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Sorting Versus Screening in Decentralized Markets With Adverse Selection

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Sorting versus Screening in Decentralized Markets with Adverse Selection[*]

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Abstract

We study the role of traders' meeting capacities in decentralized markets with adverse selection. Uninformed customers choose trading mechanisms in order to find a provider for a service. Providers are privately informed about their quality and aim to match with one of the customers. We consider a rich set of meeting technologies and characterize the properties of the equilibrium allocations for each of them. In equilibrium, different provider types can be separated either via sorting—they self-select into different submarkets—or screening within the trading mechanism, or a combination of the two. We show that, as the meeting technology improves, the equilibrium features more screening and less sorting. Interestingly, this reduces both the average quality of trade as well as the total level of trade in the economy. The trading losses are, however, compensated by savings in entry costs, so that welfare increases.

Keywords: Competitive Search, Adverse Selection, Market Segmentation.

1 Introduction

The recent years have seen significant innovations in the way potential trading partners can contact each other in decentralized markets. A key role has been played

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by the internet and the development of a variety of platforms to facilitate meetings between market participants. In particular, in the case of services, a distinctive and novel feature of several recently emerged platforms is the fact that they allow customers to specify the kind of service they need and providers are then invited to submit bids for the service. For instance, on Thumbtack and HomeAdvisor one can indicate the kind of work which she or he needs to be done at home—carpentry, plumbing, electricity, lawn maintenance—providing various details on the task. The platform then shares those details with various professionals in the area who will compete for the provision of the service by providing a quote and other information. Other websites operate similarly for different services, such as moving,[1] or translation and editing services (Upwork). While these markets are clearly decentralized, platforms put customers in touch with a number of providers, who can then compete over the terms at which the service is provided. Furthermore, the examples above refer to procurement problems, albeit simple, where the customer seeks the provision of a specific, customized service. In most of these situations, a crucial element will be the quality of the provided service, about which the customer may have limited information.

The objective of this paper is to present a theoretical framework which allows to analyze the impact of these developments for the level and quality of the transactions occurring in the described markets. Our framework has three key features. First, the market is decentralized, that is, meetings between market participants are subject to search frictions. Second, customers may meet more than one provider and can use this feature to enhance competition among them via the design of the trading mechanism they select. Third, the market features adverse selection: providers are privately informed about the quality of their service, where quality affects both the customers' benefits of the service and the providers' cost. Hence, values are interdependent as in Akerlof (1970). While the model will be interpreted in terms of service procurement, we emphasize that the framework is more general and the results we derive apply to other markets featuring search frictions, many-to-one meetings, and adverse selection, such as decentralized financial markets or labour markets.

We consider a directed search model of a market, where uninformed customers seek to hire a provider, whose quality can be high or low. We allow customers to post general direct mechanisms that specify trading probabilities and transfers for

[1] See, e.g., https://www.moving.com/movers/moving-company-quotes.asp.

participating providers, contingent not only on their own reported type, but also on the number and the reported types of the other providers meeting the same customer. This feature can be interpreted as customers choosing one among several available platforms, characterized by different trading mechanisms. Given the posted mechanisms, each provider picks one of them in order to find a match. The number of providers meeting a specific customer is random and its distribution depends on the market tightness—i.e. the relative number of customers and providers choosing a given mechanism—as well as on the meeting technology. The latter reflects the extent to which a customer is able to be contacted by several providers at the same time. To clarify ideas, in a meeting technology with no capacity constraints, a customer can meet with all the providers who attempt to contact her, for instance by letting all of them participate in a suitably designed auction. On the other hand, under a meeting technology with very tight capacity constraints, a customer can only meet a single provider at a given point in time (as in the case of bilateral meetings).

In this paper, we consider a rich set of meeting technologies, ranging between these two extremes. The only restriction is that a customer's probability of meeting a particular provider decreases in the number of other providers attempting to meet the same customer (that is, who selected her). Hence, we assume that there is some crowding out in the meeting process, though the degree to which providers crowd each other out can be arbitrarily small. The properties of the meeting technology matter for how in equilibrium customers discriminate privately informed providers of different quality. In general, such discrimination may occur via *sorting*, that is, via market segmentation with different mechanisms posted in equilibrium to attract different types of agents, or via *screening*, that is, within the mechanism (Eeckhout and Kircher, 2010). Sorting is costly in markets with search frictions, as market fragmentation increases the likelihood that potential trading partners remain unmatched. On the other hand, screening within a mechanism is hampered by the presence of crowding out in the meeting technology since a mechanism is able to effectively discriminate only among the agents that are present in the same meeting. In the presence of adverse selection, trade is not only constrained by search frictions but also by incentive compatibility and this, as we will show, has important, distinctive implications for the properties of equilibrium allocations and for the effects of varying the degree of crowding out in the meeting technology.

We first establish some general properties of the equilibrium allocation. We show that for all the meeting technologies that are considered equilibria satisfy the following three features. First, whenever a customer meets at least one provider, the customer will trade. Hence, there is no rationing within the trading mechanisms that are posted in equilibrium, in contrast to what one might see in screening menus or in auctions with reserve prices. Second, the incentive constraints of low-quality providers always bind in the equilibrium mechanisms. Third, these mechanisms exhibit the property that, whenever the customer meets at least one low-quality provider, she will trade with one of the low types. Hence, perfect discrimination occurs within the mechanisms: among the providers a customer meets (can contract with), the low-quality ones are always granted priority. Notably, this property does not depend on the relative number of low-quality providers in the economy and holds even when the gains from trade with high-quality providers are arbitrarily large with respect to the low-quality ones.

In the second part of the paper, we consider a parametrized family of meeting technologies, proposed by Cai et al. (2022), where the degree to which providers crowd each other out in the meeting process is captured by a single parameter σ, with $\sigma = 0$ corresponding to the case of bilateral meetings (complete crowding out) and $\sigma = 1$ corresponding to the case where customers can meet all the providers that select them (no crowding out). We characterize the properties of equilibrium allocations as a function of σ and of the fraction of low-quality providers in the population. We show that there are three relevant parameter regions for equilibria. When σ is below a threshold $\sigma^S > 0$, perfect market segmentation occurs in equilibrium, with low- and high-quality providers trading in separate submarkets. Since in this type of equilibrium the pool of providers any given customer attracts is homogenous, the trading mechanisms take the form of posted prices. The equilibrium is thus the same as in the case where meetings are bilateral (see Guerrieri et al. (2010)) and features sorting but no screening.

As σ increases and the capacity of customers to meet providers is raised, screening different types of providers within the trading mechanism becomes more cost effective. For values of σ above the threshold σ^S, screening becomes indeed profitable and the equilibrium always features some degree of pooling, that is, some of the posted trading mechanisms attract both types of providers. Such mechanisms take the form of an auction. A low-quality (and low-cost) provider always wins the auction when providers of this type participate. High-quality providers get to trade only when they happen to be participating in an auction without any low-quality ones. When the fraction of low-quality providers in the population is sufficiently high and/or σ is sufficiently close to the threshold σ^S, a second submarket is active in equilibrium. The trading mechanism posted in this sub-market only attracts low-quality providers and takes again the form of a posted price. The equilibrium thus features partial pooling, with a mix of sorting and screening. Finally, when the meeting technology is characterized by a low level of crowding out (σ is sufficiently high) *and* the fraction of low-quality providers is low, a single mechanism is posted in equilibrium, with the features described above, attracting all providers. Hence, the equilibrium exhibits perfect screening within the trading mechanism and no sorting.

We then characterize the implications of changes in σ for the level and pattern of trade, entry and welfare in equilibrium. To this end, we focus on intermediate values of σ, where the equilibrium features both sorting and screening. As σ increases, more and more low-type providers migrate from the sub-market with price posting to the sub-market where both types are present and the trading mechanism is an auction. Since low-quality providers are given priority to trade in this market, the average quality of trade decreases. Still welfare increases: high-quality providers receive higher payments, which more than compensate the decrease in their probability of trade, while the welfare of low-quality providers remains constant.[2] Given that customers always break even in equilibrium, an increase in σ thus constitutes a Pareto improvement. Interestingly, this happens in spite of the fact that both the average quality and quantity of trades decline. To understand the source of the welfare improvement we show that the entry level decreases in this region. The associated reduction in entry costs contributes positively to welfare.

Finally, the paper makes a methodological contribution by taking a new approach to establish the existence of a competitive search equilibrium. In our environment, due to the presence of adverse selection, the equilibrium is not constrained efficient. hence an argument relying on the decentralization of a planner's solution, a method often used in the existing literature, does not work in our setting. Instead, the proof in the paper relies on a fixed point argument. The key step is to reinterpret providers' market utilities as competitive prices and simplify the customers' design problem by

[2] Low-quality providers can be viewed as being in excess supply here, since not all of them can be attracted in the submarket where high-quality providers trade while still satisfying incentive compatibility.

reducing it to a standard demand problem. The proof of existence is then akin to that commonly used for equilibria in Walrasian markets. We believe that this approach is applicable well beyond our setting.

Related literature Eeckhout and Kircher (2010) were the first to highlight the fact that the properties of the meeting technology have important consequences for equilibrium outcomes. They consider a market with independent private values and compare the two extreme cases, on which most of the literature focused its attention:[3] bilateral meetings (where crowding out is complete) and urn ball meetings, where the principal can meet at the same time all the agents that selected her (no crowding out). They show that in the first case the equilibrium features complete market segmentation, that is perfect sorting, with principals posting different prices. In the second case, instead, all principals post the same mechanism, given by a second price auction, and discrimination among the different types of agents occurs within the mechanism. In a similar private value environment, Cai et al. (2022) allow for a rich set of meeting technologies and show that the equilibrium may feature a mix of sorting and screening. We discuss more in detail the differences with respect to our results in Section 4.

A number of papers have investigated the properties of competitive search equilibria in markets with adverse selection. Focusing on the case of one-to-one meetings, Gale (1992), Inderst and Müller (2002), Guerrieri et al. (2010) showed that an equilibrium always exists and features complete market segmentation.[4] The case of urn ball meetings and general mechanisms was instead analyzed by Auster and Gottardi (2019). They prove the existence of an equilibrium in which all principals post the same screening mechanism (no sorting). In the current paper, we build on the formalism developed in this previous work and extend it to a rich class of meeting technologies. Our main focus here is different and lies on the implications of changes in the ability of customers to meet counterparts for equilibrium outcomes, such as patterns of trade, market entry and welfare.

Finally, we should mention that the effects of allowing one-to-many meetings have also been investigated in random search models, by considering the case where an agent may meet more than one principal (in our case instead a principle may meet

[3]E.g. Moen (1997), Shimer (2005), Albrecht et al. (2014).

[4]As investigated by Chang (2018) and Williams (2021), this property may not extend to the case of multidimensional private information.

multiple agents). The effects of this are rather different from the ones found in the papers mentioned above, as they concern primarily the principals' bargaining power. Building on the earlier work by Burdett and Judd (1983), Lester et al. (2019) have carried out a systematic and very interesting analysis of these effects for adverse selection economies.

2 Environment

There is a measure one of providers and a large measure of homogenous customers. Each provider offers a service of uncertain quality. Quality is identically and independently distributed across providers. It can be either high or low and is private information of the provider. The fraction of providers that offer a low-quality service is μ. Customers can freely enter the market at a cost K. The valuation/cost of customers and providers for the low-quality service is denoted, respectively, by $\underline{v}$ and $\underline{c}$, and that for the high-quality service by $\overline{v}$ and $\overline{c}$. We assume customers care for quality and high quality is more costly: $\overline{v} > \underline{v}$, $\overline{c} > \underline{c}$. Furthermore, there are always positive gains from trade, with those for the high-quality service being weakly greater than those for the low-quality service:

$$\overline{v} - \overline{c} \geq \underline{v} - \underline{c} > 0.$$

Meeting Technologies: The trading process operates as follows. Customers simultaneously choose mechanisms that specify how trade takes place with the providers they meet. Providers observe the chosen mechanisms and select one of the mechanisms they prefer, as well as one of the customers offering it. We refer to the collection of customers and providers choosing the same mechanism as constituting a submarket. We have in mind markets that are decentralized and anonymous, where interactions are relatively infrequent. In line with the first feature, the matching between customers and providers in any submarket does not occur in a centralized way but is determined by the individual choices of providers, each of them selecting a customer. Anonymity is captured by the assumption that the offered mechanisms do not condition on the identity of providers, and that providers do not condition their choice on the identity of customers, only on the mechanism they offer. Providers thus pick at random one of the customers offering the selected mechanism (see, for example, Shimer (2005)). Also, since each provider can only select one customer, contracting is exclusive.

More specifically, the probability for a customer to meet a certain number of providers in a given submarket depends on the queue length λ in that submarket, defined as the ratio of the measure of providers to the measure of customers present in that submarket.[5] Let the probability that a customer meets $n = 0, 1, 2, ...$ providers as a function of the queue length λ be denoted by $P_n(\lambda)$. We assume that the meeting probability does not depend on the providers' types; that is, conditional on a customer meeting n providers, the types of these providers are n independent draws from the population of providers present in the submarket.

The two cases that have received most attention in the literature are bilateral meetings and urn-ball meetings. the urn-ball matching technology captures a situation where in any submarket a provider always meets one, randomly selected customer and customers have no capacity constraint in their ability to meet providers. Hence, providers are certain to meet a customer, but do not know about how many other providers show up. Moreover, a customer's probability of meeting a provider of a given type is fully determined by the queue length of that type of provider in the submarket, while it does not depend on the presence of other types of providers. The class of meeting technologies that have this property is called 'invariant' (Lester et al., 2015). Under the bilateral meeting technology, each customer can meet instead at most one provider. this means that—in contrast to urn-ball matching—a provider is not certain to meet the selected customer and the presence of other providers negatively affects the provider's chances to meet the customer. In this case, we have $P_n(\lambda) = 0$ for all $n \geq 2$.

In this paper, we are interested in more general situations where customers can meet multiple providers—as under urn-ball matching—and where providers visiting a submarket impose externalities on the meeting possibilities of other providers in that market—as under bilateral matching. The idea is that customer's face constraints in their ability to meet providers but this constraint needs not be equal to one.

Mechanisms and payoffs: For the specification of mechanisms, payoffs and the definition of equilibrium, we follow closely Auster and Gottardi (2019). A direct

[5] In principle, we can have a continuum of active submarkets, each with a measure zero of customers and providers. In that case, we can use the Radon-Nikodym derivatives to define queue lengths.

mechanism m is defined by the map:

$$\left(\underline{X}_m, \overline{X}_m, \underline{T}_m, \overline{T}_m\right) : \mathbb{N}^2 \to [0,1]^2 \times \mathbb{R}^2,$$

where the first argument is the number of low messages and the second argument is the number of high messages received by a customer from the providers he meets. The maps $\underline{X}_m(L,H), \overline{X}_m(L,H)$ describe the trading probabilities specified by mechanism m for providers reporting, respectively, to be of low and of high type. The associated transfers (unconditional on whether or not trade occurs) are given by the maps $\underline{T}_m(L,H), \overline{T}_m(L,H)$. For instance, $\underline{T}_m(L,H)$ is the transfer to a provider who reports to be of low type when $L-1$ other providers report to be of low type and H other providers report to be of high type. We say a mechanism m is feasible if:

$$\underline{X}_m(L,H)L + \overline{X}_m(L,H)H \leq 1, \forall (L,H) \in \mathbb{N}^2. \tag{1}$$

Let M denote the measurable set of feasible mechanisms.[6] We assume that when matched with a customer, a provider does not observe how many other providers are actually matched with the same customer nor their types.

Given a meeting technology, the queue lengths of low- and high-type providers, $\underline{\lambda}$ and $\overline{\lambda}$, induce a joint distribution over the number of low types and high types meeting a customer. We define

$$P(L,H;\underline{\lambda},\overline{\lambda}) \equiv P_n(\underline{\lambda}+\overline{\lambda})\frac{(L+H)!}{L!H!}\left(\frac{\underline{\lambda}}{\underline{\lambda}+\overline{\lambda}}\right)^L \left(\frac{\overline{\lambda}}{\underline{\lambda}+\overline{\lambda}}\right)^H$$

as the probability for a customer to meet L low types and H high types when the queue lengths of low- and high-type providers are, respectively, $\underline{\lambda}$ and $\overline{\lambda}$. on that basis, we determine the expected trading probabilities of the two types of providers

[6]The set M is identified by the collection of sequences of vectors in $\mathbb{R}^4$, indexed by the set $I = \mathbb{N} \times \mathbb{N}$. Letting $\mathcal{M}_i$ denote the Borel σ-algebra of $\mathbb{R}^4$, we can consider the family of measurable spaces $\{(M_i, \mathcal{M}_i), i \in I\}$ and use the Kolmogorov extension theorem to define a probability measure for the set of these sequences.

induced by the mechanism:

$$\begin{aligned} \underline{x}_m(\underline{\lambda}, \overline{\lambda}) &= \sum_{L,H} P(L, H; \underline{\lambda}, \overline{\lambda}) \underline{X}(L+1, H), \\ \overline{x}_m(\underline{\lambda}, \overline{\lambda}) &= \sum_{L,H} P(L, H; \underline{\lambda}, \overline{\lambda}) \overline{X}(L, H+1). \end{aligned}$$

Analogously, we can determine expected transfers $\underline{t}_m(\underline{\lambda}, \overline{\lambda})$ and $\overline{t}_m(\underline{\lambda}, \overline{\lambda})$. The expected payoff for low- and high-type providers when choosing mechanism m and revealing their type truthfully, net of the utility when they do not trade, is then given by:

$$\begin{aligned} \underline{u}(m|\underline{\lambda}, \overline{\lambda}) &= \underline{t}_m(\underline{\lambda}, \overline{\lambda}) - \underline{x}_m(\underline{\lambda}, \overline{\lambda})\underline{c}, \\ \overline{u}(m|\underline{\lambda}, \overline{\lambda}) &= \overline{t}_m(\underline{\lambda}, \overline{\lambda}) - \overline{x}_m(\underline{\lambda}, \overline{\lambda})\overline{c}. \end{aligned}$$

Truthful reporting is optimal if the following two inequalities hold:

$$\underline{t}_m(\underline{\lambda}, \overline{\lambda}) - \underline{x}_m(\underline{\lambda}, \overline{\lambda})\underline{c} \geq \overline{t}_m(\underline{\lambda}, \overline{\lambda}) - \overline{x}_m(\underline{\lambda}, \overline{\lambda})\underline{c}, \quad (2)$$

$$\overline{t}_m(\underline{\lambda}, \overline{\lambda}) - \overline{x}_m(\underline{\lambda}, \overline{\lambda})\overline{c} \geq \underline{t}_m(\underline{\lambda}, \overline{\lambda}) - \underline{x}_m(\underline{\lambda}, \overline{\lambda})\overline{c}. \quad (3)$$

The expected payoff for a customer posting mechanism m, when providers report truthfully and the expected number of high- and low-type providers, respectively, is $\overline{\lambda}$ and $\underline{\lambda}$, is then:

$$\pi(m|\underline{\lambda}, \overline{\lambda}) = \overline{\lambda}(\overline{x}_m(\underline{\lambda}, \overline{\lambda})\overline{v} - \overline{t}_m(\underline{\lambda}, \overline{\lambda})) + \underline{\lambda}(\underline{x}_m(\underline{\lambda}, \overline{\lambda})\underline{v} - \underline{t}_m(\underline{\lambda}, \overline{\lambda})).$$

Equilibrium: An allocation in this setting is defined by a probability measure β on M with support M^β, where $\beta(M')$ describes the measure of customers that post mechanisms in $M' \subseteq M$, and two maps $\underline{\lambda}, \overline{\lambda} : M^\beta \to \mathbb{R}^+$ specifying, respectively, the queue lengths of low- and high-type providers selecting mechanism m. We say that an allocation is *feasible* if:

$$\frac{1}{\beta(M^\beta)} \int_{M^\beta} \frac{\underline{\lambda}(m)}{\underline{\lambda}(m) + \overline{\lambda}(m)} d\beta(m) = \mu. \quad (4)$$

Likewise, we call an allocation *incentive compatible* if, for all $m \in M^\beta$, (2) and (3) hold.[7]

[7] The restriction to incentive compatible allocations is w.l.o.g.

An equilibrium is then given by a feasible and incentive compatible allocation such that the values of β and $\underline{\lambda}, \overline{\lambda}$ are consistent with customers' and providers' optimal choices. For mechanisms not offered in equilibrium, we extend the maps $\underline{\lambda}, \overline{\lambda}$ to the domain $M \backslash M^\beta$ in order to describe the beliefs of customers over the queue lengths of low- and high-type providers that such mechanisms attract. We require these beliefs to be pinned down by a similar consistency condition with providers' optimal choices out of equilibrium. More specifically, a customer believes that a deviating mechanism attracts some low-type providers only if low-type providers are indifferent between this mechanism and the one they choose in equilibrium, and similarly for high-type providers.[8]

$$\underline{u}(m|\underline{\lambda}(m), \overline{\lambda}(m)) \leq \max_{m' \in M^\beta} \underline{u}(m'|\underline{\lambda}(m'), \overline{\lambda}(m')) \text{ holding with equality if } \underline{\lambda}(m) > 0, \quad (5)$$

$$\overline{u}(m|\underline{\lambda}(m), \overline{\lambda}(m)) \leq \max_{m' \in M^\beta} \overline{u}(m'|\underline{\lambda}(m'), \overline{\lambda}(m')) \text{ holding with equality if } \overline{\lambda}(m) > 0. \quad (6)$$

This specification of the beliefs for mechanisms that are not posted in equilibrium is standard in the literature of directed search, both with and without common value uncertainty (see Guerrieri et al. (2010) and Eeckhout and Kircher (2010), among others).

In our environment, conditions (5,6) may not uniquely pin down the out of equilibrium beliefs $\underline{\lambda}(m), \overline{\lambda}(m)$ for $m \notin M^\beta$. To this end we postulate the following:[9]

i) if (5,6) admit a unique solution, $\underline{\lambda}(m)$ and $\overline{\lambda}(m)$ are given by that solution;

ii) if (5,6) admit no solution, we set $\underline{\lambda}(m)$ and/or $\overline{\lambda}(m)$ equal to $+\infty$ and $\pi(m|\underline{\lambda}(m), \overline{\lambda}(m)) = c$ for some $c \leq 0$;

iii) if (5,6) admit multiple solutions, $\underline{\lambda}(m), \overline{\lambda}(m)$ are given by the solution for which the customer's payoff $\pi(m|\underline{\lambda}(m), \overline{\lambda}(m))$ is the highest.

We are now ready to define a directed search equilibrium.

[8] Conditions (5),(6) below are perfectly analogous to the providers' optimality conditions appearing in the equilibrium Definition 1 below. Hence, conditions (5),(6) indeed require that queue lengths are consistent with providers' optimal choices also for out of equilibrium mechanisms, as if all mechanisms were effectively available to providers. This is analogous to existing refinements in other competitive models with adverse selection, such as Gale (1992) and Dubey and Geanakoplos (2002).

[9] See Auster and Gottardi (2019) for further discussion of these conditions. Similar specifications appear also in McAfee (1993), Eeckhout and Kircher (2010) and Guerrieri et al. (2010), among others.

Definition 1. *A directed search equilibrium is a feasible and incentive compatible allocation, given by a measure β with support M^β and two maps $\underline{\lambda}, \overline{\lambda} : M \to \mathbb{R}^+ \cup +\infty$, such that the following conditions hold:*

- *customer optimality: for all $m \in M$ such that $(m, \underline{\lambda}(m), \overline{\lambda}(m))$ satisfies incentive compatibility,*

$$\pi(m|\underline{\lambda}(m), \overline{\lambda}(m)) \leq K, \text{ holding with equality if } m \in M^\beta;$$

- *provider optimality: for all $m \in M^\beta$,*

$$\begin{aligned} \underline{u}(m|\underline{\lambda}(m), \overline{\lambda}(m)) &\leq \max_{m' \in M^\beta} \underline{u}(m'|\underline{\lambda}(m'), \overline{\lambda}(m')) \text{ holding with equality if } \underline{\lambda}(m) > 0, \\ \overline{u}(m|\underline{\lambda}(m), \overline{\lambda}(m)) &\leq \max_{m' \in M^\beta} \overline{u}(m'|\underline{\lambda}(m'), \overline{\lambda}(m')) \text{ holding with equality if } \overline{\lambda}(m) > 0; \end{aligned}$$

- *beliefs: for all $m \notin M^\beta$, $\underline{\lambda}(m)$ and $\overline{\lambda}(m)$ are determined by conditions i)-iii).*

3 Analysis

A distinguishing feature of the environment with common value uncertainty is that the equilibrium cannot be found by decentralizing the constrained planner's solution. To characterize directed search equilibria we must therefore study the solution of the customers' optimization problem. To this end, we rewrite this problem in terms of an auxiliary problem. The latter consists in choosing the expected trading probabilities, expected transfers and queue lengths so as to maximize profits, taking as given the utility gain attained in the market by low- and high-type providers relative to their endowment points, denoted by $\underline{U}$ and $\overline{U}$ (in short, their market utilities). Auster and Gottardi (2019) demonstrated the validity of this approach for the case of urn-ball meetings. We now extend the result to the general class of meeting technologies considered here.

3.1 A Customer's Auxiliary Optimization Problem

To state the auxiliary problem of an arbitrary customer, it is useful to define the probability for a customer to meet at least one provider of a certain type when the queue of that type is $\lambda$and the overall queue length in the submarket is $\lambda' \geq \lambda$:

$$\phi(\lambda, \lambda') = 1 - \sum_{n=0}^{+\infty} P_n(\lambda') \left(1 - \frac{\lambda}{\lambda'}\right)^n.$$

Cai et al. (2022) show that, under the assumption that meeting probabilities are type independent, the function ϕcharacterizes the meeting technology. The probability $\phi(\lambda, \lambda')$ is obtained as the complement to the probability of meeting no provider or meeting only providers of a different type. Given a submarket with a low-type queue length $\underline{\lambda}$ and a high-type queue length $\underline{\lambda}$, $\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})$ corresponds to the probability that in such market a customer meets at least one low type, $\phi(\overline{\lambda}, \underline{\lambda}+\overline{\lambda})$ is instead the probability of meeting at least one high type, and $\phi(\underline{\lambda} + \underline{\lambda}, \underline{\lambda} + \overline{\lambda}) = 1 - P_0(\underline{\lambda} + \overline{\lambda})$ the probability that a customer meets at least one provider.

Proposition 1. *Consider an equilibrium where the set of posted mechanisms is M^β. For every $m \in M^\beta$ with queue lengths $\underline{\lambda} = \underline{\lambda}(m), \overline{\lambda} = \overline{\lambda}(m)$, the vector*

$$\left(\underline{x}_m(\underline{\lambda}, \overline{\lambda}), \overline{x}_m(\underline{\lambda}, \overline{\lambda}), \underline{t}_m(\underline{\lambda}, \overline{\lambda}), \overline{t}_m(\underline{\lambda}, \overline{\lambda}), \underline{\lambda}, \overline{\lambda}\right)$$

solves the problem

$$\max_{\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda}} \overline{\lambda}(\overline{x}\,\overline{v} - \overline{t}) + \underline{\lambda}(\underline{x}\,\underline{v} - \underline{t}) \tag{P^{aux}}$$

subject to:

$$\begin{aligned}
\underline{t} - \underline{x}\,\underline{c} &\leq \underline{U} \quad \textit{holding with equality if } \underline{\lambda} > 0, & (7)\\
\overline{t} - \overline{x}\,\overline{c} &\leq \overline{U} \quad \textit{holding with equality if } \overline{\lambda} > 0, & (8)\\
\underline{t} - \underline{x}\,\underline{c} &\geq \overline{t} - \overline{x}\,\underline{c}, & (9)\\
\overline{t} - \overline{x}\,\overline{c} &\geq \underline{t} - \underline{x}\,\overline{c}, & (10)\\
\underline{\lambda}\,\underline{x} &\leq \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}), & (11)\\
\overline{\lambda}\,\overline{x} &\leq \phi(\overline{\lambda}, \underline{\lambda} + \overline{\lambda}), & (12)\\
\overline{\lambda}\,\overline{x} + \underline{\lambda}\,\underline{x} &\leq \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}). & (13)
\end{aligned}$$

An equilibrium mechanism that attracts low- or high-type providers must yield these providers a payoff equal to their market utility. Hence, the associated trading probabilities and transfers must satisfy constraints (7-8). Likewise, they must satisfy the providers' incentive constraints, which correspond to conditions (9- 10). The remaining three conditions say that the mechanism is feasible according to (1) and that meetings take place according to technology ϕ. In particular, inequality (11) requires that a customer's probability of trading with a low-type provider, $\underline{\lambda}\,\underline{x}$, is weakly smaller than a customer's probability of meeting at least one low-type provider, $\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})$. Inequality (12) is the analogous condition for the high-type provider. Inequality (13) requires that a customer's probability of trading with any provider, $\overline{\lambda}\overline{x} + \underline{\lambda}\,\underline{x}$, is weakly smaller than the probability of meeting at least one provider, $\phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda})$.

While it is easy to see that any feasible and incentive compatible equilibrium mechanism must satisfy conditions (8-13), the main role of Proposition 1 is to show that equilibrium mechanisms must solve the problem P^{aux}. This means that in order to find an equilibrium we can directly study the solutions of P^{aux}. Whenever we can assign a measure β to the solutions of the customer's auxiliary problem so that the average fraction of low- and high-type providers is equal that in the population, the solutions give us the expected trading probabilities and transfers in a candidate equilibrium.

3.2 General Properties of Search Equilibria

In order to state the first main result, we need to impose some conditions on the meeting technology.

Assumption 1. *The meeting technology function ϕ is twice differentiable in both arguments and satisfies*[10]

$$\frac{\partial \phi}{\partial \overline{\lambda}}(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) < 0, \qquad \frac{\partial^2 \phi}{\partial \overline{\lambda}^2}(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) > 0.$$

Assumption 1 guarantees that providers impose some negative externalities on each other in the meeting process. The first inequality in Assumption 1 says that having additional high-type providers in a submarket reduces the chances for a customer to meet some low-type providers. The second inequality says that the magnitude of this effect is decreasing in the queue length of the high types. This assumption is violated under the urn-ball meetings technology, where an increase in the number

[10] As explained above, the function ϕ is symmetric with respect to the type appearing in the first entry, so the condition equally applies to $\phi(\overline{\lambda}, \underline{\lambda} + \overline{\lambda})$.

of providers attempting to meet a given customer has no effect on the chances to meet that customer of the providers who already selected him. Under Assumption 1 instead, customers face some constraints in their ability to meet providers, so there is a chance that providers crowd each other out in the meeting process.

Proposition 2. *A directed search equilibrium exists. In any equilibrium, the posted mechanisms satisfy the following properties:*

1. *All meetings lead to trade.*
2. *In any meeting where low-type providers are present, the customer will trade with one of them.*
3. *Low-type incentive constraints are binding.*

We start by discussing each of the three stated properties which equilibrium mechanisms must satisfy. Using these properties, we then explain how the existence of a directed search equilibrium is proven.

No rationing By the first property, in equilibrium customers only offer mechanisms under which every meeting ends in trade. For instance, if a customer offers an auction in equilibrium, then the reserve price of the auction would be acceptable to all providers that show up. This property is a consequence of Assumption 1. In contrast, when customers and providers meet according to the urn-ball technology, we showed in our previous work (Auster and Gottardi, 2019) that when the fraction of low quality agents is sufficiently high, multiple payoff equivalent equilibria co-exist, almost all of which exhibit rationing of high types within the mechanism. Proposition 2 demonstrates that, when there are some negative externalities in the meeting process, no equilibrium exists that features rationing within the mechanism. Put differently, if customers are constrained in their ability to meet providers—even slightly—they do not find it optimal to attract providers when they may end up not trading with any of them. To establish this property, we show that under Assumption 1, at any solution of P^{aux}, a customer's probability to trade equals his probability to meet a provider; that is, the overall feasibility constraint (13) holds as an equality.

Priority for low-type providers. The second feature which all equilibrium mechanisms satisfy is that high-type providers get to trade only in meetings where no low-type provider is present. We thus show that at any solution of P^{aux}, the low-type feasibility constraint (11) holds as an equality: a customer's probability of buying a low-quality service is equal to her probability of meeting a low-type provider. An important step for proving the above result is the observation that incentive compatibility of equilibrium mechanisms requires that $\underline{U} > \overline{U}$. That is, the expected utility gain obtained in equilibrium by trading in the market is strictly higher for low-type providers than for high-type providers (see Appendix A.2). Given this property, any mechanism that does not give priority to low-type providers is dominated by one that does. In particular, for any non-priority mechanism, consider an alternative mechanism that attracts fewer low types and more high types, but gives priority to low-types, so that the overall probability of trading with a low- and high-type provider remains unchanged for the customer. At the alternative mechanism, providers get the same utility as with the mechanisms posted in the market, but the customer's profits are higher. Since high-quality providers have a lower utility gain in equilibrium than low types, they are less costly to attract. Deviating to the alternative mechanism is reminiscent of cream skimming. It should be noted that the logic of this result does not rely on the conditions on the meeting technology imposed in Assumption 1.

Tight incentive constraints. Proposition 2 further establishes that in equilibrium the low-type incentive constraint (9) is satisfied as equality. If this property is violated, for any mechanism attracting both types, a customer could increase her payoff by replacing some low-type providers with the same number of high-type providers. Such replacement keeps the customer's probability of trade unchanged, but increases the gains from trade that are generated (recall: $\overline{v} - \overline{c} \geq \underline{v} - \underline{c}$) and reduces the rents paid to the providers since $\underline{U} > \overline{U}$. It also increases a high-type provider's probability of trade but, as long as the low-type incentive constraints are slack, this is not an issue, provided the replacement is sufficiently small. We are then left with the possibility of incentive constraints being slack at a separating equilibrium, where low- and high type providers search in separate submarkets. This would require customers to be indifferent between both markets. Since, however, high-quality providers generate higher gains from trade and have a lower market utility, indifference can only be sustained when the incentive compatibility constraints for low-type providers bind and limit trade in the high-quality market.

Existence. Given the three properties we established, a customer's auxiliary problem can be written in the following simplified way:

$$\max_{\underline{\lambda},\overline{\lambda}} \quad \phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda})(\underline{v}-\underline{c}) + [\phi(\underline{\lambda}+\overline{\lambda}, \underline{\lambda}+\overline{\lambda}) - \phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda})](\overline{v}-\overline{c}) - \underline{\lambda}\,\underline{U} - \overline{\lambda}\,\overline{U}, \tag{14}$$

subject to

$$[\phi(\underline{\lambda}+\overline{\lambda}, \underline{\lambda}+\overline{\lambda}) - \phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda})](\overline{c}-\underline{c}) = \overline{\lambda}(\underline{U}-\overline{U}). \tag{15}$$

The expression in (14) indicates a customer's expected payoff for a mechanism that leads to trade in every meeting with priority for low types as a function of the queue lengths of low- and high-type providers. With probability $\phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda})$, the customer meets some low-type provider and the gains from trade from the low-quality service are realized, while with probability $\phi(\underline{\lambda}+\overline{\lambda}, \underline{\lambda}+\overline{\lambda}) - \phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda})$, the customer meets no low-type provider but some high-type provider, so the gains from trade of the high-quality service are realized. The rent the customer has to pay to the providers he attracts is $\underline{\lambda}\,\underline{U} + \overline{\lambda}\,\overline{U}$. For all $\overline{\lambda} > 0$, the value of the low-type queue length $\underline{\lambda}$ is then determined by the low-type's incentive constraint (15). For $\overline{\lambda} = 0$, the equality (15) is always satisfied and thus imposes no restrictions on $\underline{\lambda}$.

To construct an equilibrium we need to find values of $\underline{U}, \overline{U}$ such that the maximum of (14) subject to (15) is K and a measure β can be assigned to each element of the set of solutions such that the feasibility condition (4) is satisfied. We prove existence of such values via Kakutani's fixed point theorem. The argument is similar to that of proofs for the existence of Walrasian equilibria, with queue lengths $\underline{\lambda}, \overline{\lambda}$ taking the role of quantities consumed and market utilities $\underline{U}, \overline{U}$ taking the role of prices.

4 Meeting Ability and Market Segmentation

In the previous section, we established the existence of a search equilibrium and several properties of equilibrium mechanisms, which hold for all meeting technologies in our class. In this section, we turn to the question of how the meeting technology ϕ affects other important properties of the search equilibrium, such as market segmentation, trading volumes and market entry. To address this question, we restrict attention to the class of geometric meeting technologies (see Cai et al. (2022)) under which the degree of crowding out in the meeting process is captured by a single parameter $\sigma \in [0,1]$:

$$\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) = \frac{\underline{\lambda}}{1 + \underline{\lambda} + (1-\sigma)\overline{\lambda}}.$$

For $\sigma = 0$ we can write the customer's probability of meeting at least one low-type provider as:

$$\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) = \frac{\underline{\lambda} + \overline{\lambda}}{1 + \underline{\lambda} + \overline{\lambda}} \frac{\underline{\lambda}}{\underline{\lambda} + \overline{\lambda}} = \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}) \frac{\underline{\lambda}}{\underline{\lambda} + \overline{\lambda}},$$

that is, as the probability of meeting at least one provider multiplied with the probability that a randomly selected provider is of low type. Meetings are thus bilateral. On the other hand, for $\sigma = 1$, the probability of meeting at least one low-type provider, $\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) = \frac{\underline{\lambda}}{1+\underline{\lambda}}$, only depends on the queue length of the low type but not on that of the high type. The meeting technology is invariant, which means that high- and low-type providers do not crowd each other out (as it happens under urn-ball matching). Hence, Assumption 1 boils down to the restriction $\sigma < 1$.

The following lemma shows that if the meeting technology is geometric and the condition $\sigma < 1$ holds, there can be at most two active submarkets. Moreover, only one of these markets attracts the high-type providers.

Lemma 3. *Suppose ϕ is geometric with $\sigma < 1$. A search equilibrium is of one of the following three types:*

1. *Pure sorting: two submarkets are active, one attracts low-type providers, the other attracts high-type providers.*
2. *Partial sorting: two submarkets are active, one attracts low-type providers, the other attracts both types of providers.*
3. *Pure screening: only one submarket is active and it attracts both types of providers.*

To prove the lemma, we consider a customer's simplified auxiliary problem, as written in (14). Recall that according to this problem a representative customer maximizes her expected payoff over the queue lengths $\underline{\lambda}$ and $\overline{\lambda}$ subject to the low-type incentive constraint (15). As we argued above, the latter constraint is satisfied as equality at any solution of the auxiliary problem with $\overline{\lambda} > 0$. Using this property and the geometric meeting technology, we can derive the queue length $\underline{\lambda}$ as a function of $\overline{\lambda} > 0$ from the binding incentive constraint and write the customer's expected payoff as a function of $\overline{\lambda}$. We then show that this payoff is strictly concave in $\overline{\lambda}$, implying that the customer's auxiliary problem can have at most one solution with $\overline{\lambda} > 0$. The other potential solution lies at $\overline{\lambda} = 0$.

Which type of equilibrium obtains depends on the extent to which customers are constrained in their ability to meet providers, i.e. on the value of the parameter σ. As shown in Proposition 2, whenever in equilibrium customers choose a mechanism that attracts both types of providers, the mechanism will treat the two types differently, by giving priority to low types (it is a form of auction). Screening thus happens within the mechanism. The effectiveness of such screening clearly depends on the property of the meeting technology captured by the value of σ. When σ is close to 0, that is, in most meetings there is one or only few providers, the priority rule does not allow to substantially differentiate the trading probability of the two types (and hence the price a customer pays).[11] The alternative way to differentiate providers is to offer mechanisms that only attract one type of provider, i.e. via sorting across mechanisms. In this case the mechanisms offered are simply posted prices, and a customer commits to selecting one provider at random among the ones she meets. This is effectively equivalent to having bilateral meetings, where from the providers attempting to meet a given customer one is randomly selected for the meeting. With different markets active in equilibrium, there is no limit to the difference that can be achieved in the trading probabilities of the two types, since the queue lengths in the market attracting low types and the one attracting high types can be suitably varied. Building on these considerations, we show the following.

Proposition 4. *Suppose ϕ is geometric. There exists a parameter $\sigma^S \in (0, 1)$ and a function $\overline{\mu} : (\sigma^S, 1] \to [0, 1]$ satisfying $0 < \overline{\mu}(1) < 1$ such that:*

1. *if $\sigma \leq \sigma^S$, there is a pure sorting equilibrium;*
2. *if $\sigma > \sigma^S$ and $\mu > \overline{\mu}(\sigma)$, there is a partial sorting equilibrium;*
3. *if $\sigma > \sigma^S$ and $\mu \leq \overline{\mu}(\sigma)$, there is a pure screening equilibrium.*

[11] As shown in Proposition 2, it is in fact never optimal for customers to increase this difference by offering mechanisms that entail meetings not leading to trade (i.e., that feature rationing).

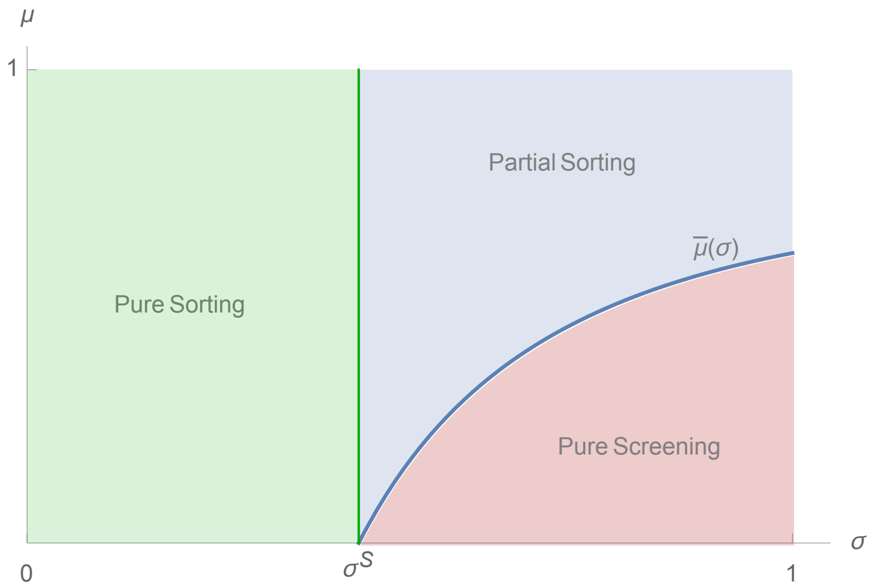

Figure 1: Equilibrium market segmentation for the following parameter specification: $\overline{v} = 1.2$, $\underline{v} = 1$, $\overline{c} = 0.1$, $\underline{c} = 0$, $K = 0.1$.

Figure 1 illustrates the parameter regions of the three different types of equilibria, described in Proposition 4. When σ is below the threshold σ^S, equilibrium mechanisms take the form of posted prices. Providers sort themselves into separate submarkets according to their type, with high-quality providers trading at a higher price in a submarket with a sufficiently longer queue, as required by incentive compatibility. Hence, customers are more likely to meet a provider in the high-quality market than in the low-quality market. For customers to be indifferent between the two markets, they must then make higher profits with low types than with high types conditionally on trading.

An increase in σ augments the number of providers that are present in a given meeting but, as long as $\sigma \leq \sigma^S$, it has no effect on the equilibrium allocation: posted prices and queue lengths are constant in σ, as are the market utilities of low- and high-type providers. What changes with σ in this parameter region is the profitability of a customer's deviation to a screening mechanism. In particular, as σ increases above σ^S, the following deviation becomes profitable: customers attracting high-quality providers post a mechanism that also attracts some low-quality providers and grants them priority in meetings. The advantage of this mechanism is that it generates a positive probability of contracting with a low-quality provider at a relatively low price,[12] while keeping the option to hire a high-quality provider with high probability in case no low-quality provider shows up. While priority allows the low types to jump the queue in meetings where the other providers are of high type, for low values of σ the incidence of meetings with multiple providers is relatively low. Hence, in such situations, the priority-rule has little bite in enhancing the probability of trade for low types. As σ increases, the priority rule becomes more effective, which reduces the compensation customers have to pay to low-cost providers for the longer queue in the high-type market, making the deviation more profitable.

For values of σ above σ^S, the equilibrium always features some degree of pooling. In particular, as stated in Proposition 4, all customers offering mechanisms that attract high-type providers also attract some low types. Two possibilities then arise. First, only a fraction of low-type providers choose the market selected by high types (the mechanism takes the form of an auction), while the remaining low types continue to trade via posted prices in the separate market. The equilibrium is thus of the partial sorting type, where the different types of providers are separated partly via their choice of mechanism and partly within the mechanism chosen. Second, all customers and providers choose the same mechanism featuring priority, so separation only occurs within this mechanism. As shown in Proposition 4, which of the two kinds of equilibria obtains depends both on the value of σ, that is, the customers' meeting capacity, and the proportion μ of low types in the economy.

To understand the role played by the meeting technology, note that for values of σ slightly above σ^S the deviation from the pure-sorting equilibrium described earlier, consisting in attracting some low-quality providers in the high-quality market, is profitable but only slightly. Hence, for σ slightly above σ^S we can expect that the fraction of low-type providers present in the market where high-quality providers trade is small. As σ increases, the priority rule becomes more effective, which implies that customers can afford to attract more low-quality providers to the market chosen by the high types and still guarantee a sufficiently high trading probability for the low types. Hence, as σ increases, more and more low-type providers migrate from the low-quality market to the market where both types of services are traded.

To determine whether the equilibrium features partial sorting or pure screening, we need to examine also the role played by the fraction μ of low types in the population. Consider a candidate partial sorting equilibrium: in this equilibrium a positive mass

[12] Recall trading with this type tends to be more profitable.

of low types still chooses the low-quality market. Terms of trade in that market do not vary with σ, so the low types' market utility $\underline{U}$ is constant. For any given $\sigma > \sigma^S$ let us indicate then with $\overline{\mu}(\sigma)$ the mass of low-quality providers choosing the mixed market, or, equivalently, the demand for low types by customers who, in this candidate equilibrium, choose to operate in the mixed market when the cost of attracting low types is $\underline{U}$.[13] When $\mu > \overline{\mu}(\sigma)$ the candidate equilibrium allocation with partial sorting is admissible, as the mass of low types in the population exceeds the demand for low types coming from customers active in the mixed market. In the threshold case where $\mu = \overline{\mu}(\sigma)$, such candidate equilibrium allocation is still admissible, but there are no providers left in the low-quality market. Hence, the equilibrium features pure screening. When instead the mass of low types in the population is sufficiently low, so that $\mu < \overline{\mu}(\sigma)$, the demand from the mixed market for low types exceeds the supply, so the candidate equilibrium allocation with partial sorting is not admissible. In this case, the equilibrium is of the pure screening type, but with a higher level of the low types' market utility.

Finally, according to Proposition 4, all three types of equilibria exist for some values of the parameters μ, σ, as in the situation depicted in Figure 1; that is, there are three non-empty subsets of the region of admissible values of $\mu, \sigma \in (0,1) \times [0,1)$, where, respectively, pure sorting, partial sorting and pure screening obtain in equilibrium. This partitioning of the parameter space clearly shows the effects of the customers' meeting capacity, as described by the meeting technology, as well as of the severity of adverse selection, as captured by the fraction of low types in the population, on the main qualitative properties of equilibria. In equilibrium the probability of trade and the payment to providers always differ for low and high types, but the extent by which they differ and how this difference in treatment is achieved, via sorting and/or screening, depend on the values of μ and σ.

Entry and welfare. In what follows, we want to analyze more in detail how the properties of the equilibrium allocation vary with the meeting constraints. To this end, we will focus our attention on the parameter region where the equilibrium fea-

[13]Note that we cannot rule out the possibility of multiple equilibria with partial sorting (the candidate partial sorting equilibrium is determined by a solution of the first order conditions of the auxiliary problem and the customers' free entry condition and such a solution may not be unique). In that case a map $\overline{\mu}(\sigma)$ can be defined for any of such equilibria. When $\mu < \overline{\mu}(\sigma)$ for all such maps no partial sorting equilibrium exists, in which case we know by the existence result in Proposition 2 that a pure screening equilibrium exists.

tures both sorting and screening. Within this region, changes in σ have no effect on the terms of trade in the low-quality market, whereas the terms of trade in the market where both types trade vary continuously with σ. Given the free entry condition, customers always make zero profits in equilibrium, but their level of entry in the mixed market (so far implicit in the analysis) also varies with σ and plays an important role in determining the equilibrium allocation.

Our next proposition shows that, in the region where the equilibrium features partial sorting, an increase in σ leads to a reduction of the high type's trading probability. Despite the lower trading probability, the market utility of high-quality providers actually increases. Hence, high types are overcompensated for the loss in trading probability by the price in the event of trade. In contrast, the welfare of low-type providers is unaffected.

Proposition 5. *Assume $\sigma > \sigma^S$ and $\mu > \overline{\mu}(\sigma)$. A marginal increase in σ leads to:*

- *a decrease of the trading probability $\overline{x}$ and an increase of the utility gain $\overline{U}$ attained in equilibrium by high-type providers;*
- *no change of the utility gain $\underline{U}$ attained by low-type providers.*

As argued above, higher values of σ increase the profitability of attracting low-quality providers to the high-type market. Priority is in fact more effective and allows to offer low types a higher trading probability and therefore reduce any compensating payment to them. Operating in the market where high types trade thus becomes more attractive for customers. As a result, the competition for high-type providers, who only search in this market, gets fiercer and this drives up their market utility $\overline{U}$, to the point that customers still break even in both markets. There is instead no increased competition to attract low types, as long as $\mu > \overline{\mu}(\sigma)$, since the demand for them coming from customers operating in the mixed market is less than the supply of low types in the economy, so the market utility $\underline{U}$ remains unchanged. Hence, in the parameter region where we have partial sorting, an increase in the ability to meet potential counterparts in decentralized markets, as described by a rise in σ, induces a Pareto improvement: at the equilibrium allocation high-type providers gain, while the utility of low types and customers is unaffected.

It is interesting to point out that this occurs even though the expected surplus generated by trades with high-type providers, for whom gains from trade are larger, decreases. Indeed, as customers attract an increasing mass of low types in the market of high-type providers and give them priority, the trading probability of high types declines. To understand why welfare increases despite this decline, we should also consider the effect of changes in σ on the level of entry by customers: since entry is costly, any change in the probability of trade for providers should be assessed against the change in the total entry costs borne by customers.

To assess the effects of the meeting technology on entry, a sharp result obtains when we compare the level of entry in the pure sorting equilibrium ($\sigma < \sigma^S$) with the one in the partial sorting equilibrium when σ is maximal ($\sigma = 1$) and the fraction of low types in the population is sufficiently high ($\mu > \overline{\mu}(1)$). When $\sigma = 1$, providers impose no negative externalities on each other in the meeting process, which means that the presence of high-quality providers in the market has no effect on the low types' probability of trade as long as they receive priority through the mechanism. We can then show the two following properties hold in equilibrium when $\sigma = 1$ (see Appendix A.7): (i) low-type queue lengths are the same in both active submarkets and (ii) customers make zero profits with high-type providers. The high effectiveness of the priority rule in this case allows each customer operating in the mixed market to attract the same queue length of low-type providers and thus offer them the same trading probability as in the low-quality market while also attracting some high types. Competition for high types is so fierce that profits for trades with them (gross of entry costs) are driven all the way down to zero. Moreover, the low-type queue length in the two active markets is exactly the same as the queue length in the low-type market of the pure sorting equilibrium (when $\sigma < \sigma^S$). Hence, it is as if those customers and providers, who in the pure sorting equilibrium are active in the low-quality market, are now split proportionally across the two submarkets and high-type providers are assigned to just one of them.

Given these properties, we can say that, when σ is increased from a value below σ^S to 1, entry is unambiguously reduced, by an amount equal to the mass of customers who in the pure sorting equilibrium are present in the high-quality market. The trading probability of low types does not change. Yet, from Proposition 5 we know that welfare is monotonically increasing in σ across the partial sorting region, hence it is higher for $\sigma = 1$ than for $\sigma \leq \sigma^S$. At the same time, both the level of trade (as measured by the average trading probability of providers) and the average quality of trades are clearly lower at $\sigma = 1$. We can thus argue that the key source of the welfare

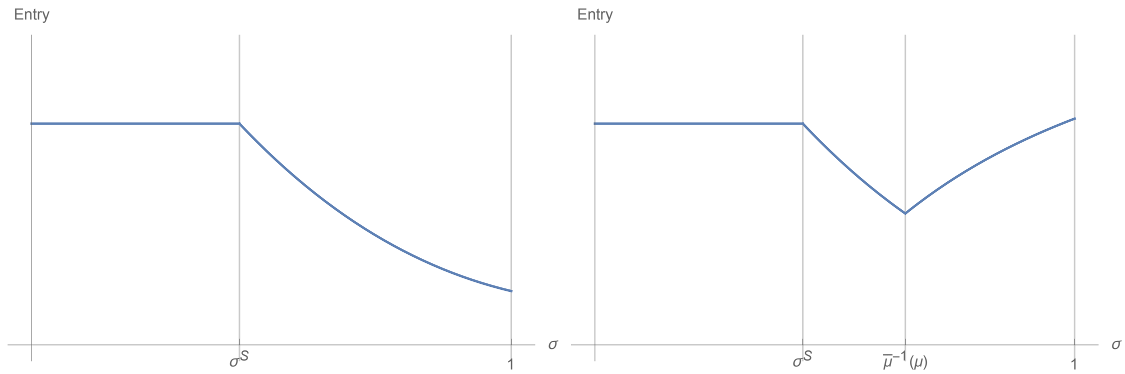

Figure 2: Entry levels for $\overline{v} = 1.2$, $\underline{v} = 1$, $\overline{c} = 0.1$ and $\underline{c} = 0$, $k = 0.1$, with $\mu = 0.7$ (left panel) and $\mu = 0.4$ (right panel).

improvement lies in the reduction of customers' entry in the market, or likewise, that in the pure sorting equilibrium we have 'excessive entry'.

Figure 2 illustrates the effect on entry of improvements in the meeting technology across the parameter regions for a numerical example. The left panel shows the case where $\mu > \overline{\mu}(1)$. For σ sufficiently low, entry is constant because the allocation in the pure sorting equilibrium does not depend on σ. When we enter the region of partial sorting, entry decreases monotonically with σ, as explained above. The right panel illustrates the case $\mu < \overline{\mu}(1)$, where at $\sigma = 1$ the mass of low types in the economy is insufficient to accommodate the demand coming from the mixed market. Under this specification, all three equilibrium types exist as σ is varied from 0 to 1. Entry is now non-monotonic in σ. As before, it is first constant and then decreasing in σ, up to the point where $\mu = \overline{\mu}(\sigma)$. For higher values of σ, the equilibrium is of the pure screening type and entry increases with σ. To gain some intuition, note that the measure of low and high types in the single market remains constant when σ increases beyond the point where $\mu = \overline{\mu}(\sigma)$. As the congestion in the meeting technology becomes lower, the (more profitable) low-cost providers in the market are crowded out by high types less often. The market thus becomes more profitable and attracts a larger number of customers, which then increases competition for both types of providers. This drives up the utility gain attained by high-type providers—as before—as well as that attained by low-type providers, who are no longer in excess supply.

Comparison to the private value case ($\underline{v} = \overline{v}$). As mentioned in the Introduction, Eeckhout and Kircher (2010) and Cai et al. (2022) study the role of the meeting technology in a setting with independent private values. Eeckhout and Kircher (2010) contrast the two extreme cases of bilateral meetings and urn-ball meetings, showing that equilibria feature pure sorting in the first case and pure screening in the second. With private values, the change in the equilibrium outcome from pure sorting to pure screening can be understood by taking into account the constrained efficiency property of the equilibrium. When all customers[14] choose the same trading mechanism, the total number of meetings increases relative to the case where the market is segmented (keeping entry unchanged). At the same time, the absence of crowding out means that all low-cost providers who selected a given customer have priority in trade, while high-cost providers simply serve as an insurance against the event that no low-cost provider is present. Hence, overall trade is higher when compared to the case of segmented markets, as is the average surplus of realized trades, since under private values surplus is higher when trade occurs with low-cost providers. Cai et al. (2022) complete the analysis of this private value environment by characterizing the equilibrium properties for the same rich class of geometric meeting technologies as the ones considered here. Like us, they find that partial sorting may obtain for intermediate values of σ, but the sorting pattern is reversed: the high-cost providers are now the ones who are active in both submarkets. The argument again relies on the constrained efficiency of the equilibrium. For $\sigma < 1$, high-cost providers crowd out low-cost providers when both are present in the same submarket. Still, for σ sufficiently large, attracting some high-cost providers in addition to the low-cost ones proves beneficial, as it provides a hedge to customers when no low-cost provider shows up, while only slightly lowering the probability of trade with low-cost providers, who are given priority in trade.

In markets with adverse selection the equilibrium allocation is not constrained efficient, hence the effects of the properties of the meeting technology on equilibrium outcomes are no longer determined by efficiency considerations, but rather by the forces of competition among customers and the binding incentive constraints. This changes the logic behind partial sorting in our setting. Indeed, attracting some high types in the low-type market, as in the case of private values, would conflict with incentive compatibility. What becomes a profitable deviation instead, when one-to-many meetings are possible with limited crowding out, is to attract some low-

[14] In their setting, the privately informed agents are the buyers, while the principals are the sellers. To facilitate the comparison with the previous analysis, in this discussion we keep referring to principals as customers and to agents with private information as providers.

quality providers on top of high-quality ones. This is to generate the possibility of trading with low-cost providers, while keeping the relatively long queue of the high-cost market. The profitability of the deviation is linked to the equilibrium feature whereby trade with low-quality providers remains more profitable for customers, even though a larger surplus is generated by trade with high-quality ones.

5 Conclusion

This paper studies the question of how recent technological innovations regarding the ability of counterparties to meet affect trading outcomes in decentralized markets with adverse selection. To address the issue, we examine a theoretical framework where uninformed customers offer general trading mechanisms in order to contract a provider for a service. The extent to which a customer in such markets can exploit competition between different providers offering the service depends on the meeting technology, in particular the customer's capacity to meet multiple providers at the same time. We show that when customers have a limited ability to meet multiple providers, in equilibrium markets are perfectly segmented, with low-quality providers searching for low-paying tasks and high-quality providers looking for high-paying tasks. As the meeting capacity increases, an increasing number of low-quality providers, as well as some customers, migrate to the submarket where high-quality providers search, while other customers leave the market altogether. The improvement of the meeting technology thus reduces both the average quality of trades and the total level of trades occurring in the market. Despite the reduction in quality and quantity of equilibrium trades, total welfare increases, as trading losses are overcompensated by the reduction in the number of customers entering the market and the corresponding savings in entry costs.

A Proofs

A.1 Proof of Proposition 1

We start by characterizing the set of tuples $(\underline{x}, \overline{x}, \underline{t}, \bar{t}, \underline{\lambda}, \overline{\lambda})$ that identifies the set of feasible and incentive compatible mechanisms in the original space.

Lemma 6. *For any* $(\underline{x}, \overline{x}, \underline{t}, \overline{t}) \in [0,1]^2 \times \mathbb{R}^2$ *and* $\overline{\lambda}, \underline{\lambda} \in [0, \infty)$*, there exists a feasible and incentive compatible mechanism* m*, such that:*

$$\underline{x}_m(\underline{\lambda}, \overline{\lambda}) = \underline{x}, \quad \overline{x}_m(\underline{\lambda}, \overline{\lambda}) = \overline{x}, \quad \underline{t}_m(\underline{\lambda}, \overline{\lambda}) = \underline{t}, \quad \overline{t}_m(\underline{\lambda}, \overline{\lambda}) = \overline{t},$$

if and only if:

$$\begin{aligned}
\underline{t} - \underline{x}\,\underline{c} &\geq \overline{t} - \overline{x}\,\underline{c}, \\
\overline{t} - \overline{x}\,\overline{c} &\geq \underline{t} - \underline{x}\,\overline{c}, \\
\overline{\lambda}\,\overline{x} &\leq \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}), \\
\underline{\lambda}\,\underline{x} &\leq \phi(\overline{\lambda}, \underline{\lambda} + \overline{\lambda}), \\
\overline{\lambda}\,\overline{x} + \underline{\lambda}\,\underline{x} &\leq \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}).
\end{aligned}$$

Proof. **Only if:** We first show that for any feasible and incentive compatible mechanism m, expected trading probabilities and prices satisfy conditions (9)-(13). Let $\underline{x} = \underline{x}_m(\underline{\lambda}, \overline{\lambda}), \overline{x} = \overline{x}_m(\underline{\lambda}, \overline{\lambda})$ and $\underline{t} = \underline{t}_m(\underline{\lambda}, \overline{\lambda}), \overline{t} = \overline{t}_m(\underline{\lambda}, \overline{\lambda})$. Incentive compatibility of m trivially implies (9) and (10). Feasibility will imply the remaining conditions.

Rather than using the queue lengths $\underline{\lambda}, \overline{\lambda}$, it will be convenient to work with the total queue length $\lambda = \underline{\lambda} + \overline{\lambda}$ and the fraction of low types $\mu = \underline{\lambda}/\lambda$. Let $\underline{X}^n_m(\mu)$ and $\overline{X}^n_m(\mu)$ denote, respectively, the trading probability for low- and high-type providers in a meeting with $n-1$ other providers according to mechanism m. From a provider's perspective there is a probability $Q_n(\lambda)$ of arriving at a customer who meets n providers. Consistency between $P_n(\lambda)$ and $Q_n(\lambda)$ requires $nP_n(\lambda) = \lambda Q_n(\lambda)$ (Eeckhout and Kircher, 2010). We can then write:

$$\underline{x}_m(\mu\lambda, (1-\mu)\lambda) = \sum_{n=1}^{+\infty} Q_n(\lambda)\underline{X}^n_m(\mu), \quad \overline{x}_m(\mu\lambda, (1-\mu)\lambda) = \sum_{n=1}^{+\infty} Q_n(\lambda)\overline{X}^n_m(\mu).$$

The feasibility condition, $\underline{X}_m(L,H)L + \overline{X}_m(L,H)H \leq 1, \forall L, H$, implies the following two inequalities:

$$\underline{X}_m(L,H) \leq 1/L, \quad \overline{X}_m(L,H) \leq 1/H.$$

Using these conditions, we can write:[15]

$$\begin{aligned}
\underline{X}_m^n(\mu) &= \sum_{L=1}^{n} \underline{X}_m(L, n-L)\frac{(n-1)!}{(L-1)!(n-L)!}\mu^{L-1}(1-\mu)^{n-L} \\
&\leq \sum_{L=1}^{n} \frac{1}{L}\frac{(n-1)!}{(L-1)!(n-L)!}\mu^{L-1}(1-\mu)^{n-L} \\
&= \frac{1}{\mu n}\sum_{L=1}^{n} \frac{n!}{L!(n-L)!}\mu^{L}(1-\mu)^{n-L} \\
&= \frac{1}{\mu n}\left(\sum_{L=0}^{n} \frac{n!}{L!(n-L)!}\mu^{L}(1-\mu)^{n-L} - (1-\mu)^n\right) \\
&= \frac{1}{\mu n}(1-(1-\mu)^n).
\end{aligned}$$

The condition $\underline{X}_m^n(\mu) \leq \frac{1}{\mu n}(1-(1-\mu)^n)$ allows us to show that any feasible mechanisms satisfies constraint (11):

$$\begin{aligned}
\mu\lambda \underline{x}_m(\mu\lambda, \lambda) &= \mu\lambda \sum_{1}^{+\infty} Q_1(\lambda)\underline{X}_m^n(\mu) \\
&= \mu\lambda \sum_{n=1}^{+\infty} P_n(\lambda)\frac{n}{\lambda}\underline{X}_m^n(\mu) \\
&\leq \sum_{n=1}^{+\infty} P_n(\lambda)(1-(1-\mu)^n) = \phi(\mu\lambda, \lambda).
\end{aligned}$$

Analogously, we can show $\overline{X}_n(\mu) \leq \frac{1}{(1-\mu)n}(1-\mu^n)$ and, hence, $(1-\mu)\lambda\overline{x}_m(\mu\lambda, \lambda) \leq \phi((1-\mu)\lambda, \lambda)$.

Finally, for each n and μ, the expected probability of trade in a meeting cannot

[15] Note that the number of low and high types in a meeting is distributed binomially (n is the number of trials, L the number of successes).

exceed one, that is, $\mu n\underline{X}_m^n(\mu) + (1-\mu)n\overline{X}_m^n(\mu) \leq 1$. Hence:

$$\begin{aligned}
\mu\lambda\underline{x}(\mu\lambda, \lambda) + (1-\mu)\lambda\overline{x}(\mu\lambda, \lambda) &= \mu\lambda\sum_{n=1}^{+\infty} Q_n(\lambda)\underline{X}_m^n(\mu) + (1-\mu)\lambda\sum_{n=1}^{+\infty} Q_n(\lambda)\overline{X}_m^n(\mu) \\
&= \lambda\sum_{n=1}^{+\infty} Q_n(\lambda)(\mu\underline{X}_m^n(\mu) + (1-\mu)\overline{X}_m^n(\mu)) \\
&\leq \lambda\sum_{n=1}^{+\infty} Q_n(\lambda)/n = \sum_{n=1}^{+\infty} P_n(\lambda) = \phi(\lambda, \lambda)
\end{aligned}$$

If: Let $(\mu\lambda, (1-\mu)\lambda, \underline{x}, \overline{x}, \underline{t}, \overline{t})$ be a vector satisfying (9-13). Let $\alpha, \underline{\tau}, \overline{\tau} \in [0, 1]$ and consider the following mechanism:

$$\begin{aligned}
\underline{X}_m(L, H) &= \underline{\tau}\left(\frac{1}{L + \alpha H}\right), & \underline{T}_m(L, H) &= \underline{t}, \quad L \geq 1, H \geq 0 \\
\overline{X}_m(L, H) &= \overline{\tau}\left(\frac{\alpha}{L + \alpha H}\right), & \overline{T}_m(L, H) &= \overline{t}, \quad L \geq 0, H \geq 1,
\end{aligned}$$

with $\overline{X}_m(0, H) = 1/H$ if $\alpha = 0$. It can be easily verified that this mechanism is feasible and incentive compatible. We start by defining the trading probabilities that obtain when $\underline{\tau} = \overline{\tau} = 1$. For the low-type provider this probability is:

$$\underline{y}(\alpha) \equiv \sum_{n=1}^{+\infty} Q_n(\lambda) \sum_{L=1}^{n} \frac{(n-1)!}{(L-1)!(n-L)!}\mu^{L-1}(1-\mu)^{n-L}\frac{1}{\alpha n + (1-\alpha)L}.$$

Notice that $\underline{y}(\alpha)$ is strictly decreasing in α, with $\underline{y}(0) = \phi(\mu\lambda, \lambda)/(\mu\lambda)$ and $\underline{y}(1) = \phi(\lambda, \lambda)/\lambda$. Analogously, we define for the high-type provider:

$$\overline{y}(\alpha) \equiv \sum_{n=1}^{+\infty} Q_n(\lambda)\left((1-\mu)^{n-1}\frac{1}{n} + \sum_{L=1}^{n-1} \frac{(n-1)!}{L!(n-1-L)!}\mu^L(1-\mu)^{n-1-L}\frac{\alpha}{\alpha n + (1-\alpha)L}\right).$$

The function $\overline{y}(\alpha)$ is strictly increasing on $[0,1]$ with

$$\begin{aligned}
\overline{y}(0) &= \sum_{n=1}^{+\infty} Q_n(\lambda)(1-\mu)^{n-1}\frac{1}{n} \\
&= \frac{1}{(1-\mu)\lambda}\sum_{n=1}^{+\infty} P_n(\lambda)(1-\mu)^n \\
&= \frac{1}{(1-\mu)\lambda}\left(\sum_{n=0}^{+\infty} P_n(\lambda)(1-\mu)^n - P_0(\lambda)\right) \\
&= \frac{1}{(1-\mu)\lambda}(\phi(\lambda,\lambda)-\phi(\underline{\lambda},\lambda)).
\end{aligned}$$

and $\overline{y}(1)=\phi(\lambda,\lambda)/\lambda$. The two functions satisfy the following condition:

$$\begin{aligned}
& \mu\lambda\underline{y}(\alpha)+(1-\mu)\lambda\overline{y}(\alpha) \\
=\ & \lambda\sum_{n=1}^{+\infty}\frac{Q_n(\lambda)}{n}\left(\mu^n+(1-\mu)^n+\sum_{L=1}^{n-1}\frac{n!}{L!(n-L)!}\mu^L(1-\mu)^{n-L}\left(\frac{L}{\alpha n+(1-\alpha)L}+\frac{\alpha(n-L)}{\alpha n+(1-\alpha)L}\right)\right) \\
=\ & \sum_{n=1}^{\infty}P_n(\lambda)\sum_{L=0}^{n}\frac{n!}{L!(n-L)!}\mu^L(1-\mu)^{n-L} \\
=\ & \phi(\lambda,\lambda)
\end{aligned}$$

We now want to show that for every vector $(\mu\lambda,(1-\mu)\lambda,\underline{x},\overline{x},\underline{t},\overline{t})$ satisfying (9-13) we can find values for $\alpha,\underline{\tau},\overline{\tau}$ such that $\underline{x}_m(\mu\lambda,\lambda)=\underline{x},\overline{x}_m(\mu\lambda,\lambda)=\overline{x}$ and $\underline{t}_m(\mu\lambda,\lambda)=\underline{t},\overline{t}_m(\mu\lambda,\lambda)=\overline{t}$. For the transfers this requirement is automatically satisfied, so we just need to show that by choosing $\alpha,\underline{\tau},\overline{\tau}$ appropriately we can generate the trading probabilities $\underline{x},\overline{x}$. Using the functions $\underline{y}(\alpha)$ and $\overline{y}(\alpha)$, we can write the expected trading probabilities of mechanism m as follows:

$$\underline{x}_m(\mu\lambda,\lambda)=\underline{\tau}\,\underline{y}(\alpha),\quad \overline{x}_m(\mu\lambda,\lambda)=\overline{\tau}\,\overline{y}(\alpha).$$

Since we can scale down trading probabilities arbitrarily by using $\underline{\tau},\overline{\tau}\in[0,1]$, it suffices to show that there exists an α such that

$$\underline{y}(\alpha)\geq\underline{x}\quad\text{and}\quad\overline{y}(\alpha)\geq\overline{x}. \tag{16}$$

Condition (11) implies $\underline{x}<\phi(\mu\lambda,\lambda)/(\mu\lambda)$. We distinguish two cases.

- If $\underline{x} \leq \phi(\lambda, \lambda)/\lambda$, let $\alpha = 0$ so that $\underline{y}(\alpha) = \overline{y}(\alpha) = \phi(\lambda, \lambda)/\lambda$. Since $\overline{x} \leq \underline{x}$, both conditions in (16) are satisfied.

- If $\phi(\lambda, \lambda)/\lambda < \underline{x} \leq \phi(\mu\lambda, \lambda)/(\mu\lambda)$, let α be such that $\underline{y}(\alpha) = \underline{x}$. Then:

$$\overline{x} \leq \frac{1}{(1-\mu)\lambda}(\phi(\lambda, \lambda) - \mu\lambda\underline{x}) = \frac{1}{(1-\mu)\lambda}\big(\phi(\lambda, \lambda) - \mu\lambda\underline{y}(\alpha)\big) = \underline{y}(\alpha),$$

  where the first inequality follows from (13) and the last equality follows from the property $\mu\lambda\underline{y}(\alpha) + (1-\mu)\lambda\overline{y}(\alpha) = \phi(\lambda, \lambda)$, as demonstrated above.

Hence, for every vector $(\mu\lambda, (1-\mu)\lambda, \underline{x}, \overline{x}, \underline{t}, \overline{t})$ satisfying (9-13) there exist values of $\alpha, \underline{\tau}, \overline{\tau}$ that generate the desired parameters.

□

Conditions (7) and (8) are analogous to the providers' optimality conditions in Definition 1 for the mechanisms posted in equilibrium and conditions (5) and (6) restricting out of equilibrium beliefs. Given Lemma 6, it is clear that the trading probabilities, transfers and queue length associated to any mechanism posted in equilibrium must satisfy conditions (8-13). To see that they must also solve P^{aux}, suppose they do not and consider a tuple $(\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda})$ that satisifies constraints (8-13) and yields a higher value of $\overline{\lambda}(\overline{x}\,\overline{v} - \overline{t}) + \underline{\lambda}(\underline{x}\,\underline{v}\underline{t})$. Then there exists a feasible and incentive-compatible mechanism m, which given queue lengths $\underline{\lambda}, \overline{\lambda}$ generates $(\underline{x}, \overline{x}, \underline{t}, \overline{t})$, satisfies conditions (5) and (6), and generates a strictly higher expected payoff. Hence, a deviation to mechanism m is profitable, which implies that the trading probabilities, transfers and queue length associated to an equilibrium mechanism must solve P^{aux}.

A.2 Solving P^{aux}: Preliminaries

We will start by deriving some properties of the market utilities that need to be satisfied in equilibrium.

Lemma 7. *At a directed search equilibrium, we have:*

1.) $\underline{U} > \overline{U}$ *and* $\underline{U} - \overline{U} < \overline{c} - \underline{c}$*;*

2.) $\overline{U} > 0$*;*

3.) $\underline{U} < \underline{v} - \underline{c}$ *and* $\overline{U} \leq (\overline{v} - \overline{c})/(\overline{v} - \underline{c})\underline{U}$.

Proof. Let $(\underline{x}, \underline{t})$ and $(\overline{x}, \overline{t})$ be pairs of expected trading probabilities and transfers associated to (possibly different) mechanisms chosen by low- and high-type providers in a given equilibrium. These values must then also be part of a solution of P^{aux}. Market utilities are therefore $\underline{U} = \underline{t} - \underline{x}\,\underline{c}$ and $\overline{U} = \overline{t} - \overline{x}\,\overline{c}$. The following properties must hold:

1a. $\underline{U} > \overline{U}$: the low-type incentive constraint (9) can be rewritten as $\overline{x}(\overline{c} - \underline{c}) \leq \underline{U} - \overline{U}$. Since $\overline{x} \geq 0$, this inequality can only be satisfied if $\underline{U} \geq \overline{U}$. Suppose now that $\underline{U} = \overline{U}$ so that $\overline{x} = 0$. Since, under any solution of P^{aux}, customers must make weakly positive profits with both types of provider,[16] we must have $\overline{t} = 0$ and hence $\underline{U} = \overline{U} = 0$. Given these market utilities, a customer's payoff is strictly increasing in both queue lengths, implying that no finite values of $\underline{\lambda}, \overline{\lambda}$ can solve P^{aux}. Hence, $\underline{U} = \overline{U}$ are not be admissible equilibrium values.

1b. $\underline{U} - \overline{U} < \overline{c} - \underline{c}$: the high type incentive constraint (10) requires $\overline{t} - \overline{x}\,\overline{c} \geq \underline{t} - \underline{x}\overline{c}$, or $\underline{x}(\overline{c} - \underline{c}) \geq \underline{U} - \overline{U}$. Since $\underline{x} \leq \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})/\underline{\lambda} < 1$, the inequality $\underline{x}(\overline{c} - \underline{c}) \geq \underline{U} - \overline{U}$ can only be satisfied if $\underline{U} - \overline{U} < \overline{c} - \underline{c}$.

2. $\overline{U} > 0$: Let $(\underline{\lambda}, \overline{\lambda}, \underline{x}, \overline{x}, \underline{t}, \overline{t})$ describe a mechanism and associated queue lengths posted in equilibrium with $\overline{\lambda}\overline{x} > 0$. To see that such mechanism exists in all equilibria, consider a candidate equilibrium where this is not satisfied and, hence, high types do not trade. A customer could then deviate and offer a mechanism attracting only high types with terms of trade described by $(\overline{x}, \overline{t})$ such that $\overline{t}/\overline{x} = c_H$ and $\overline{x} \leq \underline{U}/(\overline{c} - \underline{c})$. The first equality says that the mechanism yields zero payoff for high types and the second inequality says that the low-type incentive constraint (9) is satisfied. To satisfy the overall feasibility constraint (13), set $\underline{\lambda} = 0$ and $\overline{\lambda}$ such that $\phi(\overline{\lambda}, \overline{\lambda})/\overline{\lambda} = \overline{x}$. Notice that the value of $\overline{\lambda}$ solving this equation strictly decreases in $\overline{x}$ and tends to $+\infty$ as $\overline{x} \to 0$. The customer's payoff associated to this mechanism is given by $\overline{\lambda}(\overline{x}\overline{v} - \overline{t}) = \phi(\overline{\lambda}, \overline{\lambda})(\overline{v} - \overline{c})$. Since $k < \overline{v} - \overline{c}$, we can then choose $\overline{x}$ sufficiently small and hence $\overline{\lambda}$ sufficiently large such that $\phi(\overline{\lambda}, \overline{\lambda})(\overline{v} - \overline{c}) > k$ and the deviation is strictly possible.

   Having shown that there is an equilibrium mechanism, described by $(\underline{\lambda}, \overline{\lambda}, \underline{x}, \overline{x}, \underline{t}, \overline{t})$ with $\overline{\lambda}\overline{x} > 0$, we want to prove $\overline{U} > 0$. Towards a contradiction, assume $\overline{U} = 0$

[16] If customers make losses with one type of provider, they can always set the respective queue length, $\underline{\lambda}$ or $\overline{\lambda}$, equal to zero.

and consider an alternative mechanism $(\underline{\lambda}, \overline{\lambda}', \underline{x}, \overline{x}', \underline{t}, \bar{t})$ with $\overline{\lambda}' > \overline{\lambda}$ and $\overline{x}'$ such that $\overline{\lambda}'\overline{x}' = \overline{\lambda}\overline{x}$ and $\overline{t}' = \overline{x}'\overline{c}$. Due to $\overline{\lambda}'\overline{x}' = \overline{\lambda}\overline{x}$, the customer's payoff associated to this mechanism, $\underline{\lambda}\underline{x}(\underline{v} - \underline{c}) - \underline{\lambda}\underline{U} + \overline{\lambda}'\overline{x}'(\overline{v} - \overline{c})$, is the same as under the original mechanism. Moreover, since $\overline{x}' < \overline{x}$, this mechanism satisfies the low-type incentive compatibility constraint (9) and since

$$\underline{\lambda}\,\underline{x} + \overline{\lambda}'\overline{x}' = \underline{\lambda}\,\underline{x} + \overline{\lambda}\overline{x} \leq \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}) < \phi(\underline{\lambda} + \overline{\lambda}', \underline{\lambda} + \overline{\lambda}')$$

it satisfies the overall feasibility constraint (13) with strict inequality. A increase of $\overline{\lambda}'$ is then feasible for the customer and it strictly increases his expected payoff. The customer thus has a profitable deviation when $\overline{U} = 0$.

3a. $\underline{U} < \underline{v} - \underline{c}$: Suppose not, $\underline{U} \geq \underline{v} - \underline{c}$. Since, as shown in 1b. above, $\underline{x} < 1$ whenever $\underline{\lambda} > 0$, this implies that $\underline{x}(\underline{v} - \underline{c}) - \underline{U} < 0$; that is, a customer's payoff with each low-type provider is strictly negative. As a consequence, at any solution of P^{aux} we have $\underline{\lambda} = 0$. This in turn implies that the low types' market utility $\underline{U}$ must equal zero and therefore $\underline{U} < \underline{v} - \underline{c}$. A contradiction.

3b. $\overline{U} \leq (\overline{v} - \overline{c})/(\overline{v} - \underline{c})\underline{U}$: Suppose not, $\overline{U} > (\overline{v} - \overline{c})/(\overline{v} - \underline{c})\underline{U}$. As argued above, the low-type incentive constraint (9) can be written as $\overline{x} \leq (\underline{U} - \overline{U})/(\overline{c} - \underline{c})$. This implies that the payoff of a customer with each high-type provider is negative:

$$\overline{x}(\overline{v} - \overline{c}) - \overline{U} \leq \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(\overline{v} - \overline{c}) - \overline{U} = \frac{(\overline{v} - \overline{c})\underline{U} - (\overline{v} - \underline{c})\overline{U}}{\overline{c} - \underline{c}} < 0.$$

All solutions of P^{aux} must therefore satisfy $\overline{\lambda} = 0$, which in turn implies $\overline{U} = 0$ and therefore $\overline{U} < (\overline{v} - \overline{c})/(\overline{v} - \underline{c})\underline{U}$. A contradiction.

□

A.3 Proof of Proposition 2

To prove the statement of the proposition, we start by establishing three properties of solutions of P^{aux}.

Lemma 8. *Let Assumption 1 be satisfied. At a solution of P^{aux}, the overall feasibility constraint (13) holds as equality.*

Proof. Suppose not and let $(\underline{\lambda}, \overline{\lambda}, \underline{x}, \overline{x})$ be a solution of P^{aux}. Observe first that (13) can only be satisfied with strict inequality if $\overline{\lambda} > 0$. Given $\overline{\lambda} > 0$, we must have $\overline{x} = \frac{\underline{U}-\overline{U}}{\underline{c}-\overline{c}}$, as otherwise an increase in $\overline{x}$ would be feasible, incentive compatible and profitable. Substituting for $\overline{x}$ and $\underline{\lambda x}$ (the latter determined by (11) holding as equality), the customer's payoff can be written as

$$\hat{\pi}(\underline{\lambda}, \overline{\lambda}) = \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})(\underline{v} - \underline{c}) + \overline{\lambda}\frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(\overline{v} - \overline{c}) - \underline{\lambda U} - \overline{\lambda U},$$

Since the overall feasibility constraint is not binding at a solution of P^{aux}, the pair $(\underline{\lambda}, \overline{\lambda})$ must be a maximizer of the function $\hat{\pi}$. Notice however that

$$\frac{\partial^2 \hat{\pi}}{\partial \overline{\lambda}^2}(\underline{\lambda}, \overline{\lambda}) = \frac{\partial^2 \phi}{\partial \overline{\lambda}^2}(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) > 0,$$

The function $\hat{\pi}(\underline{\lambda}, \overline{\lambda})$ does not have an interior maximimum. This implies that at a solution of $P^{aux\prime}$ the overall feasibility constraint (13) is satisfied with equality. $\square$

Lemma 9 (Auster and Gottardi, 2019)**.** *At any solution of P^{aux}, the low-type feasibility constraint (11) is satisfied with equality.*

Proof. See the proof of Lemma 3.3 in Auster and Gottardi (2019) and replace $1 - e^{-\underline{\lambda}}$ with $\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})$ and $1 - e^{-\underline{\lambda} - \overline{\lambda}}$ with $\phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda})$. $\square$

Lemma 10. *At a solution of P^{aux} with $\overline{\lambda} > 0$, the low-type incentive constraint (9) is satisfied as an equality.*

Proof. To prove the claim we proceed in two steps:

1. Given Lemma 8 and Lemma 9, we can write the customer's payoff as in (14). We start by proving that if the incentive constraint (9) were slack, customers would not find it optimal to attract both types of providers. In particular, we show that the objective function (14) has its unique maximum at $\underline{\lambda} = 0$ and $\overline{\lambda}$ such that

$$\frac{\partial \phi}{\partial \overline{\lambda}}(\overline{\lambda}, \overline{\lambda})(\overline{v} - \overline{c}) = \overline{U}. \tag{17}$$

To prove this claim, suppose, towards a contradiction, there is a local maximum with $\underline{\lambda} > 0$ and consider the pair $(\underline{\lambda} - \varepsilon, \overline{\lambda} + \varepsilon)$ with $\varepsilon \in (0, \underline{\lambda})$. We then have

$$\begin{aligned} & \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})[(\underline{v} - \underline{c}) - (\overline{v} - \overline{c})] + \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda})(\overline{v} - \overline{c}) - \underline{\lambda U} - \overline{\lambda U}, \\ < \ & \phi(\underline{\lambda} - \underline{\lambda}, \underline{\lambda} + \overline{\lambda})[(\underline{v} - \underline{c}) - (\overline{v} - \overline{c})] + \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda})(\overline{v} - \overline{c}) - \underline{\lambda U} - \overline{\lambda U} - \varepsilon(\underline{U} - \overline{U}) \end{aligned}$$

where the inequality follows from the facts that (i) ϕ is decreasing in the first argument, (ii) $\overline{v} - \overline{c} \geq \underline{v} - \underline{c}$ and (iii) $\overline{U} < \underline{U}$. Since the expression of the second line corresponds to the value of the objective function in (14) at $(\underline{\lambda} - \varepsilon, \overline{\lambda} + \varepsilon)$, the pair $(\underline{\lambda}, \overline{\lambda})$ cannot be a local maximizer: by replacing some low types with high types the customer can strictly increase his payoff. Moreover, the maximum of the function in (14), if it exists, is attained at a point with $\underline{\lambda} = 0$. It can be found by solving the one-variable optimization problem

$$\max_{\overline{\lambda}} \phi(\overline{\lambda}, \overline{\lambda})\,(\overline{v} - \overline{c}) - \overline{\lambda}\,\overline{U}. \tag{18}$$

Since $\phi(\overline{\lambda}, \overline{\lambda})$ is concave in $\overline{\lambda}$ this problem has a unique solution, characterized by the first-order condition (17).

2. We are then left to consider the possibility of a separating equilibrium, where some customers attract low types and others attract high types. If incentive constraints are slack, customers attracting low-types make a profit equal to

$$\max_{\underline{\lambda}} \phi(\underline{\lambda}, \underline{\lambda})(\underline{v} - \underline{c}) - \underline{\lambda}\,\underline{U}$$

while those attracting high types make a profit equal to (18). Since $\underline{U} > \overline{U}$ and $\underline{v} - \underline{c} \leq \overline{v} - \overline{c}$, the value of the latter is strictly greater than the value of the former. This means that customers cannot be indifferent between both markets, which then precludes such an equilibrium.

□

Proposition 11. *Let Assumption 1 be satisfied. A directed search equilibrium exists.*

Proof. Consider the following modified (truncated) customer's auxiliary problem as follows. The customer chooses $\underline{\lambda}, \overline{\lambda}$ so as to maximize

$$\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})(\underline{v} - \underline{c}) + [\phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}) - \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})](\overline{v} - \overline{c}) - \underline{\lambda U} - \overline{\lambda U}, \qquad (P^{aux,T})$$

subject to

$$\begin{aligned}
[\phi(\underline{\lambda}+\overline{\lambda},\underline{\lambda}+\overline{\lambda})-\phi(\underline{\lambda},\underline{\lambda}+\overline{\lambda})](\overline{c}-\underline{c}) &\leq \overline{\lambda}(\underline{U}-\overline{U}), \\
\Lambda &\geq \underline{\lambda}\geq 0, \\
\Lambda &\geq \overline{\lambda}\geq 0
\end{aligned}$$

for a given pair of market utilities, $\underline{U},\overline{U}$, and a parameter Λ set at an arbitrarily large positive level. The problem differs from the auxiliary problem (as in the paper) only for the upper bound imposed on $\underline{\lambda},\overline{\lambda}$.

Consider the following domain for market utilities:

$$\mathcal{U}=\left\{\underline{U},\overline{U}:\overline{v}-\overline{c}\geq\underline{U}\geq\overline{U}\geq 0\right\},$$

a convex, compact set.

It is easy to verify that a solution of the above modified auxiliary problem exists for all $\underline{U},\overline{U}\in\mathcal{U}$. Moreover, the solution is described by a map $\left(\underline{\lambda},\overline{\lambda}\right):\mathcal{U}\rightarrow[0,\Lambda]^2$, which is u.h.c. by the Maximum Theorem. The value of the customer's profits at a solution is then described by the map $\pi:\left(\underline{\lambda},\overline{\lambda}\right):\mathcal{U}\rightarrow[0,\overline{v}-\overline{c}]$, a continuous function.

Consider then the convex hull of this map: $co\left(\underline{\lambda},\overline{\lambda}\right)\left(\underline{U},\overline{U}\right)$. This is u.h.c. and convex valued.

Next, we define another map $\left(\underline{U},\overline{U}\right):[0,\Lambda]^2\times[0,\overline{v}-\overline{c}]\rightarrow\mathcal{U}$, that associates to any value of $\underline{\lambda},\overline{\lambda},\pi$ the solution of the following optimization problem:

$$\max_{\underline{U},\overline{U}}\left(\underline{U}-\overline{U}\right)\left(\underline{\lambda}-\mu\left(\underline{\lambda}+\overline{\lambda}\right)\right)+\left(\underline{U}+\overline{U}\right)(\pi-K)$$

It is immediate to verify that the solution of the above problem always exists, hence the map $\left(\underline{U},\overline{U}\right)\left(\underline{\lambda},\overline{\lambda},\pi\right)$ is non empty. Furthermore, it is u.h.c. and convex valued.

Finally, consider the composite map:

$$\left(\underline{U},\overline{U}\right):\mathcal{U}\rightarrow\mathcal{U}$$

defined by $\left(\underline{U},\overline{U}\right)\left(\underline{\lambda},\overline{\lambda},\pi\right)$ for all $\underline{\lambda},\overline{\lambda}\in co(\underline{\lambda},\overline{\lambda})\left(\underline{U},\overline{U}\right)$, $\pi\in\pi\left(\underline{U},\overline{U}\right)$. This map is non empty, u.h.c. and convex-valued, since these properties are satisfied by all composing functions, and its domain $\mathcal{U}$ is a compact, convex set. Hence, by Kakutani's fixed point theorem, a fixed point exists:

$$\begin{aligned} \underline{U}^*, \overline{U}^* &\in \arg\max \left(\underline{U} - \overline{U}\right)\left(\underline{\lambda} - \mu\left(\underline{\lambda} + \overline{\lambda}\right)\right) + \left(\underline{U} + \overline{U}\right)(\pi - K) \\ \text{for } \underline{\lambda}, \overline{\lambda} &\in co(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right), \pi \in \pi\left(\underline{U}^*, \overline{U}^*\right) \end{aligned}$$

It remains to establish that the fixed point pair of market utilities, $\underline{U}^*, \overline{U}^*$, and the associated values of the queue lengths $\underline{\lambda}^*, \overline{\lambda}^* \in co(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right)$, such that

$$\underline{U}^*, \overline{U}^* \in \arg\max \left(\underline{U} - \overline{U}\right)\left(\underline{\lambda}^* - \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right)\right) + \left(\underline{U} + \overline{U}\right)\left(\pi\left(\underline{U}^*, \overline{U}^*\right) - K\right), \quad (19)$$

constitute a directed search equilibrium, that is:

$$\begin{aligned} \underline{\lambda}^* &= \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right) \text{ and } \underline{\lambda}^* + \overline{\lambda}^* > 0 \quad (20) \\ \pi\left(\underline{U}^*, \overline{U}^*\right) &= K \end{aligned}$$

and the upper bound imposed on λ does not bind.

We prove the claim by contradiction, by considering in turn various ways in which the two above are violated:

1. $\underline{\lambda}^* = \overline{\lambda}^* = 0$ and hence $\pi\left(\underline{U}^*, \overline{U}^*\right) = 0$. At these values, the solution of (19) is given by the minimum value of $\underline{U} + \overline{U}$, that is $\underline{U}^* = \overline{U}^* = 0$, but then $(\underline{\lambda}, \overline{\lambda})(0, 0) > 0$, a contradiction. Hence we must have $\underline{\lambda}^* + \overline{\lambda}^* > 0$.

2. $\underline{\lambda}^* \geq \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right)$, $\pi\left(\underline{U}^*, \overline{U}^*\right) \geq K$, with at least one of the two inequalities holding strict. At these values, the solution of (19) is a corner solution, given either by $\underline{U}^* = \overline{v} - \overline{c}, \overline{U}^* = 0$, in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (0, \Lambda)$, acontradiction, or by $\underline{U}^* = \overline{U}^* = \overline{v} - \overline{c}$ in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (0, 0)$, also a contradiction.

3. $\underline{\lambda}^* \leq \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right)$, $\pi\left(\underline{U}^*, \overline{U}^*\right) \leq K$, with at least one of the two inequalities holding strict. At these values, the solution of (19) is a corner solution, given by $\underline{U}^* = \overline{U}^* = 0$, in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (\Lambda, 0)$, a contradiction.

4. $\underline{\lambda}^* > \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right)$, $\pi\left(\underline{U}^*, \overline{U}^*\right) < K$. At these values, the solution of (19) is a corner solution, given either by $\underline{U}^* = \overline{v} - \overline{c}, \overline{U}^* = 0$, in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) =$

$(0,\Lambda)$, a contradiction, or by $\underline{U}^* = \overline{U}^* = 0$, in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (\Lambda, 0)$, and $\pi\left(\underline{U}^*, \overline{U}^*\right) \simeq \underline{v} - \underline{c} > K$, a contradiction.

5. $\underline{\lambda}^* < \mu\left(\underline{\lambda}^* + \overline{\lambda}^*\right)$, $\pi\left(\underline{U}^*, \overline{U}^*\right) > K$. At these values, the solution of (19) is a corner solution, given by $\underline{U}^* = \overline{U}^* = \overline{v} - \overline{c}$ in which case $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (0,0)$, $\pi\left(\underline{U}^*, \overline{U}^*\right) = 0 < K$, also a contradiction.

The above argument shows that, at a fixed point, the equilibrium conditions (20) hold. The last property to be shown, is that $\underline{\lambda}^* < \Lambda, \overline{\lambda}^* < \Lambda$, that is the constraint we imposed does not bind, for Λ sufficiently high, and hence $\underline{\lambda}^*, \overline{\lambda}^*$ are also a solution of the original auxiliary problem, given $\underline{U}^*, \overline{U}^*$, not only of the modified/truncated one.

Notice first that we must have $\underline{U}^* > 0, \overline{U}^* > 0$. If $\underline{U}^* = \overline{U}^* = 0$, as argued above we have $(\underline{\lambda}, \overline{\lambda})\left(\underline{U}^*, \overline{U}^*\right) = (\Lambda, 0)$, in which case (20) cannot hold, thus a contradiction. Suppose next $\underline{U}^* > \overline{U}^* = 0$. In this case $\underline{\lambda} = 0, \overline{\lambda} = \Lambda$ is a feasible choice for the modified auxiliary problem $P^{aux,T}$ and the value of the objective function, when $\underline{\lambda} = 0, \overline{\lambda} = \Lambda$ is larger than K, since it would equal $\overline{v} - \overline{c}$ (a customer would trade with a high-type provider with probability one and extract all the surplus), which is greater than K, thus contradicting the second equilibrium property in (20).

Having established that market utilities are strictly positive, $\underline{U}^* > 0, \overline{U}^* > 0$, observe that:

$$\phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda}) + [\phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}) - \phi(\underline{\lambda}, \underline{\lambda} + \overline{\lambda})] \leq 1$$

Hence the positive component of the payoff of a customer is bounded above by $\overline{v} - \overline{c}$. If the constraint on the queue length binds, the negative component of the customer's payoff is bounded below by $\Lambda\overline{U}^*$. Hence $\pi < \overline{v} - \overline{c} - \Lambda\overline{U}^*$. If the term on the r.h.s. were smaller than K we would have a contradiction. I do not think we can claim this property holds for any given Λ, no matter how large it is. However, we can consider a sequence of values of Λ,going to infinity, and examine the associated sequence of fixed points. We should be able to argue, on the basis of a similar argument as above that the sequence of values of $\underline{U}^*, \overline{U}^*$ at these fixed points, must be bounded away from 0 (if not, by the same argument as in the previous paragraph, as we approach the limit we would violate at least one of the two equilibrium properties). Given this, as we approach the limit, the value of the queue lengths must be strictly smaller than Λ, or we would violate the second property of (20). □

A.4 Proof of Lemma 3

Setting $\lambda = \underline{\lambda} + \overline{\lambda}$, for $\lambda > \underline{\lambda}$ the low-type incentive constraint (15) can be written as

$$\frac{1 + (1-\sigma)\lambda}{(1+\lambda)(1+\sigma\underline{\lambda} + (1-\sigma)\lambda)} = \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}} \tag{21}$$

For $\sigma > 0$, we can solve this condition for $\underline{\lambda}$ and write the low-type queue length as a function of the total queue length

$$\underline{\lambda}(\lambda) = \frac{(1 + (1-\sigma)\lambda)\left(1 - \frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(1+\lambda)\right)}{\sigma(1+\lambda)\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}} \tag{22}$$

The admissibility requirements $\underline{\lambda} \geq 0$ and $\underline{\lambda} \leq \lambda$ impose restrictions on the total queue length λ. When $\underline{\lambda} = 0$, the λ is such that

$$\frac{1}{1+\lambda} = \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}. \tag{23}$$

Let us call the solution of this equality $\overline{l}$. When $\underline{\lambda} = \lambda$, then λ is determined by

$$\frac{1}{1+\lambda}\left(1 - \frac{\sigma\lambda}{1+\lambda}\right) = \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}. \tag{24}$$

Calling the solution of this equality $\underline{l}$, we thus require $\lambda \in [\underline{l}, \overline{l}]$.

Next, we can use (22) to substitute for $\underline{\lambda}$ in the customers' expected payoff (14) and obtain

$$\frac{1}{\sigma}\left(1 - \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(1+\lambda)\right)(\underline{v} - \underline{c}) + \lambda\left(\frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(\overline{v} - \overline{c}) - \overline{U}\right) - \underline{\lambda}(\lambda)\frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(\overline{v} - \underline{c}) \tag{25}$$

with $\underline{\lambda}(\lambda)$ specified by (22). Notice that only the last term in (25) is non-linear in λ. Differentiation of $\underline{\lambda}(\lambda)$ yields

$$\underline{\lambda}'(\lambda) = -\frac{(1-\sigma)(1+\lambda)^2\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}} + \sigma}{\sigma(1+\lambda)^2\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}} < 0$$

and

$$\underline{\lambda}''(\overline{\lambda}) = \frac{2}{(1+\lambda)\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}} > 0$$

The last inequality implies concavity of the customers' expected payoff as written in (25) with respect to λ.

For $\sigma = 0$ the left-hand side of (21) does not depend on $\underline{\lambda}$, as the trading probability in this market only depends on the overall queue length λ. It follows that there is at most one value of $\lambda > \underline{\lambda}$ at which (21) holds. Assuming that such value of λ exists, the only free parameter is $\underline{\lambda}$. Since for a fixed λ, a customer's expected payoff

$$\phi(\underline{\lambda}, \lambda)(\underline{v} - \underline{c}) + (\phi(\lambda, \lambda) - \phi(\underline{\lambda}, \lambda))(\overline{v} - \overline{c}) - \underline{\lambda}\, \underline{U} - (\lambda - \underline{\lambda})\, \overline{U}$$

strictly decreases in $\underline{\lambda}$, the optimal value of $\underline{\lambda}$ is zero. Hence, on the domain $\lambda > \underline{\lambda}$, or equivalently $\overline{\lambda} > 0$, the solution of P^{aux} is unique. □

A.5 Proof of Proposition 4

Separating equilibrium. Consider first the possibility of an equilibrium where high-and low type providers search in two different submarkets. Let us start by describing the term of trade in the low-quality market. Since the high-type incentive constraint is not binding, the queue length in the low-quality market, $\underline{\lambda}_1$, is determined by the first-order condition of P^{aux} with respect to $\underline{\lambda}$ under the restriction $\overline{\lambda} = 0$:

$$\underline{U} = \left(\frac{1}{1+\underline{\lambda}_1}\right)^2 (\underline{v} - \underline{c}). \tag{26}$$

Substituting the market utility back into customer's payoff, the free-entry condition pins down the queue length in the low quality market:

$$\left(\frac{\underline{\lambda}_1}{1+\underline{\lambda}_1}\right)^2 (\underline{v} - \underline{c}) = K \quad \Rightarrow \quad \underline{U} = \left(\sqrt{\underline{v} - \underline{c}} - \sqrt{K}\right)^2 \tag{27}$$

Given $\underline{U}$, the queue length of high types $\overline{\lambda}_2$ and market utility $\overline{U}$ are determined by the low-type incentive constraint

$$\frac{1}{1+\overline{\lambda}_2} = \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}$$

and the customers' free-entry condition

$$\frac{\overline{\lambda}_2}{1+\overline{\lambda}_2}(\overline{v}-\overline{c})-\overline{\lambda}_2\overline{U}=K$$

The separating equilibrium exists, if a customer cannot gain by posting a mechanism that attracts a mix of low- and high-type providers. In the proof of Proposition 3, Section A.4, we derived the bounds for the total queue length λ for which there exists a low-type queue length $\underline{\lambda}$ such that a priority mechanism satisfies the low-type incentive constraint with equality. We showed that the customer's payoff from such mechanism, (25), is differentiable and strictly concave in λ for all λ strictly above the lower bound for λ. At the lower bound, determined by (24), we have $\underline{\lambda}=\lambda$, which means that the associated mechanism attracts no high-type providers and the low-type incentive constraint imposes no restrictions. The customer's payoff as a function of λ has a discontinuity at this point, because the choice of the queue length of low-type providers is unconstrained. Since any optimal mechanism attracting a positive queue of high type providers—on and off path—satisfies the low-type incentive constraint with equality, the payoff function (25) provides an upper bound for the customer's payoff associated to mechanisms that attract both types of the provider.

Given the concavity of (25) and the continuity of (25) at the upper bound for λ where $\underline{\lambda}=0$, attracting both types does not constitute a profitable deviation if the first derivative of (25) at the upper bound for λ, given by $\left(1-\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}\right)/\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}$, determined by (23), is weakly positive. That is:

$$\frac{1}{\sigma}\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}\left((1-\sigma)(\overline{v}-\underline{c})-(\underline{v}-\underline{c})\right)+\left(\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\overline{v}-\overline{c})-\overline{U}\right)+\left(\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}\right)^2(\overline{v}-\underline{c})\geq 0. \tag{28}$$

Notice that the first term on the left-hand side of (28) is strictly decreasing in σ. Moreover, this term is positive for σ small and approaches infinity as $\sigma\to 0$. Hence, the above condition is satisfied for σ sufficiently close to 0; equivalently, there is a threshold $\sigma^S>0$ such that a separating equilibrium exists if and only if $\sigma\leq\sigma^S$.

We also want to prove that the threshold σ^S is strictly smaller than one. To establish this property we show in what follows that for σ sufficiently close to 1 a profitable deviation exists at at the upper bound for λ. To this end, it is useful to establish that market utilities in the candidate separating equilibrium satisfy the inequality

$$\underline{U}(\overline{v}-\overline{c}) > \overline{U}(\overline{v}-\underline{c}). \tag{29}$$

To show this, note first that, given the binding low-type incentive constraint (9), the customers' expected profits in the high-quality market can be written as

$$\overline{\lambda}\left(\underbrace{\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}}_{=\overline{x}}(\overline{v}-\overline{c})-\overline{U}\right).$$

Using the property that in the candidate separating equilibrium these profits are equal to $K > 0$, the following inequality holds:

$$\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\overline{v}-\overline{c})-\overline{U} > 0$$

A simple manipulation of this inequality yields condition (29).

We then need to show that at $\sigma = 1$ inequality (28) is always violated. As argued above, given the concavity of (25), condition (28) is equivalent to the requirement that customers cannot profit by attracting a mix of high- and low-type providers.

Starting from a candidate separating equilibrium, consider then a mechanism that attracts the same low-type queue length as in the low quality market, $\underline{\lambda}_1$, and a queue $\overline{\lambda} > 0$ of high-type providers.[17] Since under $\sigma = 1$ there is no crowding out in the meeting process, this mechanism generates the same payoff with low-type providers as the candidate equilibrium mechanism attracting only low-type providers. Under the alternative mechanism, the trading probability for high-type providers is:

$$\overline{x} = \frac{1}{\overline{\lambda}}\left(\frac{\underline{\lambda}_1+\overline{\lambda}}{1+\underline{\lambda}_1+\overline{\lambda}}-\frac{\underline{\lambda}_1}{1+\underline{\lambda}_1}\right) = \frac{1}{(1+\underline{\lambda}_1+\overline{\lambda})(1+\underline{\lambda}_1)}. \tag{30}$$

Notice that for $\overline{\lambda} > 0$, we have $\overline{x} < 1/(1+\underline{\lambda}_1)^2 = \underline{U}/(\underline{v}-\underline{c})$ (see first-order condition (26)). The payoff which the alternative mechanism generates with high-type providers

[17] This is a different deviation than the one considered in condition (28), but all we need to show is that there is a profitable deviation to *some* mechanism attracting both types. If this is true, then concavity of (25) implies that condition (28) is violated.

is given by:

$$\overline{\lambda}\left(\overline{x}(\overline{v}-\overline{c})-\overline{U}\right) = \overline{\lambda}\left(\frac{1}{(1+\underline{\lambda}_1+\overline{\lambda})(1+\underline{\lambda}_1)}(\overline{v}-\overline{c})-\overline{U}\right) \tag{31}$$

$$= \overline{\lambda}\left(\frac{1+\underline{\lambda}_1}{1+\underline{\lambda}_1+\overline{\lambda}}\frac{\overline{v}-\overline{c}}{\underline{v}-\underline{c}}\underline{U}-\overline{U}\right), \tag{32}$$

where the second equality follows from (26). Since $\underline{U} > \overline{U}$ and $\overline{v}-\overline{c} \geq \underline{v}-\underline{c}$, the term in the bracket is strictly positive for values of $\overline{\lambda}$ belonging to a right neighbourhood of zero. If $\underline{U}/(\underline{v}-\underline{c}) \leq (\underline{U}-\overline{U})/(\overline{c}-\underline{c})$, then the low-type incentive constraint (9) is satisfied for values of $\overline{\lambda}$ sufficiently close to zero (recall $\underline{x} < \underline{U}/(\underline{v}-\underline{c})$). Hence, in this case, for small values of $\overline{\lambda}$ the alternative mechanism is incentive compatible and constitutes a profitable deviation. Consider next the case $\underline{U}/(\underline{v}-\underline{c}) > (\underline{U}-\overline{U})/(\overline{c}-\underline{c})$. Since

$$\frac{1}{(1+\underline{\lambda}_1)^2} = \frac{\underline{U}}{\underline{v}-\underline{c}}, \tag{33}$$

given $\underline{U}/(\underline{v}-\underline{c}) > (\underline{U}-\overline{U})/(\overline{c}-\underline{c})$, we can pick $\overline{\lambda} > 0$ so as to satisfy

$$\frac{1}{(1+\underline{\lambda}_1)(1+\underline{\lambda}_1+\overline{\lambda})} = \frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}. \tag{34}$$

Given this specification of $\overline{\lambda}$, the alternative mechanism satisfies the low-type incentive compatibility constraint and, by (29), generates a strictly positive profit with high-type providers, therefore constituting a profitable deviation when $\sigma = 1$. By continuity the same is true for σ sufficiently close to 1. Having established a profitable deviation exists at $\overline{\lambda} = 0$, this point is not a maximum of (25); given the concavity of this function it follows its derivative at $\overline{\lambda} = 0$ must be negative.

Partial sorting. When $\sigma > \sigma^S$, no pure sorting equilibrium exists. Due to Proposition 11 and Lemma 3, we then know that either a partial sorting or pure screening equilibrium must exist.

In a partial sorting equilibrium, several conditions must be satisfied. First, conditions (26) and (27) pin down the queue length $\underline{\lambda}_1$ and market utility $\underline{U}$ in market 1 (recall $\overline{\lambda}_1 = 0$). Next, the customer's first-order condition of (25), pinning down the optimal total queue length $\lambda_2 = \underline{\lambda}_2 + \overline{\lambda}_2$ must hold:

$$-\frac{1}{\sigma}\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\underline{v}-\underline{c}) + \left(\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\overline{v}-\overline{c}) - \overline{U}\right) - \underline{\lambda}'(\lambda_2)\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\overline{v}-\underline{c}) = 0$$

with $\underline{\lambda}(\lambda_2)$ specified by (22). A simple manipulation of the above equality yields

$$\frac{1}{\sigma}\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}(\overline{v}-\underline{v}) - \underline{U} + \left(\frac{1}{1+\lambda_2}\right)^2(\overline{v}-\underline{c}) = 0. \tag{35}$$

The queue of low types $\underline{\lambda}_2 = \underline{\lambda}(\lambda_2)$ is determined by the low-type incentive constraint

$$\frac{1}{\lambda_2-\underline{\lambda}_2}\left(\frac{\lambda_2}{1+\lambda_2} - \frac{\underline{\lambda}_2}{1+\sigma\underline{\lambda}_2+(1-\sigma)\lambda_2}\right) = \frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}. \tag{36}$$

Finally, the customers' free-entry condition must hold

$$\frac{\underline{\lambda}_2}{1+\sigma\underline{\lambda}_2+(1-\sigma)\lambda_2}(\underline{v}-\underline{c}) + \left(\frac{\lambda_2}{1+\lambda_2} - \frac{\underline{\lambda}_2}{1+\sigma\underline{\lambda}_2+(1-\sigma)\lambda_2}\right)(\overline{v}-\overline{c}) - \underline{\lambda}_2\underline{U} - (\lambda-\underline{\lambda}_2)\overline{U} = K. \tag{37}$$

Whenever there is a solution $(\underline{\lambda}_2, \lambda_2, \overline{U})$ of conditions (35-37) with $\underline{\lambda}_2/\lambda_2 < \mu$, we can find two measures β_1, β_2 of customers entering markets 1 and 2 and a measure of low types $l_1 < \mu$ entering market 1 such that $l_1/\beta_1 = \underline{\lambda}_1$, $(1-l_1)/\beta_2 = \underline{\lambda}_2$, $(1-l_1+1-\mu)/\beta_2 = \lambda_2$. This establishes that if for some σ a partial sorting equilibrium exists for some μ, it also exists for higher values of μ. In the last part of the proof, we show that, assuming $\sigma > \sigma^S$, the equilibrium exists if μ is sufficiently close to one.

Pure screening. Assume $\sigma > \sigma^S$ and consider the possibility of a pure screening equilibrium ($\underline{\lambda}_1 = \overline{\lambda}_1 = 0$). Consistency with the population parameters requires that the fraction of low types in market 2 is μ, hence $\underline{\lambda}_2 = \mu\lambda_2$. The remaining parameters of the candidate pure screening equilibrium, $\lambda_2, \underline{U}, \overline{U}$, are then determined by the customers' first-order condition (35), by the low-type incentive constraint (36) and by the free-entry condition (37), as for the partial sorting equilibrium.

A pure screening equilibrium exists if customers have no incentives to deviate to the best mechanism that only attracts low types. Hence, K must be weakly larger than the payoff a customer can obtain when attracting only low types:

$$K \geq \max_{\lambda} \left(\frac{\lambda}{1+\lambda}(\underline{v} - \underline{c}) - \lambda \underline{U} \right), \tag{38}$$

or equivalently

$$K \geq \left(\sqrt{\underline{v} - \underline{c}} - \sqrt{\underline{U}} \right)^2.$$

Notice that as $\mu \to 1$, a customer's payoff in market 2 (the only active market in the pure screening equilibrium) converges to $\lambda_2/(1+\lambda_2)(\underline{v} - \underline{c}) - \lambda_2 \underline{U}$. In order for (38) not to be violated, λ_2 must converge to the maximizer of the right-hand side of (38). Hence, as $\mu \to 1$, $1/(1+\lambda_2)^2 \to \underline{U}/(\underline{v} - \underline{c})$. However, this implies that the right-hand side of (35) tends to

$$\frac{1}{\sigma} \frac{\underline{U} - \overline{U}}{\overline{c} - \underline{c}}(\overline{v} - \underline{v}) + \left(\frac{\overline{v} - \underline{c}}{\underline{v} - \underline{c}} - 1 \right) \underline{U},$$

which is strictly positive. Hence, when $\mu \to 1$, there is no solution to the system of equations characterising the candidate equilibrium with pure screening. Note the above argument holds for all σ for which a separating equilibrium does not exists. This in turn implies that for every $\sigma > \sigma^S$, there exists a threshold $\overline{\mu}(\sigma)$ such that for all $\mu > \overline{\mu}(\sigma)$ there is an equilibrium with partial sorting. □

A.6 Proof of Proposition 5

Assume $\sigma > \sigma^S$ and $\mu > \overline{\mu}(\sigma)$ and consider the partial sorting equilibrium, which we have shown exists under these conditions. In this equilibrium, the low-type market utility is determined by (26) and thus independent of σ. Hence, a marginal increase in σ leads to no change in $\underline{U}$.

Consider next the high-type market utility $\overline{U}$ and let $\mathrm{d}\sigma > 0$. Further, let the low-type incentive constraint (36) be called (IC) and the customer's free-entry condition (37) be called (FE). These two conditions, together with the first-order condition (35), determine the market utility $\overline{U}$, the total queue length in the mixed market λ_2, and the queue length of high types in the mixed market $\overline{\lambda}_2$. We will show that $\overline{U}$ is monotonically increasing in σ by differentiating (IC) and (FE), and using (35). The total derivative of (IC) is:

$$\frac{\partial (IC)}{\partial \lambda_2} d\lambda_2 + \frac{\partial (IC)}{\partial \overline{\lambda}_2} d\overline{\lambda}_2 + \frac{\partial (IC)}{\partial \overline{U}} d\overline{U} + \frac{\partial (IC)}{\partial \sigma} d\sigma = 0.$$

Solving for $d\lambda_2$ and substituting in

$$\frac{\partial(FE)}{\partial\lambda_2}d\lambda_2 + \frac{\partial(FE)}{\partial\overline{\lambda}_2}d\overline{\lambda}_2 + \frac{\partial(FE)}{\partial\overline{U}}d\overline{U} + \frac{\partial(FE)}{\partial\sigma}d\sigma = 0,$$

we obtain

$$\begin{aligned} 0 \;=\; & \left(\frac{\partial(FE)}{\partial\overline{U}} - \frac{\partial(FE)}{\partial\lambda_2}\frac{\partial(IC)/\partial\overline{U}}{\partial(IC)/\partial\lambda_2}\right)d\overline{U} + \left(\frac{\partial(FE)}{\partial\sigma} - \frac{\partial(FE)}{\partial\lambda_2}\frac{\partial(IC)/\partial\sigma}{\partial(IC)/\partial\lambda_2}\right)d\sigma \\ & + \left(\frac{\partial(FE)}{\partial\overline{\lambda}_2} - \frac{\partial(FE)}{\partial\lambda_2}\frac{\partial(IC)/\partial\overline{\lambda}_2}{\partial(IC)/\partial\lambda_2}\right)d\overline{\lambda}_2. \end{aligned} \tag{39}$$

The first-order condition (35) can be rewritten as

$$\frac{\partial(FE)}{\partial\lambda_2} + \frac{\partial(FE)}{\partial\overline{\lambda}_2}\left(-\frac{\partial(IC)/\partial\lambda_2}{\partial(IC)/\partial\overline{\lambda}_2}\right) = 0 \tag{40}$$

so the last term in (39) is zero. Notice further that $\partial(IC)/\partial\overline{\lambda}_2 > 0, \partial(IC)/\partial\lambda_2 < 0$ and

$$\frac{\partial(FE)}{\partial\overline{\lambda}_2} = -\underbrace{\frac{\phi(\lambda_2 - \overline{\lambda}_2, \lambda_2)}{\partial\overline{\lambda}_2}}_{<0}[(\overline{v} - \overline{c}) - (\underline{v} - \underline{c})] + (\underline{U} - \overline{U}) > 0.$$

Condition (40) thus implies $\partial(FE)/\partial\lambda_2 < 0$. With regard to the term multiplying $d\overline{U}$ in (39), we observe

$$\underbrace{\frac{\partial(FE)}{\partial\overline{U}}}_{(-)} - \underbrace{\frac{\partial(FE)}{\partial\lambda_2}}_{(-)}\underbrace{\frac{\overbrace{\partial(IC)/\partial\overline{U}}^{(+)}}{\partial(IC)/\partial\lambda_2}}_{(-)} < 0.$$

Next, we consider the term in (39) multiplying $d\sigma$ and show

$$\underbrace{\frac{\partial(FE)}{\partial\sigma}}_{(-)} - \underbrace{\frac{\partial(FE)}{\partial\lambda_2}}_{(-)}\underbrace{\frac{\overbrace{\partial(IC)/\partial\sigma}^{(-)}}{\partial(IC)/\partial\lambda_2}}_{(-)} > 0.$$

To prove this we rewrite the latter inequality as

$$\begin{aligned} \frac{\partial(FE)/\partial\sigma}{\partial(FE)/\partial\lambda_2} &< \frac{\partial(IC)/\partial\sigma}{\partial(IC)/\partial\lambda_2} \\ \frac{-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\sigma}[(\overline{v}-\overline{c})-(\underline{v}-\underline{c})]}{\frac{\partial\phi(\lambda_2,\lambda_2)}{\partial\lambda_2}(\overline{v}-\overline{c})-\underline{U}-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\lambda_2}[(\overline{v}-\overline{c})-(\underline{v}-\underline{c})]} &< \frac{-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\sigma}}{\frac{\partial\phi(\lambda_2,\lambda_2)}{\partial\lambda_2}-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\lambda_2}} \end{aligned}$$

which in turn can be written as

$$\begin{aligned} &\frac{\partial\phi(\lambda_2,\lambda_2)}{\partial\lambda_2}(\overline{v}-\overline{c})-\underline{U}-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\lambda_2}[(\overline{v}-\overline{c})-(\underline{v}-\underline{c})] \\ < \; &\left(\frac{\partial\phi(\lambda_2,\lambda_2)}{\partial\lambda_2}-\frac{\partial\phi(\lambda_2-\overline{\lambda}_2,\lambda_2)}{\partial\lambda_2}\right)[(\overline{v}-\overline{c})-(\underline{v}-\underline{c})] \\ \Leftrightarrow \; &\frac{\partial\phi(\lambda_2,\lambda_2)}{\partial\lambda_2}(\underline{v}-\underline{c})<\underline{U} \end{aligned}$$

Given $\partial\phi(\lambda_1,\lambda_1)/\partial\lambda_1(\underline{v}-\underline{c})=\underline{U}$, concavity of $\phi(\lambda,\lambda)=\lambda/(1+\lambda)$ implies that the latter inequality is satisfied as long as $\lambda_1<\lambda_2$. In this case, (39) has the form $(-)d\overline{U}+(+)d\sigma=0$, which then implies $d\overline{U}>0$.

To complete the argument, we thus need to show that the property $\lambda_1<\lambda_2$ is satisfied in the partial sorting equilibrium. We start by showing that in order not to have a profitable deviation, λ_1 must satisfy

$$\frac{1}{1+\lambda_1}\left(1-\frac{\sigma\lambda_1}{1+\lambda_1}\right)\geq\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}. \tag{41}$$

To see this, suppose that this inequality is violated and let $\varepsilon>0$. Consider an alternative mechanism, described by $(\underline{\lambda},\overline{\lambda},\underline{x},\overline{x},\underline{t},\overline{t})$, with $\underline{\lambda}=\lambda_1-\varepsilon,\overline{\lambda}=\varepsilon$, $\underline{x},\overline{x}$ determined by the priority rule (11) and overall feasibility condition (13) holding as equality, and transfers determined by the participation constraints. The difference in a customer's expected payoff between the alternative mechanism and the one in market 1 is

$$\left(\frac{\lambda_1}{1+\lambda_1}-\frac{\lambda_1-\varepsilon}{1+\lambda_1-\varepsilon}\right)[(\overline{v}-\overline{c})-(\underline{v}-\underline{c})]+\varepsilon(\underline{U}-\overline{U})>0.$$

The mechanism thus yields a higher payoff than the one attracting only low types. It satisfies the low-type incentive constraint (9) if

$$\overline{x} = \frac{1+(1-\sigma)(\underline{\lambda}+\overline{\lambda})}{(1+(\underline{\lambda}+\overline{\lambda}))(1+\sigma\underline{\lambda}+(1-\sigma)(\underline{\lambda}+\overline{\lambda}))} \quad (42)$$

$$= \frac{1+(1-\sigma)\lambda_1}{(1+\lambda_1)(1+\sigma(\lambda_1-\varepsilon)+(1-\sigma)\lambda_1)} \quad (43)$$

$$= \frac{1}{1+\lambda_1}\left(1-\frac{\sigma(\lambda_1-\varepsilon)}{1+\sigma(\lambda_1-\varepsilon)+(1-\sigma)\lambda_1}\right) \quad (44)$$

$$\leq \frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}. \quad (45)$$

If (41) is violated, then for $\varepsilon > 0$ sufficiently small, the above inequality is satisfied and a profitable deviation exists. Hence, condition (41) must be satisfied in a partial sorting equilibrium. Notice that in a partial sorting equilibrium, λ_2 belongs to the interval $(\underline{l}, \overline{l})$, where the bounds $\underline{l}$ and $\overline{l}$ are, respectively, defined by (24) and (23). By definition of the lower bound $\underline{l}$ and (41), we have:

$$\frac{1}{1+\lambda_1}\left(1-\frac{\sigma\lambda_1}{1+\lambda_1}\right) \geq \underbrace{\frac{1}{1+\underline{l}}\left(1-\frac{\sigma\underline{l}}{1+\underline{l}}\right)}_{=\frac{\underline{U}-\overline{U}}{\overline{c}-\underline{c}}} \quad (46)$$

As can be verified, the term $\frac{1}{1+\lambda}\left(1-\frac{\sigma\lambda}{1+\lambda}\right)$ is strictly decreasing λ.[18] Hence, inequality (46) implies $\lambda_1 \leq \underline{l} < \lambda_2$. From $\lambda_1 < \lambda_2$, it then follows $\mathrm{d}\overline{U} > 0$.

Since in a partial sorting equilibrium, $\underline{U}$ is constant in σ and $\overline{U}$ is strictly increasing in σ, it follows that an increase in σ constitutes a pareto improvement. The fact that $\underline{U}$ is constant and $\overline{U}$ is increasing in σ also implies that a high type's trading probability, $\overline{x} = (\underline{U}-\overline{U})/(\overline{c}-\underline{c})$, is decreasing in σ (see (36)). □

A.7 The Case $\sigma = 1$

Proposition 12. *Assume $\sigma = 1$, $\phi(\underline{\lambda}, \underline{\lambda}+\overline{\lambda}) = \frac{\underline{\lambda}}{1+\underline{\lambda}}$. A pure screening equilibrium exists and is unique if and only if*

$$\mu \leq \underbrace{\frac{\sqrt{K(\underline{v}-\underline{c})}}{\overline{v}-\underline{v}+\sqrt{K(\underline{v}-\underline{c})}}}_{=\overline{\mu}(1)}. \quad (47)$$

[18] The first derivative of $\frac{1}{1+\lambda}\left(1-\frac{\sigma\lambda}{1+\lambda}\right)$ with respect to λ is given by $-\frac{1+\sigma+(1-\sigma)\lambda}{1+\lambda} < 0$.

If (47) is violated, there exists a partial sorting equilibrium satisfying the following properties:

- *low-type queue lengths are the same in both active submarkets;*
- *customers make zero profits with high-type providers.*

Proof. With $\sigma = 1$, we have $\phi(\underline{\lambda}, \lambda) = 1/(1+\underline{\lambda})$. Notice that the proof of Lemma 9 continues to apply, so at any solution of P^{aux} the low-type feasibility constraint (11) binds. However, since Assumption 1 is not satisfied, the feasibility constraint (13) does not necessarily hold as an equality at a solution of P^{aux}. Nevertheless, we can show that for any mechanism that does not satisfy the overall feasibility constraint (13), there is an alternative mechanism that yields the same expected payoff for the customer and satisfies (13). To see this, consider a mechanism $(\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda})$ such that

$$\underline{\lambda}\,\underline{x} + \overline{\lambda}\,\overline{x} < \phi(\underline{\lambda} + \overline{\lambda}, \underline{\lambda} + \overline{\lambda}).$$

For a customer this mechanism generates a payoff equal to

$$\underline{\lambda}(\underline{x}(\underline{v} - \underline{c}) - \underline{U}) + \overline{\lambda}(\overline{x}(\overline{v} - \overline{c}) - \overline{U}).$$

If $\overline{x}(\overline{v} - \overline{c}) - \overline{U} > 0$, then a marginal increase in $\overline{\lambda}$ is feasible and strictly improves the customer's payoff (since the low-type feasibility (11) is binding, the high-type feasibility constraint (12) is slack). If $\overline{x}(\overline{v} - \overline{c}) - \overline{U} = 0$, then the customer is indifferent between the mechanism $(\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda})$ and a mechanism $(\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda}')$, where $\overline{\lambda}'$ is such that the overall feasibility constraint (13) is satisfied with equality.

Following this argument, we can consider a modified problem where customers are restricted to post mechanisms that satisfy the overall feasibility constraint (13) (no rationing). For this case our existence proof (Proposition 11) applies. Moreover, since for each mechanism that features rationing, there is another one that does not and generates a weakly higher payoff, this implies that also in the original environment, there is an equilibrium where customers only post mechanisms that satisfy the overall feasibility constraint (13). For this equilibrium all arguments in the proofs of Lemma 3 and Proposition 4 apply. Hence, in the equilibrium where customer post mechanisms that satisfy the overall feasibility constraint (13), there are at most two active submarket, one that attracts only low types and one that attracts also the high type.

To characterize these and other equilibria, we distinguish the cases according to whether or not customers can make positive profits with high-type providers. Incentive compatibility for low-type providers implies that the maximal incentive compatible trading probability for high-type providers is $x^{max} = (\underline{U} - \overline{U})/(\overline{c} - \underline{c})$. When $x^{max}(\overline{v} - \overline{c}) - \overline{U} = 0$, any incentive compatible mechanism yields a weakly negative profit with high types. In terms of market utilities this condition can be written as $\overline{U}(\overline{v} - \underline{c}) = \underline{U}(\overline{v} - \overline{c})$.

We start by considering the case where customers cannot make positive profits with high-type providers: $\overline{U}(\overline{v} - \underline{c}) = \underline{U}(\overline{v} - \overline{c})$. An optimal mechanism then satisfies $\overline{\lambda} = 0$ or $\overline{x} = \overline{x}^{max}$ or both. Since profits with high types are zero, any equilibrium mechanism must maximize the payoff with low-type providers and thus solve the problem:

$$\max_{\underline{\lambda}} \quad \frac{\underline{\lambda}}{1+\underline{\lambda}}(\underline{v} - \underline{c}) - \underline{\lambda}\,\underline{U}$$

The optimal low-type queue length satisfies the first-order condition:

$$\frac{1}{(1+\underline{\lambda})^2}(\underline{v} - \underline{c}) = \underline{U}.$$

Together with the free-entry condition, $\underline{\lambda}/(1+\underline{\lambda})(\underline{v} - \underline{c}) - \underline{\lambda}\underline{U} = K$, we can solve for the market utility

$$\underline{U} = (\sqrt{\underline{v} - \underline{c}} - \sqrt{K})^2,$$

and the optimal queue length of low-type providers

$$\underline{\lambda}^* = \frac{\sqrt{K}}{\sqrt{\underline{v} - \underline{c}} - \sqrt{K}}.$$

The market utility for high-type providers is then determined by our initial condition $\overline{U}(\overline{v} - \underline{c}) = \underline{U}(\overline{v} - \overline{c})$ and given by:

$$\overline{U} = \frac{\overline{v} - \overline{c}}{\overline{v} - \underline{c}}(\sqrt{\underline{v} - \underline{c}} - \sqrt{K})^2.$$

The overall feasibility constraint (13) can be written as

$$\overline{x} \leq \frac{1}{\lambda - \underline{\lambda}^*}\left(\frac{\lambda}{1+\lambda} - \frac{\underline{\lambda}^*}{1+\underline{\lambda}^*}\right) = \frac{1}{(1+\underline{\lambda}^*)(1+\lambda)}.$$

For mechanisms with $\lambda > \underline{\lambda}^*$, we have $\overline{x} = \overline{x}^{max} = (\underline{U} - \overline{U})/(\overline{c} - \underline{c})$, so the previous inequality can be written as:

$$\frac{1}{1+\lambda} \geq \frac{\underline{v} - \underline{c} - \sqrt{K(\underline{v} - \underline{c})}}{\overline{v} - \underline{c}}. \tag{48}$$

Consistency with the population parameters then requires that there is at least one market with

$$\underline{\lambda}^*/\lambda \leq \mu.$$

This inequality is compatible with (48) if and only if

$$\mu \geq \frac{\sqrt{K(\underline{v} - \underline{c})}}{\overline{v} - \underline{v} + \sqrt{K(\underline{v} - \underline{c})}}. \tag{49}$$

We now show that if (49) is satisfied with strict inequality, there exists a partial sorting equilibrium in which customers post mechanisms that satisfy the overall feasibility constraint (13). The pair of queue lengths in the first market is $(\underline{\lambda}^*, 0)$ and in the second market is $(\underline{\lambda}^*, \lambda - \underline{\lambda}^*)$, where λ solves (48) with equality. Since (49) is satisfied as a strict inequality, the fraction of low types in the second market $\mu_2 \equiv \underline{\lambda}^*/\lambda$ is strictly smaller than the population ratio μ. Hence, we can find two values, β_1 and β_2, that describe the measures of customers visiting, respectively, the first and second submarket, such that

$$\frac{\beta_1}{\beta_1+\beta_2} \cdot 1 + \frac{\beta_2}{\beta_1+\beta_2}\mu_2 \;=\; \mu, \tag{50}$$

$$\frac{\beta_2}{\beta_1+\beta_2}(1-\mu_2) \;=\; 1-\mu. \tag{51}$$

Note that if condition (49) holds as an equality, this system of equalities is solved by $\beta_1 = 0$, hence the first submarket is inactive (pure screening).

If instead condition (49) holds as a strict inequality, we can construct additional, payoff-equivalent equilibria where customers post mechanisms that satisfy the overall feasibility constraint as a strict inequality and thus feature rationing. In particular, there is an equilibrium where all customers post the same mechanism so that all providers visit a single submarket. In this case, consistency with the population parameters requires that the fraction of low-type providers in the single market is equal to the population ratio μ, hence the overall queue length λ satisfies $\underline{\lambda}^*/\underline{\lambda} = \mu$. Given that there is a unit measure of providers in the economy, the measure of customers entering the market is simply $1/\lambda$. Provided condition (49) holds as a strict inequality, the overall feasibility condition (48) is then satisfied as a strict inequality. Hence, high types are rationed in meeting where no low-type providers are present.

Evidently, in this case we can construct other equilibria with a set of M markets, each attracting a measure β of customers, such that

$$\frac{1}{\beta(M)} \int_m \frac{\underline{\lambda}^*(m)}{\lambda(m)} \mathrm{d}\beta(m) = \mu.$$

If condition (49) is not satisfied, there must exist an equilibrium where customers post mechanisms that satisfy the overall feasibility constraint (13) and make strictly positive profits with high-type providers. Market utilities thus satisfy $\overline{U}(\overline{v} - \underline{c}) > \underline{U}(\overline{v} - \overline{c})$. It is in fact easy to see that customers never find it optimal to post a mechanism that features rationing when they can make positive profits with high-type providers: any mechanism, $(\underline{x}, \overline{x}, \underline{t}, \overline{t}, \underline{\lambda}, \overline{\lambda})$, that satisfies the overall feasibility constrain (13) as a strict inequality can be improved upon by either increasing $\overline{\lambda}$ if $\overline{x} = \overline{x}^{max}$ or $\overline{x}$ if $\overline{x} < \overline{x}^{max}$ or both. Such change does not affect the payoff that is generated with the low types but strictly increases a customer's payoff with the high type.

Having observed that any optimal mechanism satisfies the overall feasibility constraint (13), it can be proven that there is no solution of P^{aux} with $\overline{\lambda} = 0$. For any mechanism that attracts only the low type, there is an alternative mechanism that attracts the same queue length of low-type providers and a positive queue of high-type providers, which generates the same expected profit with the low type and a strictly positive profit with the high type, as we show in the proof of Proposition 4, Section A.5, conditions (30-34). Hence, given $\overline{U}(\overline{v} - \underline{c}) > \underline{U}(\overline{v} - \overline{c})$, there is no solution of P^{aux} with $\overline{\lambda} = 0$. Moreover, since the solution of P^{aux} is unique on the domain with $\overline{\lambda} > 0$, it follows that any equilibrium where customers make strictly positive profits with high-type providers is of the 'pure screening' type: all customers and provider trade in a single submarket according to a mechanism that features no rationing.

□

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