta_L^*)}$$

Moreover,

$$\tau = \bar{\lambda}\eta_H^* + (1 - \bar{\lambda})\eta_L^*,$$

It is easy to check that under symmetric information, when the loan contracts can be conditioned directly upon entrepreneurs' types, the model produces a pricing rule that induces each type to choose efficiently from the set Φ . The next section discusses possible credit market equilibria under asymmetric information.

3.2 Candidate regimes

Lemma 3 (i) Type- θ_H plays pure strategies by choosing either a safe project or a risky investment with probability 1; i.e. either $\eta_H^* = 0$ or $\eta_H^* = 1$. (ii) Type- θ_H chooses a risky project with probability 1 if type- θ_L either chooses a risky project with probability 1 or randomizes her choice; i.e. $\eta_H^* = 1$ iff $\eta_L^* \in (0, 1]$.

Proof. (i) Assume the contrary, i.e. $\eta_H^* \in (0, 1)$, which implies $U_\sigma^H = U_s$. Since $U_\sigma^H > U_\sigma^L$, we must have $U_\sigma^L < U_s$, which in turn implies $\eta_L^* = 0$ so that $\tau = \bar{\lambda}\eta_H^*$ and $\xi = p_H$. But then by Lemma 1, the indifference condition $U_\sigma^H = U_s$ is satisfied only if $p_H = w_s$, which contradicts with assumption $p_H > w_s$.

(ii) If $\eta_L^* \in (0, 1]$, then $U_\sigma^L \geq U_s$ and $U_\sigma^H > U_s$, which implies $\eta_H^* = 1$. ■

Hence, up to four different type of equilibria are possible.

- *Separating equilibrium (SE) (first-best)*, where entrepreneurs of type- θ_H choose risky projects with probability 1, and entrepreneurs of type- θ_L choose safe projects with probability 1,
- *Pooling equilibrium I (PE_I)*, where both types choose risky projects with probability 1,
- *Semi-separating equilibrium (SSE)*, where type- θ_H chooses a risky project with probability 1 while type- θ_L randomizes between risky and safe projects, and
- *Pooling equilibrium II (PE_{II})*, where both types stick to safe projects with probability 1.

We will start the equilibrium analysis with the first three regimes. In fact, SE and PE_I are special cases of SSE. After that, existence of the fourth possibility, PE_{II}, is discussed separately.

3.3 Existence of SE, PE_I and SSE

In a SSE, we have $\eta_H^* = 1$ and $\eta_L^* \in (0, 1)$, and

$$\begin{aligned}\mu^*(\omega_\sigma) &= \frac{\bar{\lambda}}{\bar{\lambda} + (1 - \bar{\lambda})\eta_L^*}, \quad \tau = \bar{\lambda} + (1 - \bar{\lambda})\eta_L^*, \text{ and} \\ \xi^{SSE} &= \frac{\bar{\lambda}p_H + (1 - \bar{\lambda})\eta_L^*p_L}{\bar{\lambda} + (1 - \bar{\lambda})\eta_L^*}.\end{aligned}\quad (13)$$

In any SSE, eq. (12) hold for type- θ_L . Using (13) in (12) and solving for η_L yields

$$\eta_L = \frac{\bar{\lambda}}{1 - \bar{\lambda}} \frac{(p_H - w_s)\psi\beta - (\alpha + r)[p_H(w_s - p_L) - (p_H - p_L)b]}{(w_s - p_L)\psi\beta + (\alpha + r)p_L(w_s - p_L)}, \quad (14)$$

where $\psi = \bar{\lambda}p_H + (1 - \bar{\lambda})p_L$.

Proposition 1 (i) *Separating equilibrium (SE), i.e. $\eta_H^* = 1$ and $\eta_L^* = 0$, exists, if η_L derived in (14) is non-positive. $\eta_L \leq 0$ if*

$$\beta \leq \frac{p_H(w_s - p_L) - (p_H - p_L)b}{(p_H - w_s)\psi} (\alpha + r) \equiv \hat{\beta}^{SE}(\alpha).$$

(ii) *Pooling equilibrium I (PE_I), i.e. $\eta_H^* = 1$ and $\eta_L^* = 1$, exists, if $\eta_L \geq 1$, which is the case if*

$$\beta \geq \frac{\psi(w_s - b) - p_L(\psi - b)}{\psi(\psi - w_s)} (\alpha + r) \equiv \hat{\beta}^{PE_I}(\alpha).$$

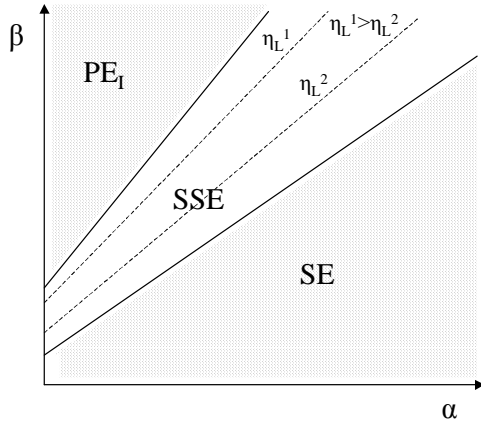


Figure 3: Location of different regimes on $\alpha\beta$ -plane

(iii) The credit market is in a semi-separating equilibrium (SSE), $\eta_H^* = 1$ and $\eta_L^* \in (0, 1)$, if

$$\hat{\beta}^{SE}(\alpha) < \beta < \hat{\beta}^{PE_I}(\alpha).$$

Proof. See Appendix A. ■

Figure 3 illustrates the information provided by Proposition 1; i.e., the prevalence of different regimes in $\alpha\beta$ -plane. The 'iso-strategy' lines, i.e. the locuses that depict the combinations of α and β which support the same equilibrium strategies, are linear and increasing. Credit market tightness, φ , increases as one moves counter-clockwise in Figure 3. Obviously, an increase in φ - which strenghtens financiers' 'bargaining power' - tends to induce inefficiency by encouraging the 'low-types' to choose risky projects. The reason is that the gains available from safe investments for type- θ_L entrepreneurs decrease more rapidly along with financiers' market power than the gains from risky projects. This is because the 'low-types' benefit from the cross-subsidization by the entrepreneurs with high success probability. The negative relationship between market tightness and allocative efficiency is easy to verify by substituting $\beta = \varphi\alpha$ into (14) and differentiating w.r.t. the index of credit market tightness, φ . It is also straight-forward to show that, when the fraction of the high-types, $\bar{\lambda}$, is increased, the 'low-types' are the more likely to deviate in favor of less efficient project selection. This is because the low-types enjoy greater cross-subsidization in risky projects when $\bar{\lambda}$ is larger.

Since in steady state $\beta = \varphi\alpha$, α can be used as a general measure of search fric-

tions in the market. Interestingly, lower search frictions tend to increase the probability of adverse selection. Better matching frequency generally improves entrepreneurs' position by diluting financiers' first-mover advantage and increasing the value of the option to continue search for a competing financier. However, these improvements reduce the loan prices for risky investments disproportionately, which unambiguously increases the threat of adverse selection. This asymmetry is easy to see if the expected utility equations derived in Lemma 1 are rewritten as

$$U_s = \frac{1}{r} \left[\frac{w_s - b}{1 + \varphi + \frac{r}{\alpha}} - \frac{\tau\varphi(\xi - w_s)}{(1 + \varphi + \frac{r}{\alpha})(1 + \frac{r}{\alpha})} \right], \text{ and}$$

$$\hat{U}_\sigma = \frac{1}{r} \left[\frac{\xi - b}{1 + \varphi + \frac{r}{\alpha}} + \frac{\tau(\xi - w_s)}{(1 + \varphi + \frac{r}{\alpha})(1 + \frac{r}{\alpha})} \right].$$

Clearly, better matching efficiency increases entrepreneurs' expected utility from risky projects (\hat{U}_σ), while the effect on the utility available from safe investments (U_s) is ambiguous. Hence, even though greater search frictions hinder financial matchmaking and thereby reduce the total volume of trading, they may also - at least under some circumstances - improve allocative efficiency.

The comparative static results are collected in the following lemma:

Lemma 4

$$\frac{\partial \eta_L^*}{\partial \varphi} > 0, \quad \frac{\partial \eta_L^*}{\partial \alpha} > 0 \text{ and } \frac{\partial \eta_L^*}{\partial \bar{\lambda}} > 0.$$

Proof. Follows directly from differentiating (14) w.r.t. φ , α and $\bar{\lambda}$. ■

As α approaches infinity, search frictions become infinitesimal. Therefore, a Walrasian competitive equilibrium, where each market participant has frictionless access to any trading opportunity, can be thought as a limiting case of the current model. Does the result $\partial \eta_L^* / \partial \alpha > 0$ imply that there will inevitably be adverse selection in the Walrasian limit? Not necessarily, since $\lim_{\alpha \rightarrow \infty} \eta_L$ may converge to a negative number, which, by definition, means that $\eta_L^* = 0$ and we have the efficient separating equilibrium. Whether this actually happens depends crucially on the index of market tightness and the distribution of types. If one considers the symmetric case where there is no excess demand nor excess supply, i.e., $\varphi = 1$, efficient allocation is obtained in the Walrasian limit if the 45-degree line eventually is in the SE-region as the matching efficiency is improved; i.e. one moves further from the origin in Figure 3.

This will be the case if the slope of the frontier $\hat{\beta}^{SE}(\alpha)$ is greater than one. In order to have a sufficiently steep slope for the frontier $\hat{\beta}^{SE}(\alpha)$, the fraction of the high-type borrowers is small enough; i.e.

Lemma 5 *Under unit market tightness, $\varphi = 1$, SE remains feasible in the Walrasian limit iff*

$$\bar{\lambda} \leq \frac{p_H(w_s - p_L) - (p_H - p_L)b - p_L(p_H - ws)}{(p_H - p_L)(p_H - ws)}.$$

Proof. Requiring that the slope of the frontier $\hat{\beta}^{SE}(\alpha)$ is greater than one, i.e.

$$\frac{p_H(w_s - p_L) - (p_H - p_L)b}{(p_H - w_s)\psi} > 1,$$

and remembering that $\psi = \bar{\lambda}p_H + (1 - \bar{\lambda})p_L$ yields the result. ■

Otherwise our model produces 'overinvestment' in risky projects as a limiting case, the result that also arises in the model by de Meza and Webb (1987).

3.4 Existence of PE_{II}

Under PE_{II} both types choose safe projects with probability 1; i.e. $\{1 - \eta_H^*, \eta_H^*\} = \{1, 0\}$ and $\{1 - \eta_L^*, \eta_L^*\} = \{1, 0\}$. Now choosing risky project is a 'zero-probability' event and Bayes' rule has no bite. If an entrepreneur deviates and chooses a risky investment, the equilibrium beliefs regarding her type can be any distribution on Θ^{19} . Therefore, there will be a continuum of PE_{II}s, depending on how the equilibrium beliefs are chosen.

Under PE_{II}, $\tau = 0$. Then according to Lemma 1,

$$U_s^{PE_{II}} = \frac{\alpha(w_s - b)}{(\alpha + \beta + r)r}, \quad \hat{U}_\sigma^{PE_{II}} = \frac{\alpha(\alpha + r)(\xi^{PE_{II}} - b) + \alpha\beta(\xi^{PE_{II}} - w_s)}{(\alpha + r)(\alpha + \beta + r)r}.$$

Obviously, since $U_\sigma^{H,PE_{II}} > U_\sigma^{L,PE_{II}}$, it suffices to derive the condition under which type- θ_H does not deviate from PE_{II}. The condition, $U_\sigma^{H,PE_{II}} \leq U_s^{PE_{II}}$ obtains

Lemma 6 *PE_{II}, i.e. $\eta_H^* = 0$ and $\eta_L^* = 0$, exists, if*

$$\beta \geq \frac{p_H(\xi^{PE_{II}} - b) - \xi^{PE_{II}}(w_s - b)}{p_H(w_s - \xi^{PE_{II}})}(\alpha + r) \equiv \hat{\beta}^{PE_{II}}(\alpha),$$

and if $\xi^{PE_{II}} - w_s < 0$. Otherwise, PE_{II} is not feasible.

¹⁹Note that the same is true in the case of PE_I where the 'zero-probability' event is the case where an entrepreneur chooses a safe project. However, since entrepreneur's type do not affect the outcome of safe projects, the stability of PE_I is not sensitive to the beliefs $\mu(w_s)$.

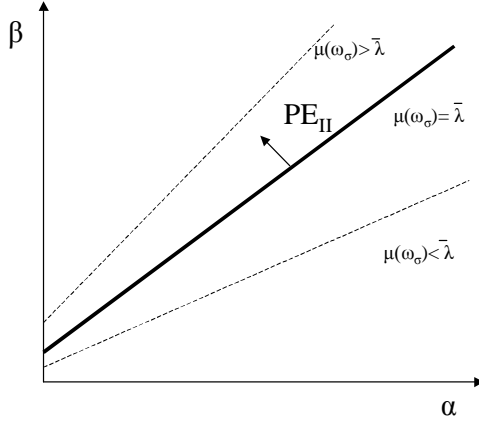


Figure 4: Feasibility of PE_{II}

The magnitude of the threshold $\hat{\beta}^{PE_{II}}(\alpha)$ depends on the equilibrium beliefs $\hat{\mu}(\omega_\sigma)$. Hence, there is a continuum of PE_{II} s supported by different beliefs. In order to limit the amount of equilibria, one needs to restrict the way in which beliefs can be updated in the case of 'zero-probability' events. One option is the requirement of consistency of sequential equilibrium á la Kreps and Wilson (1982):

Lemma 7 *The consistency requirement of sequential equilibrium implies*

$$\mu^*(\omega_\sigma) = \bar{\lambda},$$

so that $\xi^{PE_{II}} = \bar{\lambda}p_H + (1 - \bar{\lambda})p_L = \xi^{PE_I} \equiv \psi$.

Proof. See Appendix B. ■

Figure 4 represents the frontiers above which the PE_{II} - under different equilibrium beliefs - exists in the $\alpha\beta$ -plane. The bold line represents the frontier associated with the 'off-equilibrium' beliefs that satisfy the consistency requirement. Note that PE_{II} exists globally if $\xi^{PE_{II}} < p_H b / (p_H - w_s + b)$.

3.5 Supplement: Confirming financiers' participation

We still need to check that, under any candidate equilibrium, financiers are willing to trade. The mode of the bilateral trading implies that financiers can never earn

less than their reservation value, V_0 . Therefore, financiers are always willing to trade, unless the reservation value is negative (we want to rule out the possibility of losses in steady state). In order to confirm that V_0 is non-negative, we derive the following result

Lemma 8 *Under any credit market equilibrium, either $\xi^* > b$ or each type's optimal strategy obtains $\{1 - \eta_i^*, \eta_i^*\} = \{1, 0\}$ implying $\tau = 0$ (i.e. risky investments are never implemented).*

Proof. See Appendix C. ■

Lemma 8 states that, under any equilibrium regime, entrepreneurs choose risky projects only if the expected output from those investments exceeds financier's opportunity cost, b . Since loan contracts guarantee financiers at least a repayment equal to b , a fact that can be confirmed by considering the worst possible scenario from financiers' point of view, i.e. $\varphi \rightarrow 0$, and obtain $\lim_{\varphi \rightarrow 0} R_i = b$, Lemma 8 directly implies that $V_0 \geq 0$, which guarantees financiers' participation.

4 Concluding remarks

The paper postulates a bilateral trading mechanism that enables a convenient introduction of informational asymmetries into a credit market model with search frictions. The model incorporates heterogeneity not only in the borrowers' types but also in the intrinsic riskiness of the available entrepreneurial projects. The observable riskiness of the chosen project works as an informative signal about the unobservable type of the entrepreneur. The efficiency of trading is determined by relative loan prices and borrower's self-selection among the available business opportunities. Perfect Bayesian equilibrium is used as a solution concept.

The efficient allocational regime, the separating equilibrium, exists only under sufficiently 'liquid' market conditions; i.e., when the number of financiers in the credit market is relatively large compared to the number of loan applicants. Better market liquidity increases the rate at which a financier can be located - a feature which improves entrepreneurs' 'bargaining power' through more valuable 'outside option'. As a result, entrepreneurs' private return from financial matching comes closer to the

available social return so that entrepreneurs face greater incentives to select projects efficiently. Efficiency deteriorates gradually as credit market 'tightness' increases. These findings contradict with the previous results due to Becsi, Li and Wang (2003) who conclude that greater credit market liquidity tends to dilute the average quality of projects. Moreover, since greater liquidity indicates more intense competition among financiers, the commonly asserted trade-off between competition and excess risk taking does not emerge in our model: default risk (or *financial fragility*) is more prominent under less competitive (tight) rather than more competitive (liquid) market conditions.

We also find that lower search frictions tend to increase the probability of adverse selection so that a trade-off between total volume of trading and efficient project selection may arise. This general trade-off does not, however, necessarily imply that there would be adverse selection in the competitive limit. That depends crucially on the index of credit market tightness and the distribution of types.

Appendix

A Proof of Proposition 1

Proof. (i) Under separating regime, Bayes' rule gives $\mu^*(\omega_\sigma) = 1$. Moreover, $\xi^{SE} = p_H$ and $\tau = \bar{\lambda}$, which together with Lemma 1 imply

$$\begin{aligned} U_\sigma^{H,SE} &= \hat{U}_\sigma^{SE} = \frac{\alpha(\alpha+r)(p_H-b) + \alpha(1-\bar{\lambda})\beta(p_H-w_s)}{(\alpha+r)(\alpha+\beta+r)r} \\ U_s^{SE} &= \frac{\alpha(\alpha+r)(w_s-b) - \alpha\bar{\lambda}\beta(p_H-w_s)}{(\alpha+r)(\alpha+\beta+r)r}. \end{aligned}$$

It is easy to check that type- θ_H has no incentives to deviate from the first-best separating equilibrium:

$$U_\sigma^{H,SE} = \frac{\alpha}{\alpha+r}(p_H-w_s) + U_s^{SE} > U_s^{SE}.$$

Hence, type- θ_H will never deviate. On the other hand, type- θ_L will not deviate only if

$$U_\sigma^{L,SE} = \frac{p_L}{p_H} U_\sigma^{H,SE} \leq U_s^{SE},$$

which can be written as

$$\beta \leq \frac{p_H(w_s-p_L) - (p_H-p_L)b}{(p_H-w_s)\psi} (\alpha+r) \equiv \hat{\beta}^{SE}(\alpha),$$

which in turn coincides with the condition that implies $\eta_L \leq 0$.

(ii) Under PE_I , $\mu^*(\omega_\sigma) = \bar{\lambda}$, $\tau = 1$ and $\xi = \bar{\lambda}p_H + (1 - \bar{\lambda})p_L \equiv \psi$. By Lemma 1 and Corollary 1 U_σ^{L,PE_I} and $U_s^{PE_I}$ yield respectively

$$\begin{aligned} U_\sigma^{L,PE_I} &= \frac{\alpha}{(\alpha + \beta + r)r} \frac{(\psi - b)}{\psi} p_L, \\ U_s^{PE_I} &= \frac{\alpha(\alpha + r)(w_s - b) - \alpha\beta(\psi - w_s)}{(\alpha + r)(\alpha + \beta + r)r}. \end{aligned}$$

Thus, $U_\sigma^{L,PE_I} \geq U_s^{PE_I}$ iff

$$\beta \geq \frac{\psi(w_s - b) - p_L(\psi - b)}{\psi(\psi - w_s)} (\alpha + r) \equiv \hat{\beta}^{PE_I}(\alpha),$$

which is the same as the conditions that implies $\eta_L \geq 1$.

(iii) Points (i) and (ii) confirm that no pure-strategy equilibrium is feasible if $0 < \eta_L < 1$. Eq. (14) was derived given the condition $U_\sigma^{L,SSE} = U_s^{SSE}$, which is the necessary and sufficient condition for having a SSE. ■

B Proof of Lemma 7

Proof. The consistency of off-equilibrium beliefs requires that if

$$\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^*(\omega) = 0,$$

then there exists a sequence of strategies, $\{1 - \eta_i^n, \eta_i^n\}$, such that

$$\begin{aligned} 1) \eta_i^n &= \varepsilon^n, \text{ and } \lim_{n \rightarrow \infty} \varepsilon^n = 0, \\ 2) \eta_i^* &= \lim_{n \rightarrow \infty} \eta_i^n, \text{ and} \\ 3) \mu^*(\omega) &= \lim_{n \rightarrow \infty} \frac{\lambda(\theta_H) \eta_H^n(\omega)}{\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^n(\omega)}. \end{aligned}$$

These conditions presume that financiers' beliefs can be regarded as limits of totally mixed strategies and associated beliefs converging to the candidate equilibrium. Conditions 1-3 state that, 1) n th strategy in the sequence puts positive probability on both ω_s and ω_σ , 2) these strategies converge to entrepreneur's candidate equilibrium strategy, and 3) the beliefs calculated from Bayes' rule using strategies in the sequence converge to the candidate equilibrium beliefs.

Now, assuming the consistency requirement, we get

$$\mu^*(\omega_\sigma) = \lim_{n \rightarrow \infty} \frac{\lambda(\theta_H) \eta_H^n}{\sum_{\theta_j \in \Theta} \lambda(\theta_j) \eta_j^n} = \lim_{n \rightarrow \infty} \frac{\bar{\lambda} \varepsilon^n}{\bar{\lambda} \varepsilon^n + (1 - \bar{\lambda}) \varepsilon^n} = \bar{\lambda}.$$

■

C Proof of Lemma 8

Proof. At least some risky investments are implemented in SE, SSE and PE_I. Evidently, by Assumption 1, $\xi^{SE} = p_H > b$. Moreover, PE_I exists only if $\xi^{PE_I} = \psi \geq w_s > b$. Now, if $\psi - w_s < 0$, the condition that would guarantee the existence of PE_I would obtain $\beta \leq \hat{\beta}^{PE_I}(\alpha) < 0$, which is impossible because negative arrival rates are ruled out.

Regarding SSE, if $\psi - w_s < 0$, there must be a threshold $\bar{\eta}_L \in (0, 1)$ s.t.

$$\xi^{SSE} |_{\bar{\eta}_L \in (0,1)} - w_s = 0.$$

But $\xi^{SSE} |_{\bar{\eta}_L \in (0,1)} - w_s = 0$ implies that $\hat{U}_\sigma^{SSE} |_{\bar{\eta}_L \in (0,1)} - U_s^{SSE} = 0$, which in turn implies that $U_\sigma^{L,SSE} |_{\bar{\eta}_L \in (0,1)} - U_s^{SSE} < 0$. Thus, in order to have $U_\sigma^{L,SSE} = U_s^{SSE}$, one must have $\eta_L^* < \bar{\eta}_L$, which directly implies $\xi^{SSE} |_{\eta_L^* \in (0,1)} > w_s > b$. ■

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Chapter IV

Non-linear wages and the distribution of skills

Abstract

The paper provides a theory of wage formation in a simple continuous time search model with vertically differentiated labor. Workers can opt to search for alternative contacts meanwhile the ongoing meeting with an employer. Unlike under Nash bargaining, the resulting sharing rule is endogenous and it depends on the rate at which (i) workers locate alternative employers and (ii) employers receive applications from the unemployed. The model produces non-linear wage structure in a sense that more skilled workers earn strictly larger fraction of the output than workers belonging to lower skill groups. Non-linear wages mitigate the need for strong skill-biased technological change to explain the simultaneous increase in both supply and price of skilled labor. Other predictions of the model include: 1) A mean-preserving spread in the skill distribution induces greater wage dispersion. 2) A worker can extract the more surplus the less there are equally able workers in the market. 3) There is a Laffer-curve type relationship between market tightness and upper tail wage differentials.

1 Introduction

The paper provides a theory of wage formation in a simple continuous-time search model with heterogeneous labor. We postulate a trading process that produces an endogenous sharing rule arising from economic fundamentals and which establishes a theoretical linkage between equilibrium wage differentials and the distribution of skills. Neither of these features typically arise in models with one-sided heterogeneity where the transferable surplus is divided according to an exogenous sharing rule, e.g. Nash bargaining.

We utilize and extend a framework developed by Kultti (2000) and Kultti and Virrankoski (2004). The main idea is that, upon a meeting, the employer makes a wage

offer to the unemployed worker in a 'take-it-or-leave-it' manner. However, if trading seems unfavorable for the worker, he does not have to trade immediately but may choose to wait and continue search besides the ongoing meeting. If the worker decides to wait, either a new employee candidate may show up or the worker manages to locate another employer. Then, the party with two competing players must engage in a bidding contest. As shown by Kultti and Virrankoski (2004), employers' equilibrium strategy upon the initial meeting is to propose a wage offer that is just good enough to prevent the worker from exercising his waiting option. The wage is unique for each skill group.

This construction may connote the work by Julien, Kennes and King (2000) who develop a "competing-auction" setting to model wage formation. In their model, each unemployed worker announces a reserve wage (the lowest wage that would be acceptable for him) to attract employers to trade with him. If only one employer approaches the candidate worker, then trading takes place at the reserve wage. If there will be more than one interested employers, then the worker sells his labor services to the highest bidder. However, the aim of Julien et al.'s (2000) paper is to derive wage dispersion with homogeneous workers and postulate a mechanism that generates an endogenous matching function. They do not seek to discuss the linkage between the distribution of skills and the wage structure. Our model is also related to the earlier contribution by Bester (1988), who considers equilibrium price distributions in a search theoretic context with differentiated sellers. Likewise in our case, the driving force in his model is the consumer's option to quit the current bargaining in order to search for another seller.¹ The key difference between Bester's model and ours is that, even though the value of the option to quit depends on the expected bargaining outcome in all other meetings, Bester does not directly allow competitive situation between agents of the same kind.

We will show that, given any two skill levels, the 'wait-and-continue-search' option is disproportionately more valuable for the more skilled than for the less skilled worker. The equilibrium wages are therefore non-linear: more skilled workers earn strictly larger fraction of the matching surplus than workers belonging to lower skill groups. Quite surprisingly, non-linear prices emerge in a 'quasi-competitive' set-up

¹Another paper that utilizes this kind of intuition is the work by Samuelson (1992). However, his main aim is to explain disagreement as an equilibrium phenomenon.

under homogenous buyer preferences (i.e. identical employers) and without any informational frictions or active market segmentation. When conventional Nash bargaining is used as a price formation method wages are typically linear in the sense that the price of the productivity unit is the same for all skill groups². Moreover, under exogenous Nash sharing rule, the skill composition of the work force does not affect the shape of the wage schedule. Instead, our construction give rise to the appealing intuition that a high-skilled worker is able to extract more surplus from the employer when there are only few equally able workers in the market than in the case when the market is flooded with high-skilled workers. In other words, the wage differential between a productivity level x_{i+m} and a lower reference level x_i is the greater the larger is the fraction of workers being less skilled than the level x_{i+m} , say $F(x_{i+m-1})$. Thus, if the skill distribution of a country A is 'better' than that of a country B in a first-order stochastic dominance sense (i.e. $\forall x F^A(x) \leq F^B(x)$), then the wage structure should be narrower in country A than in country B .³ This result therefore supports the view that the differences in the distribution of skills might well be an important determinant behind the well-documented German-US differences in wage structure (e.g. Nickell, 1997, 1998, and Freeman and Schettkat, 2001). Moreover, non-linearity of wages imply that a mean-preserving spread in the skill distribution leads to greater wage dispersion - a feature that is also supported by number of empirical studies (e.g. Blackburn et al., 1991, and Devroy and Freeman, 2001).

Our theory can also help to explain the puzzling trend (cf. Katz and Autor, 1999, for an overview) that a substantial growth in the relative supply of skilled labor has in most industrialized economies been accompanied by increasing 'skill premium' in

²Non-linear wages may also arise under Nash bargaining in models with two-sided heterogeneity (e.g. Sattinger, 1995 and Delacroix, 2003). If not only workers differ in their skills but also jobs are different in terms of skill requirements, labor market equilibria entailing mismatch between skills and skill requirements may generate irregular wages. In these models, however, the wage dispersion is driven by the equilibrium matching pattern (e.g. Acemoglu, 1999, Albrecht and Vroman, 2002, Blázquez and Jansen, 2003, and Dolado et al., 2003) rather than by the composition of talents and job characteristics.

³A somewhat similar result is obtained by Kremer and Maskin (1997) who consider a model where workers of different skills form teams. Reminiscent of Kremer's (1993) "O-ring theory", if the distribution of skills is sufficiently disperse, only alike workers are assembled in a team. As a result, high- and low skilled workers produce in their own teams (or firms) which leads to greater wage dispersion.

wages. Many previous studies (e.g. Katz et al., 1993, Katz and Autor, 1999, and Krusell et al. 2000) assert that a strong skill-biased technological change has to be the key factor explaining the phenomenon⁴. However, if there is a common increase in labor productivity throughout the skill groups, non-linear wages imply that workers belonging to upper tail skill groups gain disproportionately. Therefore even if the distribution of skills would be transformed to weight higher skill groups, the wage dispersion may still generally increase if the magnitude of the general productivity upgrade is sufficiently large. Hence, non-linear wages mitigate the need for strong skill-biased technological change to explain the simultaneous increase in both supply and price of skilled labor.

Regarding the effect of labor market tightness on equilibrium wage structure, we show that an increase in the ratio of vacant jobs and the number of unemployed always leads to an increase in lower tail wage differentials. In the upper tail, however, we identify a Laffer-curve type relationship between market tightness and wage gaps. When the labor market is sufficiently tight initially, a marginal increase in labor demand tends to widen also the upper tail wage differentials. But when the market is 'slack' *ex ante*, increasing demand actually compresses upper tail wages. This is because a marginal increase in demand dilutes part of the high-skilled workers' comparative advantage when vacant jobs are the short side of the market.

The paper is organized as follows: Sections 2.1-2.3 define the basic environment of the model. The wage formation analysis is carried out in Section 2.4. Section 3 is devoted to elaborating the main predictions of the model. Section 4 offers an extension that supplements the basic analysis and Section 5 concludes.

2 The model

2.1 Basic set-up

The labor market is populated by a continuum of unemployed workers and a larger continuum of firms who post open vacancies. Workers are heterogeneous in their

⁴Acemoglu (1999) provides a theory of 'endogenous' skill-biased technological progress. In his model, an increase in the supply of skills increases the 'market size for skill-complementary technologies' and thereby may induce skill-biased technological change.

skills and the n different skill groups are indexed by $x_i = x_1, x_2, \dots, x_n$. Workers are distributed over these groups according to the distribution function $F(x)$. Firms are identical and have a unit demand for labor. The output flow generated by a vacancy filled with a worker belonging to a group x_i is denoted by q_i . Better skilled workers are strictly more productive than less skilled workers; i.e. $q_j > q_i \forall j > i$. Irrespective to the skill level, all unemployed have a unit supply of labor and they value their work effort at zero.

Trading takes place in private meetings between unemployed workers and firms. In order to locate a potential employer, workers must commit to a search process. Search effort is costless *per se* but it is time-consuming⁵ which creates frictions on the functioning of the market. The frequency at which firms receive applications and unemployed workers locate vacant jobs is governed by an exogenous matching function, $M(u, v)$, that gives the total number of matches at each point of time as a function of two inputs, the number of currently unemployed (u) and the number of vacant jobs (v). As usual, the matching function is assumed to be strictly increasing and strictly concave in both arguments and it exhibits constant returns to scale.

Since time is continuous, Poisson arrival rates can be used to measure the flow probabilities of locating (receiving) a vacant job (an application). An unemployed worker locates an open vacancy at rate α while a firm with an unfilled vacancy receives an application from an unemployed worker at rate β . Pairwise matching requires $\alpha u = \beta v = M(u, v)$.

Labor market tightness, $\theta = v/u$, is the ratio between open vacancies and unemployed workers. The CRS-property of the matching function implies that the meeting rates α and β can be determined as a function of labor market tightness:

$$\alpha = \frac{M(u, v)}{u} \equiv \theta m(\theta) \quad \text{and} \quad \beta = \frac{M(u, v)}{v} \equiv m(\theta), \quad (1)$$

where $m(\theta) = M(1/\theta, 1)$. The strict concavity of the matching function M implies that $m(\theta)$ is decreasing and convex in θ . $m'(\theta) < 0$ and $m''(\theta) > 0$. Thus, increasing labor market tightness improves (reduces) the rate at which unemployed workers (firms) locate vacant jobs (receive applications); i.e. $\alpha'(\theta) = \partial[\theta m(\theta)]/\partial\theta > 0$ and $\beta'(\theta) = m'(\theta) < 0$. For notational convenience, we continue to denote the meeting rates by α and β , even though they are not parameters but endogenously determined labor

⁵Having direct search costs would introduce just another friction to the search process.

market variables. This is done because our focus is on the wage formation process rather than in the construction of a complete theory of (un)employment dynamics, as is typically the case in the conventional Mortensen-Pissarides (Mortensen, 1982, and Pissarides, 1984, 2000) framework⁶. The endogeneity of these variables is taken into account as we discuss the predictions of the model.

From firms' side we assume unrestricted entry. The cost of opening a vacancy is denoted by Φ , which can be thought to capture all the other factors of production except the worker. Firms will open new vacancies until the expected profit from a filled vacancy, which will be denoted by V^0 , equals the fixed cost, Φ . New unemployed workers are born at a constant and exogenous rate η . Steady state requires that $\alpha u = \eta$.⁷ Labor contracts are lifelong relationships so that, after a successful match, both the hired worker and the filled vacancy exit the market forever. A steady state equilibrium (i.e. steady state values for u , v , α and β) is completely determined by the four equations: the pairwise matching condition and its equivalence with the exogenous matching function, firms' free-entry condition and the exogenous birth rate of new unemployed.

2.2 Trading

The trading process is an extension of the models by Kultti (2000) and Kultti and Virrankoski (2004), the key difference being the assumption of heterogeneous sellers (=unemployed workers). Upon a meeting with a worker, the employer makes a wage offer in a 'take-it-or-leave-it' manner⁸. If trading seems unfavorable for the worker, it is assumed that he does not have to break up the contact completely but he may opt

⁶In Mortensen-Pissarides framework labor market tightness, θ , is typically the key variable which determines equilibrium unemployment and employment and, if the agents are heterogeneous, the 'matching pattern'.

⁷This assumption replaces the exogenous job destruction typically assumed in the Mortensen-Pissarides model.

⁸This assumption may seem quite restrictive and arbitrary. However, it is pretty straight-forward to verify that the alternative cases where the initiative is either unilaterally granted to the workers or it is randomly allocated at every meeting change very little the main economic predictions of the model. Explicit calculations are available from the author upon request.

to *wait* and *continue search* besides the ongoing meeting⁹. If the worker decides to wait, he locates another employer at rate α . In that case, the two employer candidates raise their wage offers until driven to their reservation utilities. On the other hand, at rate β another unemployed approaches the employer and there will be two competing workers. They reduce their wage demands until either (or both) of them rather leaves the meeting than further lowers the wage demand. Figure 1 depicts the timing of events.

Obviously, the 'wait-and-continue-search' option is the only trump card in worker's hands. If he did not have that, the employer could propose a wage offer that would make the worker indifferent between accepting the offer and staying unemployed. Employer's equilibrium strategy is to propose a wage offer that is just good enough to prevent the worker from using his waiting option so that no worker ever opts to wait. The bold arrows in Figure 1 depict the 'equilibrium path' while the dashed arrows represent the 'off-equilibrium paths'. As in Kultti and Virrankoski (2004), the construction of the equilibrium is based on the following conjecture:

Conjecture 1 *(i) If the employer offers a wage that produces the worker less utility than the value of the waiting option, the worker rather waits for new agents to arrive than leaves the meeting. (ii) Instead of terminating the meeting immediately, the employer is willing to trade at equilibrium wages with any worker - regardless of his skill level.*

The first part of the Conjecture 1 is rather obvious, since the worst scenario in waiting option is that the worker is driven to his reservation utility level - which is the utility the worker gets if he opts to discard the initial contact immediately. The second part requires that any match in the labor market creates enough surplus in order for employers to have sufficient incentive to trade. If trading with the least able worker produces more output¹⁰ than the fixed cost Φ , then the requirement is met in equilibrium. A formal confirmation of the Conjecture 1 is given in Section 2.4.

In the main analysis we assume that employers cannot commit to throwing aside an unemployed who has opted to wait; i.e. employers cannot prevent workers from

⁹The postulated set-up is a sort of continuous-time version of the 'urn-ball model' á la Butters (1977) where multiple simultaneous contacts are possible.

¹⁰In present value terms.

maintaining their previous contacts while searching for other wage offers. This assumption guarantees that the wait and search -option is available to any unemployed. The assumption is made in order to keep the focus on the main qualitative properties of the wage function. The supplementary Section 4 discusses how the equilibrium might change if we allowed employers to disregard worker candidates who has opted to wait. It turns out that the seemingly restrictive assumption is rather innocent in terms of model predictions¹¹.

Finally,

Conjecture 2 *If the unemployed worker decides to wait, then transaction is concluded once a competing agent appears in either side of the negotiation table; i.e. there will be no 'further waiting'.*

Conjecture 2 postulates that even though the workers would have unlimited possibilities to wait, transactions will be concluded immediately after either another employer has been located or another worker candidate has shown up. Also this conjecture will be shown to hold in equilibrium.¹² Conjectures 1-2 state that the 'thin' dashed lines in Figure 1 describe irrelevant off-equilibrium paths.

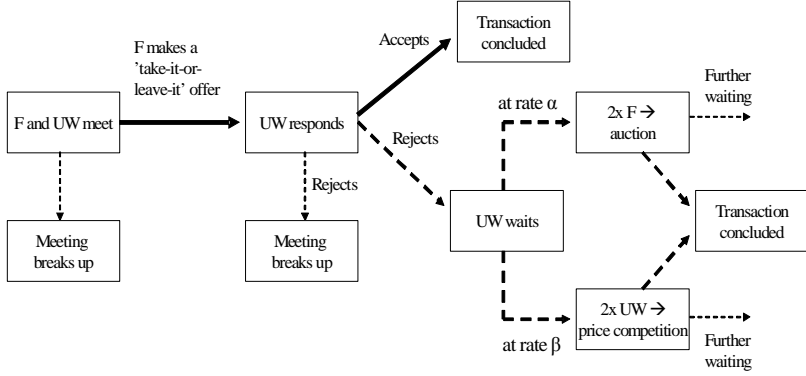
The next section enumerates the main Bellman equations of the model. After that we are ready to proceed with equilibrium wage determination in Section 2.4.

2.3 The Bellman equations

Both workers and firms are risk neutral and discount their future earnings with a common discount rate r . Assume that the equilibrium wage available for the worker possessing skills x_i is w_i . Given the equilibrium wages, the discounted value of an open vacancy is denoted by V^0 while the discounted value of a job filled with a worker with skills x_i is denoted by V_i . The discounted value of being unemployed is denoted by U_i^0 and of being employed by U_i .

¹¹In the more general case, it will be shown that the value of waiting for the lower tail skill groups may, under certain conditions, go to zero so that these workers would immediately have to trade at their reservation utility levels. However, wages for skill groups who has positive value for waiting behave exactly as in the simplified model.

¹²Essentially the same result is also verified by Kultti and Virrankoski (2004, pp. 6) in a model with homogeneous agents.



F = firm, UW = unemployed worker

Figure 1: Timing of events

Under linear preferences, U_i yields

$$U_i = \int_{\tau}^{\infty} e^{-(t-\tau)r} w_i dt = \frac{w_i}{r}, \quad \forall i \in \{1, 2, \dots, n\}. \quad (2)$$

The discounted value of unemployment U_i^0 , in turn, can be expressed as

$$\begin{aligned} rU_i^0 &= \alpha (U_i - U_i^0), \quad \Leftrightarrow \\ U_i^0 &= \frac{\alpha}{\alpha + r} U_i. \end{aligned} \quad (3)$$

Similarly, the present value of a filled job reads as

$$V_i = \frac{q_i - w_i}{r}, \quad \forall i \in \{1, 2, \dots, n\}, \quad (4)$$

while the expected value of a newly opened vacancy yields

$$V^0 = \frac{\beta}{\beta + r} \sum_{s=1}^n (F(x_s) - F(x_{s-1})) V_s, \quad (5)$$

Under unrestricted entry, firms expect to earn zero profits; i.e. $V^0 = \Phi$. Moreover, let us define $Q_i \equiv q_i/r$ and assume $Q_i > \Phi \quad \forall i \in \{1, 2, \dots, n\}$, so that the surplus generated by any match in the labor market is strictly positive.

2.4 Equilibrium wages

The analysis in this section proceeds as follows: We first find those wages for each skill group that make the workers indifferent between accepting the wage offer and

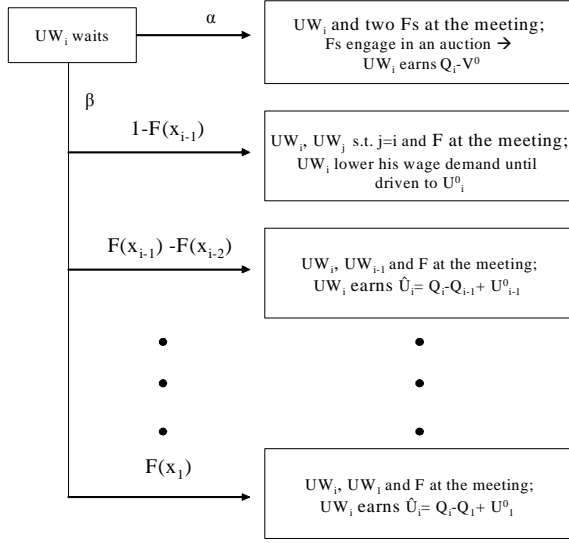


Figure 2: Unemployed waiting

waiting. After that we confirm that such a wage schedule constitutes an equilibrium; i.e. Conjectures 1-2 hold.

Consider a meeting between an employer and a worker belonging to a skill group x_i . Figure 2 illustrates the prospects of the worker if he decides to reject the employer's offer and start searching for alternative contacts. If the worker manages to locate another employer, which happens at rate α , the two competing firms engage in an auction for the right to hire the worker; i.e. firms raise their bids until the utility from hiring equals their expected reservation utility, V^0 . However, if another worker happens to appear instead (which occurs at rate β), the resulting wage will depend on whether the newcomer is at least equally skilled or less skilled than the incumbent worker.

Assume first that the appearing rival belongs to a skill group $x_k < x_i$. Then the less skilled competitor lowers his wage demand until he gets U_k^0 . The better skilled incumbent knows that his rival's lowest acceptable wage will provide the employer with a discounted value equal to

$$V_k^C = Q_k - U_k^0.$$

If the incumbent worker wants to trade, he needs to propose a wage demand that

produces the employer at least the same utility V_k^C . Let us denote the utilities gained by the firm and the incumbent worker from such a wage demand by \hat{V}_i^k and \hat{U}_i^k respectively. Clearly, the highest wage the incumbent worker with skills x_i is able to demand must satisfy the following condition:

$$\hat{V}_i^k = V_k^C \Leftrightarrow Q_i - \hat{U}_i^k = Q_k - U_k^0,$$

which can be solved for \hat{U}_i^k to yield

$$\hat{U}_i^k = U_k^0 + Q_i - Q_k, \forall k \in \{1, 2, \dots, i-1\}.$$

Yet another conjecture, which will be shown to hold in equilibrium, guarantees that the better skilled worker is willing to trade at a competitive situation:

Conjecture 3 $\hat{U}_i^k > U_i^0$.

On the other hand, with probability $1 - F(x_{i-1})$ we have $x_k \geq x_i$ so that the arriving competitor is at least equally skilled as the incumbent worker and the incumbent is driven to his reservation utility level U_i^0 .

Summarizing this lengthy description with a single equation, the Bellman equation representing the value of the 'waiting option' faced by a worker coming from the skill groups x_i reads as

$$\begin{aligned} rh_i = & \alpha (Q_i - V^0 - rh_i) + \beta [(1 - F(x_{i-1})) U_i^0 + \\ & + \sum_{k=1}^{i-1} (F(x_k) - F(x_{k-1})) \hat{U}_i^k - rh_i], \end{aligned} \quad (6)$$

where the first term on the right-hand side captures the chance of ending up to a situation with two competing employers whereas the second term reflects the expected utility available when another worker happens to show up. Solving for h_i gives

$$\begin{aligned} h_i = & \frac{\alpha}{\alpha + \beta + r} (Q_i - V^0) + \frac{\beta}{\alpha + \beta + r} [(1 - F(x_{i-1})) U_i^0 + \\ & + \sum_{k=1}^{i-1} (F(x_k) - F(x_{k-1})) \hat{U}_i^k]. \end{aligned} \quad (7)$$

Since the initiative is on the employer's side, the equilibrium wage offer proposed upon a meeting is such that it makes the worker indifferent between accepting the offer and waiting. Therefore the equilibrium wages for each skill group must satisfy

$$U_i = h_i \Leftrightarrow w_i = rh_i. \quad (8)$$

The wage at which the transaction is concluded is unique for each skill group. Uniqueness follows as (8) is linear in w_i and has a unique solution. The following lemmas confirm the conjectures made in the outset:

Lemma 1 *Assuming $Q_i > \Phi \forall i \geq \{1, 2, \dots, n\}$, Conjectures 1-2 hold in an equilibrium established by the wage schedule given in (8).*

Proof. See Appendix A. ■

Equation (7), condition (8) and the employers' free-entry condition $V^0 = \Phi$ imply that the wage earned by members of the lowest skill group, x_1 , yields

$$w_1 = \frac{\alpha(\alpha + r)}{(\alpha + r)^2 + \beta r} (q_1 - \phi), \quad (9)$$

where $\phi = r\Phi$.

In order to determine expressions for any wage levels w_i s.t. $1 < i \leq n$, let us first derive the equilibrium wage differential, $\Delta w_{i+1,i}$, between two consecutive skill levels x_{i+1} and x_i . Computing $rh_{i+1} - rh_i$ obtains the following difference equation¹³:

$$\Delta w_{i+1,i} = \frac{(\alpha + r)(\alpha + F(x_i)\beta)}{(\alpha + r)^2 + F(x_i)\beta\alpha + \beta r} \Delta q_{i+1,i} \equiv \Psi_i \Delta q_{i+1,i}, \quad (10)$$

where Ψ_i is the fraction of the productivity difference between the consecutive skill levels i and $i+1$ that the more productive worker is able to capture in the transaction. As an immediate extension of (10), the equilibrium wage differential between any two skill groups $i+m$ and i yields

$$\Delta w_{i+m,i} = \sum_{s=i}^{i+m-1} \Psi_s \Delta q_{s+1,s}, \quad \forall m \in \{1, 2, \dots, n-i\}. \quad (11)$$

Finally, by (11) we have that a worker belonging to the skill group m earns

$$w_m = \sum_{s=1}^{m-1} \Psi_s \Delta q_{s+1,s} + w_1, \quad \forall m \in \{1, 2, \dots, n\}. \quad (12)$$

¹³As a curiosity, the continuous counterpart of this expression is relatively easy to show to yield

$$\begin{aligned} w'(x) &= \frac{(\alpha + r)(\alpha + F(x)\beta)}{(\alpha + r)^2 + F(x)\beta\alpha + \beta r} q'(x) \\ &\equiv \Psi(x)q'(x), \end{aligned}$$

which is a first-order differential equation.

Since $F(x_s) \leq 1$, it is straight-forward to show that $0 \leq \Psi_s < 1, \forall s \in \{1, 2, \dots, n-1\}$ ¹⁴.

This fact also directly implies:

$$U_i^0 = \frac{\alpha}{\alpha + r} \sum_{s=k}^{i-1} \frac{\Psi_s \Delta q_{s+1,s}}{r} + U_k^0 < \hat{U}_i^k = \frac{\Delta q_{k,i}}{r} + U_k^0, \quad (13)$$

which confirms that Conjecture 3 holds in equilibrium.

3 Model predictions

3.1 Non-linearity of wages

Since $F(x_s)$ is increasing with the skill level and since the fraction Ψ_s of the productivity gain $\Delta q_{s+1,s}$ that goes to the worker belonging to the skill group x_{s+1} is increasing with $F(x_s)$, equation (12) implies that better skilled workers earn ever increasing fraction of the output. Therefore we have

Theorem 1 *The wage-schedule is non-linear in the sense that the price of the 'net productivity unit',*

$$\omega_i = \frac{w_i}{q_i - \phi},$$

is increasing with the rank of the skill level x_i in the sequence x_1, x_2, \dots, x_n .

Corollary 1 ω_i grows at a diminishing rate.

Proof. The fact that ω_i grows at a diminishing rate is because Ψ_s is increasing and concave in $F(x_s)$. ■

Note that our 'quasi-competitive' setting produces non-linear pricing rule, even though the buyer's preferences are homogeneous, there are no informational frictions nor active market segmentation. The absolute wage-schedule is 'convex' because the price of the net productivity unit is monotonically increasing. The non-linearity of wages stems from the disparity in the values of the 'waiting options' between different skill groups. This disparity is probably most transparently visible in equation (7) (or in Figure 2): The waiting option of a worker is the more valuable the less there are equally or better skilled candidates among unemployed workers. This is because the expected utility available from trading in a situation when there are two competing

¹⁴The fact that ψ is always strictly less than one is due to employers' first-mover advantage.

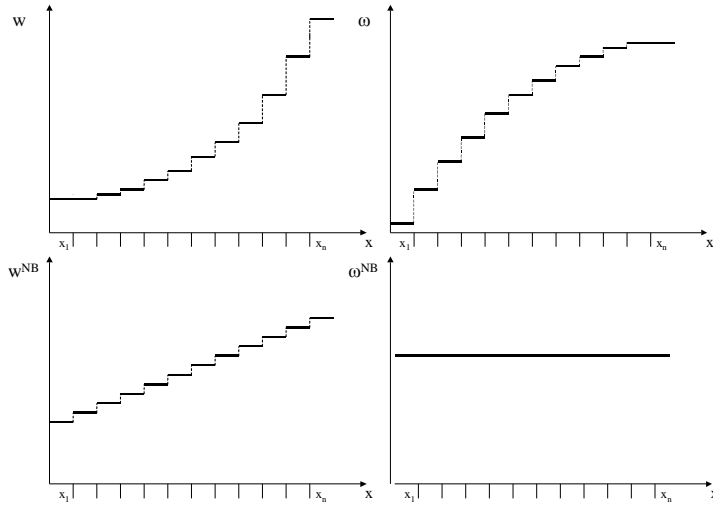


Figure 3: Equilibrium wages vs. Nash outcome

workers and one employer is the larger the smaller is the probability of having a better skilled competitor.

It is instructive to compare the outcome of the current set-up to the wages that result from generalized Nash bargaining. Let ρ ($1 - \rho$) denote worker's (employer's) exogenous 'bargaining power' in Nash bargaining. In our context, the result of this bargaining procedure can be derived from the model of alternating offers á la Rubinstein (1982), where workers (firms) make offers in a 'take-it-or-leave-it' fashion with probability ρ ($1 - \rho$). The sharing rule obtained under generalized Nash bargaining can be written as

$$(1 - \rho) (U_i - U_i^0) = \rho (V_i - V^0). \quad (14)$$

Utilizing equations (2), (3) and (4), equation (14) implies that

$$w_i^{NB} = \frac{\rho(\alpha + r)}{\rho\alpha + r} (q_i - \phi) \quad \text{and} \quad \omega_i^{NB} = \frac{\rho(\alpha + r)}{\rho\alpha + r} \equiv \bar{\omega}^{NB}.$$

Hence, Nash wages are only sensitive to the workers' contact rate with vacancies (α) and to the exogenous bargaining power parameter (ρ). Moreover, since ω_i^{NB} is a constant $\bar{\omega}^{NB}$, the pricing rule generated by Nash bargaining is linear. Unsurprisingly, ω_i^{NB} is increasing in both α and ρ . Instead, the externalities generated by employers'

contact rate with workers (β) and the skill-distribution ($F(x_s)$) do not affect the wage schedule. This is because the axiomatic bargaining game with a fixed sharing rule fails to internalize the disparity between better skilled and less skilled workers' relative bargaining powers. Figure 3 illustrates the difference between the non-linear wages derived in the current model (upper diagrams) and Nash wages (lower diagrams).

3.2 Distribution of skills and wage structure

Proposition 1 *A mean-preserving spread in the distribution of skills leads to greater wage dispersion.*

Proof. See Appendix B. ■

This result is due to the feature that the wage differential between two consecutive skill levels is increasing but concave function of the 'probability mass' below the higher skill group. In other words, a mean-preserving spread in the skill distribution increases the lower tail wage differentials more than it reduces the wage gaps in the upper tail. As a result, the overall wage dispersion becomes wider. There is a host of evidence indicating that countries where workers' skills are more polarized tend to have higher wage dispersion, too (e.g. Blackburn et al., 1991, and Devroy and Freeman, 2001). A typical case has been the comparison between Germany and the US: Germany's wage structure is substantially more compressed than in the US. Nickell (1997, 1998) and Nickell and Bell (1996) show that the distribution of skills is itself much narrower in Germany than in the US. On the other hand, Freeman and Schettkat (2001) report that the fraction of the high-skilled is roughly the same in both countries but "the lower tail of less skilled workers is practically absent in Germany while it is substantial in the US". Their finding implies that Germany's distribution of skills actually exhibits first-order stochastic dominance in relation to the corresponding distribution in the US. Therefore we have

Proposition 2 *Assume that the labor productivities of the n skill groups are identical in countries A and B ; i.e. $q_i^A = q_i^B \forall i \in \{1, 2, \dots, n\}$. Let $F^A(x)$ and $F^B(x)$ describe the distributions of workers' skills in countries A and B respectively. If*

$$F^A(x_i) \leq F^B(x_i), \forall x_i \in \{x_k, x_{k+1}, \dots, x_{k+l}\} \subset \{x_1, x_2, \dots, x_n\},$$

then

$$\Delta w_{i+m,i}^A \leq \Delta w_{i+m,i}^B, \quad \forall i \in \{k, k+1, \dots, k+l\} \text{ and } m \in \{1, 2, \dots, k+l-i\}.$$

Proof. Follows directly from equation (11). ■

According to the commonly held view, the disparity in transatlantic wage distributions is mainly due to the institutional differences in wage setting (e.g. Siebert, 1997). However, since Germany looks like country A and the US like country B in Proposition 2, our non-linear wages support the hypothesis that the shape of the distribution of skills might at least partly explain the German-US difference in wage structure.

3.3 Wage dispersion and market tightness

At this stage of the analysis, we want to point out that when deriving comparative static results, any changes in the skill distribution may affect firm's incentives to open new vacancies. More frequent market entry by firms is followed by greater market tightness; i.e. the ratio between vacant jobs and unemployed, $\theta = v/u$, is increased. Hence, besides having a direct effect on the wage structure, any change in the skill distribution that affects the expected value of an average vacancy also affect firm's entry decision and thereby the contact rates $\alpha(\theta)$ and $\beta(\theta)$. Therefore the result in Proposition 2 should also be conditioned on possible disparities in labor market tightness. A mean-preserving spread, however, is neutral in terms of θ because it does not change the average value of a filled vacancy.

Substituting α and β in equations (9)-(12) with the expressions given in (1) and differentiating Ψ_s w.r.t. θ we have

Proposition 3 (i) *The lower tail wage differentials increase along with greater labor market tightness.* (ii) *If*

$$\alpha'(\theta) + \beta'(\theta) > 0,$$

then a marginal increase in market tightness increases the upper tail wage differentials. Otherwise, the upper tail wages become more compressed.

Proof. See Appendix C. ■

Greater labor market tightness means that there are more available jobs per one unemployed worker so that it becomes easier for the unemployed to locate a potential employer; i.e. α increases. This fact generally increases workers' value of waiting because higher α means higher probability of having two employers engaging in an auction for the worker. In such an occasion transaction is concluded with a wage that drives the employers to their reservation utility levels. The worker then captures all remaining surplus, which is the larger the better skilled the worker is. As a result, high-skilled workers benefit disproportionately and wage differentials tend to increase. This prediction is in line with some earlier models (for instance Acemoglu, 1997) as well as with empirical observations (e.g. DiNardo et al., 1996). However, greater market tightness also reduces the rate at which firms receive applications (β) which lowers the probability of ending up with a situation where two workers must compete for the same vacancy. In a competitive situation, high-skilled workers are better protected against the downward pressure in wages. As increasing market tightness reduces the probability of competition between two workers, high-skilled workers' comparative advantage dilutes. If this effect is strong enough the upper tail wages may actually become more compressed. Wage compression in upper tail wages results if a marginal increase in θ worsens the congestion on employers' side more than it increases the contact probability on workers' side, i.e. when $|\beta'(\theta)| > \alpha'(\theta)$. This is the case when market tightness is initially low, so that a marginal increase in the number of vacancies improves worker's contact rate only a little but has a greater congestion effect on firms' side.

In fact, Proposition 3 establishes a Laffer-curve type relationship between upper tail wage differentials and market tightness. When unemployed workers are the short side of the market, i.e. market tightness is high enough, increasing demand unambiguously widens the upper tail wage gaps. When vacant jobs are the short side, higher demand compresses upper tail wages.

3.4 Wage dispersion, skill premium and technical change

Many empirical studies (cf. Katz and Autor, 1999, for an overview) reveal the puzzling trend that a substantial growth in the relative supply of skilled labor has in most industrialized economies been accompanied by increasing 'skill premium' in wages.

Likewise common sense, Proposition 2 suggests that an increase in the fraction of high-skilled labor should reduce that premium. However, there are also two counterbalancing effects present in our model. Firstly, an increase in the average skill level of the labor force should stimulate labor demand; i.e. market tightness should increase. Proposition 3 then implies that, especially if the unemployed workers are the short side of the market, wage differentials should become wider throughout the skill groups. Secondly, if there is a general upgrade in productivity, say by a factor δ , non-linearity of wages implies that workers belonging to upper tail skill groups gain disproportionately from the upgrade. Thus, even if the distribution of skills would be transformed to weight higher skill groups, wage dispersion may still increase, if the positive demand effect and a possible concurrent upgrade in labor productivity are large enough. A number of studies (e.g. Katz et al., 1993, Katz and Autor, 1999, and Krusell et al. 2000) indicate that skill-biased technological change has to be the key factor explaining the rise in the skill premium. Our theory of non-linear wages, however, mitigates the need for strong skill-biased technological change to explain the simultaneous increase in both supply and price of skilled labor.

Meckl and Zink (2002) point out that the wage differentials by skill groups have actually evolved non-monotonically. The time path of the relative wage has typically been U-shaped in the sense that wage differentials by skills fell during the 1970s, and started to increase only during the 1980s and 1990s. The U-shaped time path might suggest that the upgrading of skills may have overrun the demand effect and the pace of technological progress in the 1970s while the pattern would have been reversed during the 1980s and the 1990s. Indeed, according to Katz and Autor (1999), relative supply of skilled labor rose most in the 1970s.

4 Supplement: Employers can disregard workers who opt to wait

In the basic model in Section 2 the analysis was simplified by the assumption that employers cannot commit to disregarding an unemployed who has opted to wait. This restriction was made in order to keep the focus on the main qualitative properties of the wage structure. We will now consider how the equilibrium is changed if we relaxed

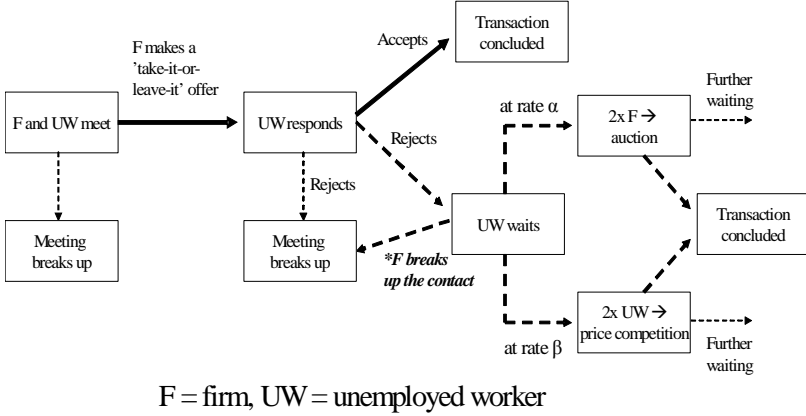


Figure 4: Timing of events when firms can disregard waiting workers

this assumption. Figure 4 depicts the more general structure of the trading process. Comparing to the basic case illustrated in Figure 1, the only difference is that now the employer may choose to break up the meeting if the worker decides to wait (marked by a star in the figure).

The essential question is whether it ever pays for the employer to leave a worker who has rejected the wage offer but decided to wait. Obviously, the employer chooses to discard the unemployed if the expected payoff from allowing the worker to keep up the initial contact is less than employer's reservation value; i.e. if $h_i^F < V^0$, where h_i^F denotes the employer's discounted value of waiting with a worker belonging to the skill group x_i .

Lemma 2 *Assume that the unemployed worker belonging to skill group x_i has chosen to wait. Then the employer will not discard the worker, if*

$$Q_1 \geq \left(1 + \frac{\alpha(\alpha + 2r) + r(\beta + r)}{\beta(2\alpha + \beta + r)}\right) \Phi = \mu(\alpha, \beta) \Phi > \Phi.$$

Proof. See Appendix D.. ■

Hence, employers are willing to maintain a contact to any worker only if the productivity of the least skilled worker is sufficiently high; i.e. if

$$Q_1 \geq \mu(\alpha, \beta) \Phi. \tag{15}$$

Obviously, $\partial\mu/\partial\alpha > 0$ and $\partial\mu/\partial\beta < 0$. Therefore the condition (15) is the less restrictive the more severe the search frictions on worker's side (the lower is α) are

and the easier it is for employers to locate unemployed workers (the higher is β); i.e. the lower is market tightness θ . This is because keeping up the meeting is the more (the less) valuable for the employer the higher is the probability that next agent to appear at the meeting is another worker (employer).

Assume now that (15) does not hold. Generally, there might be a whole subset of skill groups in the lower tail of the skill distribution who cannot choose to wait because waiting would trigger the employer to break up the contact. Let us denote by x_t the lowest skill group with whom the employer is willing to wait; i.e.

$$h_t^F \geq V^0 \text{ but } h_{t-1}^F < V^0. \quad (16)$$

Skill groups below x_t must trade immediately upon the meeting at the reservation utility level; i.e. $w_i = rU_i^0$ for $i < t$. Since there are no outside options in the model and since all workers value their working effort at zero, the equilibrium wages throughout these skill groups must obtain $\bar{w} = 0$.

Analogous to (7), the value of the waiting option for a skill level $x_i \geq x_t$ yields

$$h'_i = \frac{\alpha}{\alpha + \beta + r} (Q_i - V^0) + \frac{\beta}{\alpha + \beta + r} [(1 - F(x_{i-1})) U_i^0 + \sum_{k=1}^{i-1} (F(x_k) - F(x_{k-1})) \hat{U}_i^k], \quad (17)$$

where

$$\hat{U}_i^k = \begin{cases} Q_i - Q_k, & \forall i \geq t, k = 1, 2, \dots, t-1 \\ Q_i - Q_k + U_k^0, & \forall i \geq t, k = t, t+1, \dots, n \end{cases}.$$

Setting $h'_i = w_i/r$ and $h'_{i+1} = w_{i+1}/r$ for $i \geq t$, the equilibrium wage differential between two consecutive skill groups above x_t obtains

$$\Delta w_{i+1,i} = \frac{(\alpha + r)(\alpha + F(x_i)\beta)}{(\alpha + r)^2 + F(x_i)\beta\alpha + \beta r} \Delta q_{i+1,i} = \Psi_i \Delta q_{i+1,i},$$

which is equivalent to the formula in (10). Note that the properties of the strictly positive part of the wage schedule are perfectly isomorphic to the qualitative results derived in Section 2.

Thus, allowing employers to disregard unemployed workers who have opted to wait creates a sharp jump in the wage schedule: workers belonging to skill groups $x_1 - x_{t-1}$ must trade at $\bar{w} = 0$ while the wages above the threshold skill level x_t behave exactly in the same way as described in Section 2. From (17) it is easy to

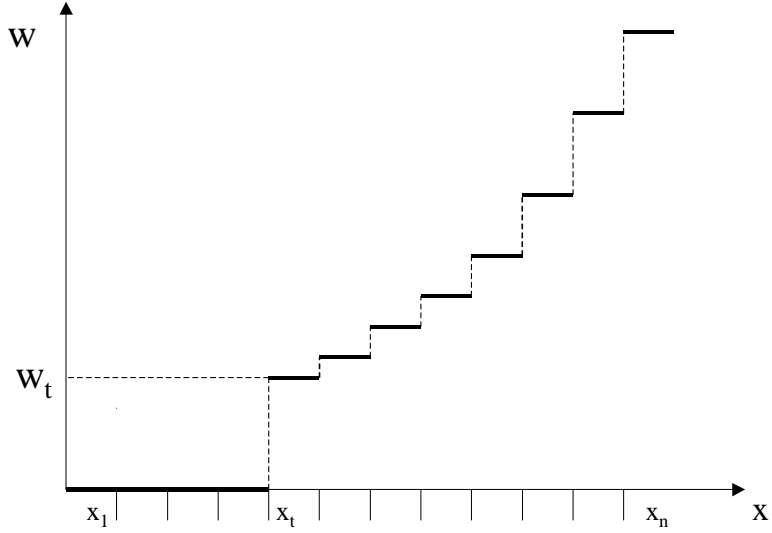


Figure 5: Equilibrium wages with firms being able to quit at any stage

compute the wage level w_t for the threshold skill group x_t so that the complete wage schedule is given by

$$w_i = \begin{cases} 0, & \forall i < t, \\ \frac{(\alpha+r)[\alpha(q_t-\phi)+\beta\sum_{k=1}^{t-1}(F(x_k)-F(x_{k-1}))(q_t-q_k)]}{(\alpha+r)^2+F(x_{t-1})\beta\alpha+\beta r}, & \text{for } i = t, \\ \sum_{s=t+1}^{i-1} \Psi_s \Delta q_{s,t} + w_t, & \forall i > t. \end{cases} \quad (18)$$

Figure 5 illustrates the schedule.

Finally,

Lemma 3 *Assuming $Q_i > \Phi \forall i \geq \{1, 2, \dots, n\}$, Conjectures 1-2 hold in an equilibrium established by the wage schedule given in (18).*

Proof. See Appendix E. ■

The explicit determination of the threshold skill class x_t according to conditions given in (16) is rather complicated. However, it should be quite obvious that the threshold is the lower the more lower tail skill groups are weighted in the distribution. This is because it is less worthy for employers to disregard low-skilled workers if the chance of locating a better skilled worker is small.

5 Concluding remarks

The paper develops a model on wage formation in a search equilibrium. The model extends the earlier works of Kultti (2000) and Kultti and Virrankoski (2004) by assuming vertically differentiated workers. It turns out that, unlike under conventional Nash bargaining, the equilibrium wages are non-linear in a sense that more skilled workers earn strictly larger fraction of the matching surplus than workers belonging to lower skill groups. The wage differentials between the consecutive skill groups are the greater the higher is their rank among the skill levels. Non-linear wages arises even the buyers'(firms') preferences are homogeneous and the model does not include any informational frictions whatsoever.

The non-linearity of wages imply that a mean-preserving spread in the skill distribution leads to greater wage dispersion. The model also predicts that countries whose distribution of skills weight lower tail skill groups should exhibit large wage dispersion. Regarding the effect of increasing demand for labor, we show that greater market tightness always increases lower tail wage differentials. In the upper tail, however, we identify a Laffer-curve type relationship between market tightness and wage gaps. When unemployed workers are the short side of the market, increasing demand tends to widen the upper tail wage differentials. When vacant jobs are the short side, higher demand actually compresses upper tail wages.

Our theory also helps to understand the widely recognized 'skill premium puzzle'. Non-linear wages imply that high-skilled workers are able to gain disproportionately from a general upgrade in productivity. This observation mitigates the need for strong skill-biased technological change to explain the simultaneous increase in both supply and price of skilled labor.

The supplementary Section 4 presents the analysis under somewhat weaker assumptions than was done in the basic model. It turns out that the 'bargaining power' of the lower tail skill groups may collapse completely and a subset of lower tail skill groups may have to trade at zero (or minimum) wages. The rest of the wage schedule behaves exactly as in the basic set-up so that also the main predictions of the model remain unchanged.

Appendix

A Proof of Lemma 1

A.1 Verification of Conjecture 1

Proof. Condition (i): The worker prefers waiting if $h_i \geq U_i^0$. By Conjecture 1 we may write $\hat{U}_i^k = \kappa_i^k U_i^0$ s.t. $\kappa_1^k = 1 \forall k \in \{1, 2, \dots, n\}$ and $\kappa_i^k > 1$ for $i > k$. Then the condition $h_i \geq U_i^0$ obtains

$$\begin{aligned} h_i &= \frac{\alpha}{\alpha + \beta + r} (Q_i - V^0) + \frac{\beta}{\alpha + \beta + r} \xi_i U_i^0 \geq U_i^0 \\ \Leftrightarrow U_i^0 &\leq \frac{\alpha}{\alpha - (\xi_i - 1)\beta + r} (Q_i - V^0), \end{aligned} \quad (19)$$

where $\xi_1 = 1$ and $\xi_i = (1 - F(x_{i-1})) + \sum_{k=1}^{i-1} \kappa_i^k (F(x_k) - F(x_{k-1})) > 1$, since $\kappa_i^k > 1$ for $i > k$. The condition expressed in (19) must hold in equilibrium since

$$U_i^0 = \frac{\alpha}{\alpha + r} \frac{w_i}{r} < \frac{\alpha}{\alpha + r} (Q_i - V^0) \leq \frac{\alpha}{\alpha - (\xi_i - 1)\beta + r} (Q_i - V^0).$$

Condition (ii): Upon a meeting, the employer is willing to trade at the equilibrium wage w_i if $V_i \geq V^0$. Remembering that $V_i = Q_i - U_i$, it follows immediately from (8) that $V_j \geq V_i$ for every $j > i$. Thus, it suffices to show that $V_1 \geq V^0$. Now,

$$\begin{aligned} V_1 &= Q_1 - U_1 = Q_1 - \frac{\alpha(\alpha + r)}{(\alpha + r)^2 + \beta r} (Q_1 - V^0) \\ &= \frac{r(\alpha + \beta + r)}{(\alpha + r)^2 + \beta r} Q_1 + \frac{\alpha(\alpha + r)}{(\alpha + r)^2 + \beta r} V^0. \\ V_1 \geq V^0 &\Leftrightarrow Q_1 \geq \Phi, \end{aligned}$$

which is equivalent to having $q_1 \geq r\Phi = \phi$. ■

A.2 Verification of Conjecture 2

Proof. Assume an unemployed worker has received a wage offer and decided to wait and search for alternative contacts.

(i) Imagine first the situation where the unemployed has located another employer candidate. By Bertrand argument we know that in this kind of situation employers raise their wage offers until driven to their reservation utilities. If the unemployed did

not accept the highest offer but opted to search even more contacts, he would locate another employer at rate α . A third bidder on the employers' side, however, would not increase the highest available bid, which would still be the wage level that produces the reservation utility for the employer. On the other hand, there is a possibility that the competing firms receive applications from other unemployed workers, which creates a downside risk to the 'incumbent' worker. Since there is no upside potential, the unemployed is not willing to wait further in a situation where two firms are competing.

(ii) The second possibility is that the incumbent worker finds himself competing with a rival candidate. Assume the incumbent worker belongs to skill group i and the rival candidate to group j s.t. $i > j$. Then the newcomer could earn U_j^0 and the incumbent $\hat{U}_i^j = U_j^0 + \Delta Q_{i,j}$. Let us first show that further waiting would again entail a down-side risk. If a third candidate belonging to group $k \leq j$ happened to appear, then the competition would still take place between the incumbent and the second candidate, and they would earn \hat{U}_i^j and U_j^0 respectively. If $k > j$, then the second candidate would 'drop out' and still earn U_j^0 while the incumbent would earn $\hat{U}_i^k < \hat{U}_i^j$, if $k < i$, or $U_i^0 < \hat{U}_i^j$, if $k \geq i$, so that the incumbent candidate would be strictly worse-off. Hence the possibility of a third candidate arriving induces a down-side risk. Then we need to show that there is no upside potential available from further waiting in a situation where two workers have a contact with a single firm. The incumbent (the better skilled) worker locates an alternative employer at rate α . Then the reservation value for the first employer is determined by the case where it is left alone with the second candidate belonging to group j ; i.e. it can trade at a wage that produces $Q_j - U_j$. Hence the highest wage offer, \tilde{w} , in the bidding game between the two firms competing for the worker belonging to group i is determined by $\tilde{U}_i^j = U_j + \Delta Q_{i,j}$. Since the present value of this offer,

$$\tilde{U}_i^{j,0} = \frac{\alpha}{\alpha + r} (U_j + \Delta Q_{i,j}) = U_j^0 + \frac{\alpha}{\alpha + r} \Delta Q_{i,j},$$

is strictly less than \hat{U}_i^j , there is no upside potential for the better skilled candidate. By the similar reasoning, the highest utility the less skilled worker could earn by waiting and locating another employer is $\tilde{U}_j^i = U_i - \Delta Q_{i,j}$. By (13) it is easy to see that the present value of this scenario is less than the utility available for the less skilled from immediate trading; i.e.

$$\tilde{U}_j^{i,0} = U_i - \frac{\alpha}{\alpha + r} \Delta Q_{i,j} < U_j^0.$$

We have now verified that workers of any type cannot gain from further waiting in a situation where two competing workers have the contact with the same employer. In fact, further waiting would make any worker strictly worse off. This observation, in turn, implies that if the single employer did not accept the lowest wage demand in the competitive situation, workers would be better off by leaving the employer and starting to look for alternative vacancies. Knowing this, the single employer infers that he is better off by accepting the lowest offer.

Points (i) and (ii) together imply that trading will take place once a competitive situation is triggered on either employers' or workers' side. ■

B Proof of Proposition 1

Proof. Without loss of generality, consider the wage differential between skill groups x_i and x_{i+2} and assume $\Delta q_{i+2,i+1} = \Delta q_{i+1,i} = \Delta \bar{q}$. A mean-preserving spread of $F(\cdot)$ within the skill groups $\{x_i, x_{i+1}, x_{i+2}\}$ then yields a new distribution $G(\cdot)$ s.t. γ workers belonging to group x_{i+1} is upgraded to group x_{i+2} and an equal number, γ , downgraded to group x_i ; i.e.

$$G(x_{i+2}) = F(x_{i+2}) + \gamma,$$

$$G(x_{i+1}) = F(x_{i+1}) - \gamma,$$

$$G(x_i) = F(x_i) + \gamma.$$

Then the new wage gap is given by

$$\begin{aligned} \Delta w_{i+2,i}^{new} &= [\Psi_{i+1}(G(x_{i+1})) + \Psi_i(G(x_i))] \Delta \bar{q} \\ &= [\Psi_{i+1}(F(x_{i+1}) - \gamma) + \Psi_i(F(x_i) + \gamma)] \Delta \bar{q} \\ &> [\Psi_{i+1}(F(x_{i+1})) + \Psi_i(F(x_i))] \Delta \bar{q} = \Delta w_{i+2,i}^{old}. \end{aligned}$$

The last inequality follows from the fact that Ψ_s is increasing and concave in the value of the cumulative distribution function. ■

C Proof of Proposition 3

Proof. Since $\alpha = \theta m(\theta)$ and $\beta = m(\theta)$, Ψ_s can be written as

$$\begin{aligned}\Psi_s &= \frac{(\theta m(\theta) + r)(\theta m(\theta) + F(x_s)m(\theta))}{(\theta m(\theta) + r)^2 + F(x_s)\theta[m(\theta)]^2 + m(\theta)r}, \\ &= \frac{\left(\theta + \frac{r}{m(\theta)}\right)(\theta + F(x_s))}{\left(\theta + \frac{r}{m(\theta)}\right)^2 + F(x_s)\theta + \frac{r}{m(\theta)}}, \\ &= \frac{K(\theta)(\theta + F(x_s))}{[K(\theta)]^2 + K(\theta) - (1 - F(x_s))\theta},\end{aligned}$$

where $K(\theta) = \theta + r/m(\theta) > 0$. Differentiating with respect to θ obtains

$$\begin{aligned}\text{sign}\left(\frac{\partial \Psi_s}{\partial \theta}\right) &= \text{sign}\left\{[K(\theta)]^2[1 + K(\theta) - K'(\theta)(\theta + F(x_s))] + \right. \\ &\quad \left. + (1 - F(x_s))[K(\theta)F(x_s) - \theta K'(\theta)(\theta + F(x_s))]\right\}.\end{aligned}\quad (20)$$

Letting $F(x_s) \rightarrow 0$, one gets

$$\begin{aligned}\text{sign}\left(\frac{\partial \Psi_s}{\partial \theta}\Big|_{F(x_s) \rightarrow 0}\right) &= \text{sign}\left\{K(\theta)\left[\frac{[K(\theta)]^2 - \theta^2 K'(\theta)}{K(\theta)} + \right. \right. \\ &\quad \left. \left. + K(\theta)(K(\theta) - \theta K'(\theta))\right]\right\}.\end{aligned}$$

Now

$$K(\theta) - \theta K'(\theta) = \frac{r(m(\theta) + \theta m'(\theta))}{[m(\theta)]^2} = \frac{r\alpha'(\theta)}{[m(\theta)]^2} > 0,$$

and

$$[K(\theta)]^2 - \theta^2 K'(\theta) = \frac{r\theta}{[m(\theta)]^2}[\alpha'(\theta) + r/\theta] > 0,$$

so that

$$\frac{\partial \Psi_s}{\partial \theta}\Big|_{F(x_s) \rightarrow 0} > 0.$$

Hence the lower tail wage differentials unambiguously increase as labor markets become tighter.

On the other hand, if one lets $F(x_s) \rightarrow 1$,

$$\text{sign}\left(\frac{\partial \Psi_s}{\partial \theta}\Big|_{F(x_s) \rightarrow 1}\right) = \text{sign}\left\{[K(\theta)]^2[1 + K(\theta) - K'(\theta)(\theta + 1)]\right\}.$$

Since

$$\begin{aligned}1 + K(\theta) - \theta K'(\theta) - K'(\theta) &= \frac{r}{[m(\theta)]^2}[m(\theta) + \theta m'(\theta) + m'(\theta)] \\ &= \frac{r}{[m(\theta)]^2}(\alpha'(\theta) + \beta'(\theta)),\end{aligned}$$

the upper tail wages become more dispersed along with greater market tightness only if $\alpha'(\theta) + \beta'(\theta) > 0$.

Note that the RHS of (20) has a global maximum with respect to $F(x_s)$ at

$$F(\bar{x}_s) = \frac{1}{2} \left[1 - \frac{K'(\theta) ([K(\theta)]^2 + \theta^2)}{K(\theta) - \theta K'(\theta)} \right].$$

The above analysis implies that $F(\bar{x}_s) \in [0, 1]$, so that the negative relationship between wage dispersion and market tightness is possible only within upper tail skill groups but not within some subset of types $\{x_i, x_{i+1}, \dots, x_k\}$ s.t. $k < n$. ■

D Proof of Lemma 2

Proof. It is easy to verify that $h_{j+1}^F > h_j^F$. Therefore, if it can be shown that $h_1^F \geq V^0$, then we know that employers will never opt to disregard a waiting unemployed. The value of waiting with the least able worker obtains

$$h_1^F = \frac{\alpha}{\alpha + \beta + r} V^0 + \frac{\beta}{\alpha + \beta + r} (Q_1 - U_1^0).$$

On the other hand, the implicit wage equation $h_1 = U_1$ can be solved for U_1^0 to obtain

$$U_1^0 = \frac{\alpha^2}{(\alpha + r)^2 + \beta r} (Q_1 - V^0).$$

Combining these two expressions and remembering that free-entry implies $V^0 = \Phi$, the condition $h_1^F \geq V^0$ can be written as

$$Q_1 \geq \left(1 + \frac{\alpha(\alpha + 2r) + r(\beta + r)}{\beta(2\alpha + \beta + r)} \right) \Phi.$$

■

E Proof of Lemma 3

E.1 Verification of Conjecture 1

Proof. For skill groups $x_i < x_t$, this condition is trivial. For skill groups $x_i > x_t$, the proof is completely isomorphic with Appendix A.1.

For skill groups $x_i < x_t$, we have $V_i = Q_i > V^0 = \Phi$. For skill groups $x_i > x_t$, it suffices to show that $V_i \geq V^0$, because $V_j \geq V_i$ for every $j > i$. By the definition of

the threshold skill level x_t we know that $h_t^F \geq V^0$. Hence, if $V_t \geq h_t^F$, then condition (ii) is automatically satisfied. Now,

$$\begin{aligned} V_t - h_t^F &= Q_t - h_t - h_t^F \\ &= Q_t - \frac{\alpha + \beta}{\alpha + \beta + r} Q_t > 0. \end{aligned}$$

■

E.2 Verification of Conjecture 2

Proof. The conjecture has to do with skill groups $x_i \geq x_t$. For proof, see Appendix A.2. ■

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