Labour Pooling, Labour Poaching, and Spatial Clustering

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ABSTRACT: When firms cluster in the same local labour market, they face a trade-off between the benefits of labour pooling (i.e., access to workers whose knowledge help reduce costs) and the costs of labour poaching (i.e., loss of some key workers to competition and a higher wage bill to retain the others). We explore this tradeoff in a duopoly game. Depending on market size, on the degree of horizontal differentiation between goods, and on worker heterogeneity in terms of knowledge transmission cost, we characterise the strategic choices of firms regarding locations, wages, poaching and prices. Our results show that co-location, although it is always efficient, is not in general the non-cooperative equilibrium outcome.

Key words: labour pooling, labour poaching, firm clustering, agglomeration.
JEL classification: J60, L13, R32.

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"Breakaways of workers - especially the very able workers - from existing organizations promote the development of new work as well as the creation of new organizations. But breakaways are not good for the parent company; they undermine its efficiency. To the company or companies in control, one of the advantages of a company town is that breakaways are not feasible there. And in any settlement where breakaways are inhibited, by whatever means, the development rate must drop, although the efficiency of already well-established work is apt to climb." (Jacobs, 1969, p.97).

1. Introduction

Why do firms cluster in some locations instead of spreading evenly over space? In his pioneering discussion of the question, Alfred Marshall (1890) argued that firms cluster to economise on the transport of goods, people and ideas. These three motives for economic agglomeration are also known as: availability of intermediate/final goods, labour market pooling, and technological spill-overs, respectively.

Following Abdel-Rahman and Fujita (1990) in urban economics and Krugman (1991) in regional economics, much of the recent work has focused on the first of the above arguments. If shipping manufactured goods is costly, firms prefer to locate where the market for final goods is larger to save on transport costs. This leads to a larger labour market, which in turn enlarges the market for final goods. In Abdel-Rahman and Fujita (1990), this agglomeration force is limited by the scarcity of urban land. In Krugman's (1991) benchmark, the same agglomeration force is limited by the cost of serving the immobile demand located in peripheral markets. This type of model has received a lot of attention in the recent past and we shall not discuss it further (see Ottaviano and Puga, 1998, and Duranton and Puga, 2000, for surveys).

Turning to labour market pooling, the existing literature is much thinner. It overwhelmingly views labour market pooling as a strong motive for economic agglomeration. The argument runs as follows. A larger pool of workers in an area makes it easier for firms to find workers with the characteristics they need. Conversely in a larger labour market, workers are more likely to find a job suited to their skills. In short, labour pooling improves the matching between firms and workers. Helsley and Strange (1990) offer an elegant and sophisticated version of this argument.

Finally, localised technological spill-overs are a popular motive for agglomeration. However, the argument is not as straightforward as it may seem. If knowledge can flow freely out of the firms, it must be explained why the effects of spill-overs are localised. Fujita and Ogawa (1982) propose a model with an information externality subject to distance decay, which aims to capture the frictions associated with the spatial propagation of information. Nonetheless it remains unclear what these spatial frictions precisely are. The second criticism of the spill-over argument is that spill-overs "leave no paper trail by which they may be measured and tracked" (Krugman, 1991, p. 53). Consequently, nothing prevents the theorists from assuming whatever they like. Although subsequent empirical research showed that spill-overs actually leave some paper trails through patent citations for instance and decrease with distance (Jaffe, Trajtenberg, and Henderson, 1993), the amount of evidence on localised spill-overs to date is still very thin.

In this paper we wish to revisit these last two agglomeration motives. We start with the premise that distance acts as a barrier for workers' job mobility. Put differently, the propensity of workers to change jobs in the same local labour market is greater than their propensity to move between local labour markets. The basic thrust of our argument is then to assume that workers have access to crucial knowledge about their own firms, be it about products, production methods, marketing or management. If we also (realistically) assume that this type of knowledge cannot all be patented and that exclusive labour contracts are not available, the clustering of firms on the same local labour market (i.e., labour market pooling) can lead to labour market poaching and the local diffusion of knowledge. Since knowledge is partly embodied in workers, flows of workers can be equated with flows of knowledge so that poaching workers is a way for firms to raise their productivity.[1] In turn, these spill-overs have a knock-on effect on product market competition between firms. Therefore, when choosing to locate close to their competitors, firms face a tradeoff between the benefits of labour market pooling and the costs of labour market poaching.

The benefits of pooling rest with the opportunities for a firm to hire workers whose knowledge was gained in other firms. Such knowledge can be profitably adapted internally. The costs of poaching are twofold. First, competitors can have access to the firm's own knowledge by poaching from its workforce. This makes them more competitive on the product market. Second, and alternatively, the firm can reduce poaching by raising the wage of its strategic workers but this comes at the cost of a higher wage bill. This is exactly what Jacobs (1969) refers to in the sentence we quote above.

To explore this trade-off more precisely and to show how and when *the labour market at the local level can act as a conduit for spill-overs*, we propose a three-stage game between duopolistic firms producing differentiated goods. First, firms need to choose a location and set-up their production facility. Workers involved with a firm at this stage have access to some of its specific knowledge. We refer to them as 'strategic workers'. When firms co-locate, they can poach each other's strategic workers. The knowledge of poached workers can then be transferred to their new employer at a cost. To limit the extent of poaching by competition, firms can raise the wage of their own strategic workers. More precisely, in the second stage of the game firms choose strategically and simultaneously the number of workers they want to poach and retain as well as their wages subject to the behaviour of the other firm. In the last stage, the final output is produced and price competition takes place.

Depending on market size, the degree of horizontal differentiation between goods, and the cost of transferring knowledge across firms, we characterise the strategic choices of firms regarding locations, wages, poaching and prices for our duopoly game. Our results show that co-location is not in general the equilibrium outcome, although it is always efficient. In particular, firms tend to locate separately when the conditions of perfect competition are approached. As product market rivalry intensifies, the incentives to retain workers become stronger. This leads firms to raise the wage of their strategic workers while poaching decreases. This implies a higher cost of co-location

[1] According to Arrow (1962, p. 615) "No amount of legal protection can make a thoroughly appropriable commodity of something as intangible as information" and then he adds that "mobility of personnel among firms provides a way of spreading information".

because of higher wages. This also implies lower benefits from co-location because of smaller flows of workers and knowledge across firms. When the costs of poaching are higher than the benefits from pooling, firms locate separately. Thus, despite the advantages of labour market pooling, *firms may choose strategically to locate in different local labour markets to avoid labour market poaching*.[2] Hence, the labour pooling argument for agglomeration is not as straightforward as envisioned in the previous literature. Furthermore, the source of spill-overs we propose here does not suffer from the two weaknesses of previous literature that we highlighted above. First, the propensity of workers to change jobs mostly in the same local labour market naturally justifies the localised aspect of spill-overs. Thus there is no need to assume an ad-hoc decay function. Second, our source of spill-overs may be fairly attractive from an empirical point of view because the movement of workers between firms usually leaves some paper trail. Finally, our model implies that *labour market pooling and spill-overs can no longer be viewed as distinct motives for agglomeration* since technological spill-overs may percolate through the labour market.

This paper is related to the labour literature on workers' flows across firms. A first strand, following Rosen (1972), views occupational mobility as the result of optimal investment decisions made by workers over their life-cycle. In a competitive labour market, where different jobs tying together work and learning are available, younger workers optimally choose jobs that offer low wages but fast acquisition of general human capital. When reaching maturity, these workers recoup their investment by switching to occupations with fewer learning opportunities. In this type of model, more experienced workers get a higher wage because they have acquired more general human capital making them more productive. Recent developments in this strand of research include Jovanovic and Nyarko (1995) and Franco and Filson (2000). The former propose micro-economic foundations for a theory of the diffusion of knowledge between managers and employees, whereas the latter are concerned by the break-aways of employees to create their own firm in a competitive environment.

Pakes and Nitzan (1983) propose an alternative two-period framework where a scientist needs to match with an entrepreneur to develop a project. At the end of the first period, the information about the project is disclosed to both parties. Pakes and Nitzan (1983) show that it is never profitable for the *unique* scientist to part from the entrepreneur and create a rival firm since the sum of the rents for a duopoly is lower than that of a monopoly — a joint-profit effect. The fundamental difference between this second type of model and the human capital approach is that more experienced workers get a higher wage, not because of higher productivity, but because defecting to a competitor could harm their employer.

In its simplest version, the Pakes and Nitzan (1983) approach predicts that scientists should never leave their firm to create their own spin-off or work for a competitor. This is obviously counterfactual (see below). This result is reversed when the joint-profit in case of separation of the

[2]There are examples of firms relocating some of their strategic facilities (R&D centres, trial production plants, etc) away from famous specialised clusters. For instance, according to Jackson (1997, p. 138) Intel in the 1980s started to limit its workforce in Silicon Valley: "Nothing was more frustrating than spending months helping an operator to learn how to work a sensitive and unpredictable piece of machinery, only to see that same operator take a job down the street at National or Fairchild for a dollar more per hour.[...] Each time it built a new fab outside the Valley, [Intel] could feed off a fresh labour pool, with fewer competitors to lure its best people away".

scientist from the incumbent firm is higher than under integration. This can happen first when sufficiently many (symmetric) firms compete on the market. In such a case, receiving a full share of profits in a market with $m + 1$ firms is better than receiving half the profit of a firm in a market with m firms (Pakes and Nitzan, 1983). Break-aways can also take place when the spin-off exploits the new innovation in a completely different market (Pakes and Nitzan, 1983; Fosfuri, Motta, and Rønde, 2001). Break-aways are also possible when there is some ex-post uncertainty. Fosfuri and Rønde (2002) consider an incumbent monopoly attempting to develop the next generation of a product. The departure of the key scientist is socially beneficial because it makes it possible for either the incumbent monopoly or the new spin-off to generate the next generation of the product. If a large ex-post asymmetry between firms is sufficiently likely, it is not worthwhile for the monopoly to retain its scientist and consequently spin-offs can occur in equilibrium.

Notwithstanding the spatial focus, we differ from these two threads of literature in two key dimensions.[3] First, unlike Rosen (1972) and his followers, we consider a restricted number of firms who behave strategically rather than a competitive environment. In this respect, a key focus of our model regards the links between the intensity of competition on the product market and competition on the labour market. Unlike Pakes and Nitzan (1983) and their followers, we consider a continuum of workers and two firms instead of a reciprocal monopoly since we believe that in many industries firms have more than one key worker. This is a fundamental difference because in our case the results are not driven by a joint-profit argument. It also goes without saying that considering a continuum yields more meaningful comparative statics results, which are essential for empirical work. The other major difference with the previous literature is that we consider a model of reciprocal poaching instead of a situation with an incumbent and an entrant. Our framework is better suited to the analysis of the interactions between existing firms. The latter have the advantage of being empirically easier to observe than potential entrants.

Last, our model also contributes to the large literature on strategic investments (see Tirole, 1988, chapter 8, for a survey). Labour poaching is a form of strategic investment that allows a firm to lower its marginal cost before product market competition takes place. In our case, the unit cost of this investment is endogenous and strategically determined.

The rest of the paper is as follows. In the next section, we discuss the empirical relevance of our main assumptions. In Section 3, we present a game in which firms compete both for each other's workers and on the product market. In Section 4, the game is solved for the prices, poaching, and wages decisions. We explore the location decision of firms and the welfare in Section 5. The last section contains some concluding remarks.

2. Workers Flows and Knowledge Flows

Before presenting the details of our model we wish to empirically substantiate its two main components. Our first stylised fact is that workers often move between firms and that these flows are mostly local. Direct evidence about this can be obtained from French employment data.

[3]There is also a literature on local labour markets, which views movements of workers across firms as a (beneficial) adjustment mechanisms when firms face idiosyncratic shocks (Krugman, 1991; Gerlach, Rønde, and Stahl, 2001; Stahl and Walz, 2001). This literature is not concerned with the transfer of knowledge across firms.

The data, extracted from the 1996 and 1997 Déclarations Annuelles de Données Sociales (DADS) database of the Institut National de la Statistique et des Etudes Economiques (INSEE), contains the employment area, the occupation and the sector of all French employees that were born in October in even years. Continental France is fully covered by 341 employment areas, whose boundaries are defined on the basis of daily commuting patterns.[4] The firms are classified by sector according to level 36 of the Nomenclature d'Activités Française of INSEE. Occupations are classified according to level 37 of the Catégories Socio-Professionelles of INSEE. We selected six of them: Scientists, Executives (commercial and administration), Engineers, Technical Personnel, Foremen, Specialised manufacturing workers. These six groups, we believe, are those whose mobility across firms is most likely to be associated with transfers of knowledge.

We first computed the intra-occupation turnover rate, that is, for each occupation, the fraction of workers who changed employer between end 1996 and end 1997.[5] Next, conditional on workers having changed employer, we computed the fraction of workers in each occupation that remained in the same sector and employment area, the fraction that remained in the same employment area but changed sector, the fraction that experienced the reverse, and the fraction that changed both employment area and sector. The results are summarised in Table 1.

Table 1. Mobility of highly skilled workers in France (1996 − 1997)

	Scientists	Executives	Engineers	Technicians	Foremen	Skilled	All
Intra-occupation turnover	9.6	10.1	11.7	8.7	8.2	9.9	9.8
Same area, same sector	43.4	39.2	46.9	42.7	48.7	43.1	43.4
Same area, different sector	16.2	32.7	28.9	33.0	25.7	32.3	30.4
Different area, same sector	30.3	13.0	9.6	8.7	12.8	8.9	11.4
Different area, different sector	10.1	15.1	14.7	15.6	12.8	15.7	14.8

Figures in percentage. Authors' own calculations from INSEE data.

Among French workers who remain in the same occupation, around one in ten changes employer every year. Regarding sectoral and geographical mobility, the results are remarkably similar across occupations (except for scientists who are slightly more mobile geographically). Around 45% of workers that change jobs remain in the same employment area and in the same sector. Another 30% remain in the same area but in a different sector. In other words, when they change employer, around 75% of skilled French workers remain in the same employment area. The levels of geographical mobility implied by these figures are low given that the average French employment area is equivalent to a circle of radius 23 km.

The French case is not exceptional. At a slightly higher level of aggregation and for all workers, the literature on internal migrations systematically reports low gross inter-regional flows (see

[4]Since within Greater Paris (Ile-de-France) changes of job do not usually involve workers changing residence and that commuting across employment areas is easy, we decided to lump together the 26 employment areas forming Greater Paris.

[5]Given the focus of our model, we only consider the population of workers who have been employed in the same occupation over two consecutive years. This is likely to yield lower turnover rates than those in the literature, which are typically computed relative to the population in the labour force at large. See Davis and Haltiwanger (1998) for the US and Burda and Wyplosz (1994) for Europe. Note also that our two snapshots ignore workers changing employer more than once.

Greenwood, 1997, for a survey). Gross inter-regional flows of less than 2% a year seem to be the norm in Europe.

Our second major assumption is that workers flows are also knowledge flows. Many case-studies strongly support the idea that workers, when they change employers, come with knowledge about their former employer and that this knowledge can be profitably used by their new employer. Saxenian (1994) made a convincing case that the incessant turnover of skilled labour between firms in the Silicon Valley was closely linked to the area's success.[6] In this paper we would like to discuss briefly another highly revealing cluster, the British Motor Valley, which has been recently investigated by Pinch and Henry (1999) and Henry and Pinch (2000 and 2001).

The British motor sport industry clusters heavily in the Thames Valley around London where it directly employs over 50,000 workers, most of them highly skilled. It is by far the leading motor sport industry at the world level. It produces sport cars in the upper end of the segment: touring cars, racing cars, Formula One cars, and even Indy cars, although all Indy car races take place in the US. In these markets, the dominance of the British Motor Valley is nearly absolute. If one breaks down the making of a Formula One into four main parts (design, base, chassis and engine), 9 teams out of 14 had three or four of these parts made in the British Motor Valley in 1997. Only one team had no presence at all.

As Pinch and Henry (1999) describe, the history of Formula One is full of radical innovations that spread throughout the sport. The diffusion is often rapid because it is difficult to keep these innovations secret for long. One reason for the rapid diffusion of ideas is the fact that the drivers, designers and engineers move from team to team, taking with them considerable knowledge of how things are done in rival teams. They observe that: "When such personnel move, they take with them crucial information about how things are done in other teams. Indeed, some teams, somewhat cynically, employ people on short term contracts to extract what they know of other teams" (p. $823-824$).

Elsewhere, Henry and Pinch, (2000 p. 195) note that: "One of the most important ways in which knowledge is spread within the motor sport industry is by the rapid and continual transfer of staff between the companies within the industry. [...] The career histories of 100 leading designer/engineers within the industry [...] revealed a move, on average, once every 3.7 years and an average total of eight moves in a career in the industry. Similarly, a study of advertisements for technical posts in Formula One between 1996 and 1997 revealed vacancies for 93 posts, more than 10% of this formula's total employment at that time." They also claim that: "As personnel move, they bring with them knowledge and ideas about how things are done in other firms helping to raise the knowledge throughout the industry. [...] The crucial point is that whilst this process may not change the pecking order within the industry, this 'churning' of personnel raises the knowledge base of the industry as a whole within the region" (p. 198). Using interviews, they show that this continual churning of staff is widely recognised in the industry to be enormously beneficial for the industry as a whole as well as for the individuals concerned if not always by teams loosing key

[6] See also Angel (1989) and Almeida and Kogut (1999) for related arguments.

workers.[7]

Because of the difficulties associated with measuring these phenomena, hard evidence regarding these issues is scarce (Møen, 2000, provides a first step in this direction). Nonetheless, we believe that these case-studies are representative of a wider trend where workers flows generate flows of knowledge across firms.

3. The Model

Consider a partial equilibrium model with two differentiated goods, each produced by a different firm. These goods are sold in a common and perfectly integrated market. We also assume different locations, each constituting a separate local labour market. These labour markets are completely segmented with workers being immobile between them. In each labour market, there is an infinite supply of labour at a wage w.

The two firms play a three-stage game.

Stage* 1 - *Location

Each firm chooses a location where to produce its good. There is no co-ordination failure at this stage. When both firms want to co-locate, they end up in the same local labour market. If one firm does not want to co-locate, they end up in separate locations. After their location decision, firms must hire an exogenous quantity Λ of workers. These workers are referred to as 'strategic workers'. Hiring these workers is necessary for the firms to set-up their production facilities. When setting up production facilities, these workers acquire part of the internal knowledge of their firm. Put differently, strategic and non-strategic workers do not differ in their productive abilities; the only difference between them is that strategic workers possess some of the knowledge of their firm following their involvement in its set-up.

We assume that firms cannot charge their strategic workers for accessing their knowledge.[8] This knowledge cannot be patented either. Finally, exclusive long-term labour contracts are not available.

This stage can be thought of as the history of the firms. When it ends, firms are ready to operate in their location. They are also 'loaded' with strategic workers who had access to their specific knowledge.

[7] See also *En Route F1* (November 1999, p. 44): "On the technical side, a driver who has decided to leave will be stopped from doing any private testing. Indeed, teams will wait until the end of the season before testing anything new that is to appear on the car the following year. There is no question of the driver who is leaving knowing the least details of how anything works."

[8] Allowing firms to charge strategic workers would just impact on the outcome of Stage 1 by neutralising effects on wages at this stage only. By a straightforward backward induction argument, the other effects would remain the same. We believe that it is more realistic to proceed as we do. Our assumption can be readily justified by a financial constraint or a minimum wage argument.

Stage 2 - Wage and poaching strategy

Depending on whether firms decided to co-locate at stage 1, two cases must be distinguished. When both firms are in the same location, they can simultaneously poach on each other's strategic labour by offering wages higher than those proposed by the other firm. A firm can next use the knowledge of these poached workers to reduce its own costs. For simplicity, there is no direct cost for a firm when it loses strategic workers.[9] On the other hand, we assume that transferring the knowledge of poached strategic workers is costly. This cost of transferring knowledge $t(\theta)$ depends on the worker's type θ where θ is distributed with a density $f(\theta)$ over $\left[0,\overline{\theta}\right]$. It may be interpreted as an idiosyncratic mobility cost incurred by poached workers when moving from one firm to the other.[10] Finally, we also assume that this cost is observed by both firms so that they can discriminate between workers.

Without loss of generality, we assume that workers are ranked according to their cost of mobility. Although it would be possible to derive some of our results with general functions $t(.)$ and $f(.)$, to keep the mathematics simple and concentrate on the economic intuitions we choose to work with a uniform density of workers, $f(\theta) = 1/\overline{\theta}$ and a linear function for the cost of transferring knowledge $t(\theta) = \gamma\theta$.

More formally, these assumptions imply that firm i can hire firm j's strategic worker of type θ provided it offers this worker a wage net of moving costs $w + \omega_i^P(\theta) - \gamma\theta$ higher than the one promised by the other firm, $w + \omega_j^R(\theta)$. This implies that to poach a worker of type θ, firm i must offer $\omega_i^P(\theta) \geq \omega_j^R(\theta) + \gamma\theta$. $\omega_i^P(\theta)$ and $\omega_i^R(\theta)$ are the gross premia over the market wage that poached and retained workers (respectively) get thanks to the knowledge they have. Conversely, the promise of a high future wage, $w + \omega_i^R(\theta) > w + \omega_j^P(\theta) - \gamma\theta$, is the only way firm i can protect itself from poaching when it co-locates with firm j. In what follows we refer to these premia chosen by the firms as the strategic wages. Although the offers made by firms are credible, note that wages are effectively paid at the production stage (stage 3) only.[11]

In summary, when firms co-locate they bid for each of their own strategic workers and each of the strategic workers of the other firm simultaneously. The choice of employer made by workers depends on the bids of both firms and their idiosyncratic cost of changing employer.[12]

When firms are not in the same location, poaching is impossible because labour is assumed to be immobile across locations.

[9]Having such a cost would only reinforce our results.

[10]If we assume that moving costs are symmetrically distributed around $\overline{\theta}/2$, we can interpret this last quantity as a measure of the (average) specificity to the firm of the human capita of workers. Then industries in which human capital is highly firm-specific correspond to industries with a high $\overline{\theta}/2$.

[11]Most of the real world mechanisms used by firms to keep their workforce use delayed payments (stock option, seniority system, etc). The alternative is to write restrictive labour contracts preventing defection to competitors. Such 'restrictive covenants' must however be reasonable in the eyes of the law. Furthermore courts in most countries are protective of employees freedom to continue to sell their services after finishing employment in the face of an ex-employer seeking to restrict that liberty.

[12]In the working paper version of this article (Combes and Duranton, 2001), we considered a different timing where firms would first offer a wage to their own strategic workers before poaching workers from the other firm at the following period. This sequence of events yields richer results. However the basic intuitions developed here carry through in this more complex setting.

Stage 3 *- Price competition*

At the final stage of the game, each firm hires its non-strategic labour, l_i, and price competition in the common market takes place between the two firms.

Specifications chosen

Let us now present the remaining details of the model. The utility function of the representative consumer is quasi-linear and quadratic:

$$U\left(q_i,q_j,M\right) = (1+\alpha)\left(q_i+q_j\right) - \beta q_i q_j - \frac{1}{2}\left(q_i^2+q_j^2\right) + M, \tag{1}$$

where q_i is the consumption of the good produced by firm i, M is an unspecified homogeneous good that is used as numéraire, $\alpha > 0$, and $0 \leqslant \beta < 1$. Maximising the utility function in equation (1), subject to the budget constraint $M + p_i q_i + p_j q_j \leqslant R$ for a large enough income, R, leads to the following linear demand functions for the good produced by firm i:

$$q_i = \frac{1+\alpha}{1+\beta} + \frac{\beta}{1+\beta} p_j - \frac{1}{1+\beta^2} p_i. \tag{2}$$

The parameter α can be interpreted as reflecting market size, whereas β is an inverse-index for the degree of differentiation between the two goods. In the particular case where $\beta = 0$, firms are in a monopoly position on their respective markets, whereas the limit case $\beta = 1$ is equivalent to Bertrand competition with homogenous goods. The concavity of the utility function guarantees that the demand derived in equation (2) defines a maximum.

Turning to production, we assume a constant labour requirement per unit:

$$L_i = c_i q_i, \tag{3}$$

where c_i is the unit labour requirement and L_i is firm i's total employment. In turn, total employment in firm i is the sum of its poached workers, λ_i^P, its retained strategic workers, λ_i^R, and its non strategic workers, l_i:

$$L_i = l_i + \lambda_i^P + \lambda_i^R. \tag{4}$$

The knowledge of poached workers can be used to reduce the firm's unit labour requirement, which decreases linearly with the number of poached workers:

$$c_i = \bar{c} - a\lambda_i^P, \tag{5}$$

with $\bar{c}$ the initial level of marginal cost and a an index of knowledge transferability. For consistency we assume $\bar{c} \geq a\Lambda$, so that firms always face positive unit labour requirements even if they poach all the strategic workforce of the other firm. For demand to be positive when the price is equal to marginal cost, we also impose $\bar{c}w \leq (\alpha+1)$.

The general resolution of the model implies that the proportions of poached workers, the profits when the two firms co-locate relative to when the firms locate separately, as well as the relative prices and strategic wages, are function only of β, $\frac{\gamma\bar{\theta}}{(aw\Lambda)^2}$, and $\frac{1+\alpha-\bar{c}w}{aw\Lambda}$. Consequently, without loss of generality, we can to normalise $\Lambda, a, \bar{c}$, w, and γ to unity.[13] Thus, the rest of the analysis considers only three parameters: α reflecting market size, β the inverse degree of differentiation between final goods, and $\overline{\theta}$ worker's heterogeneity. After these normalisations, firm i's profit can be written as:

$$\pi_i = p_i q_i - \left(l_i + \lambda_i^P + \lambda_i^R\right) - C^P\left(\lambda_i^P\right) - C^R\left(\lambda_i^R\right). \tag{6}$$

In this expression, the first term is the total revenue, the second is the direct labour cost of production, $C^P\left(\lambda_i^P\right)$ is the cost of poaching strategic workers to the other firm, and $C^R\left(\lambda_i^R\right)$ is the cost of retaining own strategic workers. Note that we take the number of firms as given so that the set-up cost is normalised to 0. The study of the entry game and that of the extension to many firms, which is discussed in conclusion, is beyond the scope of this paper. The cost of poaching workers is equal to:

$$C^P\left(\lambda_i^P\right) = \int_{\Theta_i^P} \omega_i^P(\theta) f(\theta) d\theta = \int_{\Theta_i^P} \omega_i^P(\theta) \frac{d\theta}{\overline{\theta}}, \tag{7}$$

where Θ_i^P is the set of workers poached by firm i. The cost of retaining workers is equal to:

$$C^R\left(\lambda_i^R\right) = \int_{\Theta_i^R} \omega_i^R(\theta) f(\theta) d\theta = \int_{\Theta_i^R} \omega_i^R(\theta) \frac{d\theta}{\overline{\theta}}, \tag{8}$$

where Θ_i^R is the set of workers retained by firm i. Of course, feasibility implies that the sum of the workers retained by a firm and those poached from it should be inferior to its initial number of strategic workers: $\lambda_i^P + \lambda_j^R \leq 1$ and $\lambda_j^P + \lambda_i^R \leq 1$.

4. Prices, Poaching, and Wages under Co-location

We now move to the resolution of the game.

Stage* 3 - *Price competition

Firm i maximises its profit with respect to its price, subject to demand and feasibility constraints. At this stage, it takes as given the pricing behaviour of the other firm, the number of poached workers, the unit labour requirements, and the strategic wages. Using (3), (4), and (6), its program is thus:

$$\underset{p_i}{Max}\left\{p_i q_i - c_i q_i - C^P\left(\lambda_i^P\right) - C^R\left(\lambda_i^R\right)\right\}, \tag{9}$$

with q_i given by (2).

After simplification, the first-order condition of program (9) implies:

$$p_i = \frac{1-\beta}{2-\beta}(1+\beta) + \frac{2c_i + \beta c_j}{4-\beta^2}. \tag{10}$$

[13] The derivation of this result is omitted here. Intuitions are the following. The normalisations of the number of strategic workers and initial costs are just choices of units for inputs and outputs. The normalisation of a amounts to normalising minimum marginal costs to zero. Together with the normalisation of the wage, this amounts to re-scaling both firms' profits and consumer's utility. Finally, the mobility cost γ is obviously redundant with the measure of the support of the distribution of types, $\overline{\theta}$.

It can be easily checked from the second-order conditions that this defines a sub-game perfect Nash-equilibrium in stage 3. Besides, the quantity produced is given by

$$q_i = \frac{1+\alpha}{1+\beta}(1+\alpha) + \frac{\beta c_j - \left(2-\beta^2\right) c_i}{\left(4-\beta^2\right)\left(1-\beta^2\right)}. \tag{11}$$

Using equations (5), (10), and (11), we can compute the profit at the sub-game equilibrium:

$$\pi_i = \Pi_i\left(\lambda_i^P, \lambda_j^P\right) - C^P\left(\lambda_i^P\right) - C^R\left(\lambda_i^R\right), \tag{12}$$

with

$$\Pi_i\left(\lambda_i^P, \lambda_j^P\right) = \frac{\left[(1-\beta)(2+\beta)\left(\alpha+\lambda_i^P\right) + \beta\left(\lambda_i^P - \lambda_j^P\right)\right]^2}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}. \tag{13}$$

Stage* 2 *- Wages and poaching strategy

Let us first study under which conditions firm i decides to poach or retain a worker of type θ. Poaching a worker of type θ from firm j increases firm i's net revenue by $\frac{\partial \Pi_i}{\partial \lambda_i^P}$ at a cost $\omega_i^P(\theta)$. Thus, due to the workers' cost of mobility, the maximum *net* strategic wage that firm i may offer to poach worker θ is $\widehat{\omega}_i^P - \theta$ where

$$\widehat{\omega}_i^P = \frac{\partial \Pi_i}{\partial \lambda_i^P} = \frac{2\left(2-\beta^2\right)\left[(1-\beta)(2+\beta)\left(\alpha+\lambda_i^P\right) + \beta\left(\lambda_i^P - \lambda_j^P\right)\right]}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}. \tag{14}$$

Conversely, retaining strategic worker θ (otherwise poached by firm j) increases firm i's net revenue by $-\frac{\partial \Pi_i}{\partial \lambda_j^P}$ at a cost of $\omega_i^R(\theta)$. Hence, the maximum *net* strategic wage that firm i may offer to retain worker θ is $\widehat{\omega}_i^R$ given by:

$$\widehat{\omega}_i^R = -\frac{\partial \Pi_i}{\partial \lambda_j^P} = \frac{2\beta\left[(1-\beta)(2+\beta)\left(\alpha+\lambda_i^P\right) + \beta\left(\lambda_i^P - \lambda_j^P\right)\right]}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}. \tag{15}$$

From (14) and (15), note that the *gross* incentive to poach workers, $\frac{\partial \Pi_i}{\partial \lambda_i^P}$ is larger than the *gross* incentive to retain workers, $-\frac{\partial \Pi_i}{\partial \lambda_i^R}$. This is because the goods produced by firms i and j are imperfect substitutes. Hence the direct effect on profit of a marginal own cost reduction is larger than the indirect effect of a marginal cost increase for the other firm. If we also take into account the fact that it is costly for workers to change firms, from (14) and (15), there is a unique positive threshold $\widehat{\theta}_i$ such that the *net* incentives to poach and retain a worker of this type are equal:

$$\widehat{\omega}_i^P - \widehat{\theta}_i = \widehat{\omega}_i^R. \tag{16}$$

From (16), we can see that the *net* incentive for firm i to poach a worker of type θ below $\widehat{\theta}_i$ is stronger than the *net* incentive to retain one of its own workers ($\widehat{\omega}_i^P - \theta > \widehat{\omega}_i^R$). Conversely, the *net* incentive for firm i to poach a workers of type θ above $\widehat{\theta}_i$ is weaker than the incentive to retain one of its own workers ($\widehat{\omega}_i^P - \theta > \widehat{\omega}_i^R$). If we also consider that firm i's profit is decreasing in $\omega_i^P(\theta)$ and in $\omega_i^R(\theta)$, it is clear that a dominant strategy in wages for firm i is to offer:

$$\omega_i^P(\theta) = \min\left\{\widehat{\omega}_i^P, \omega_j^R + \theta\right\} \tag{17}$$

and

$$\omega_i^R(\theta) = \min\left\{\widehat{\omega}_i^R, \omega_j^P - \theta\right\}. \tag{18}$$

For the sake for simplicity, we limit our analysis to the characterisation of symmetric equilibria in pure strategy. Assume temporarily that $\widehat{\theta}_i (= \widehat{\theta}_j \equiv \widehat{\theta})$ is interior to $[0,\overline{\theta}]$. Using equations (14)-(18), our candidate symmetric equilibrium is then characterised by:

$$\widehat{\omega}^P = \frac{(2-\beta)^2}{\beta}\widehat{\omega}^R = \frac{2\alpha(2-\beta^2)\overline{\theta}}{(2+\beta)\left[\overline{\theta}(1+\beta)(2-\beta)^2 - 2(1-\beta)\right]} \tag{19}$$

and

$$\lambda^P = 1 - \lambda^R = \frac{\widehat{\theta}}{\overline{\theta}} = \frac{2\alpha(1-\beta)}{\overline{\theta}(1+\beta)(2-\beta)^2 - 2(1-\beta)}. \tag{20}$$

This candidate symmetric equilibrium is such that all strategic workers whose type is below $\widehat{\theta}$ as defined in equation (20) are poached whereas all workers whose type is above $\widehat{\theta}$ are retained. The *net* strategic wage of poached workers is equal to $\widehat{\omega}^R$ as given in equation (19). The net wage of retained worker of type θ is $\widehat{\omega}^P - \theta$, where $\widehat{\omega}^P$ is given in equation (19).

To characterise completely the symmetric equilibria, two kinds of conditions have to be checked. First, it must be the case that no deviation from this candidate should be profitable. Second, the values defined by equation (20) must be interior, otherwise corner equilibria may be obtained.

Using equations (7) and (8), the cost of poaching strategic workers may be re-written as:

$$C^P\left(\lambda_i^P\right) = \int_0^{\widehat{\theta}_i}\left(\widehat{\omega}^R + \theta\right)\frac{d\theta}{\overline{\theta}} = \int_0^{\lambda_i^P}\left(\widehat{\omega}^R + \overline{\theta}\lambda\right)d\lambda = \widehat{\omega}^R\lambda_i^P + \frac{\overline{\theta}}{2}\left(\lambda_i^P\right)^2. \tag{21}$$

Similarly the cost of retaining strategic workers is:

$$C^R\left(\lambda_i^R\right) = \int_{\widehat{\theta}_i}^{\overline{\theta}}\left(\widehat{\omega}^P - \theta\right)\frac{d\theta}{\overline{\theta}} = \int_{1-\lambda_i^R}^{1}\left(\widehat{\omega}^P - \overline{\theta}\lambda\right)d\lambda = \widehat{\omega}^P\lambda_i^R - \frac{\overline{\theta}}{2}\left[2\lambda_i^R - \left(\lambda_i^R\right)^2\right]. \tag{22}$$

Now, to prove that no deviation from the candidate equilibrium characterised by equations (19) and (20) would be profitable, one may check that the sub-game firm's profit function given in equation (12) is concave in $\left(\lambda_i^P, \lambda_i^R\right)$. For this, the Hessian matrix of its second derivatives must be negative definite. This implies:

$$\frac{\partial^2\pi_i}{(\partial\lambda_i^P)^2} + \frac{\partial^2\pi_i}{(\partial\lambda_i^R)^2} = 2\frac{\left(4+\beta^4-3\beta^2\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)} - 2\overline{\theta} < 0, \tag{23}$$

and

$$\frac{\partial^2\pi_i}{(\partial\lambda_i^P)^2}\frac{\partial^2\pi_i}{(\partial\lambda_i^R)^2} - \left(\frac{\partial^2\pi_i}{\partial\lambda_i^P\partial\lambda_i^R}\right)^2 = \overline{\theta}\left[\overline{\theta} - \frac{2\left(4+\beta^4-3\beta^2\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}\right] > 0, \tag{24}$$

If equation (24) is satisfied, so is equation (23). Thus, a sufficient second-order condition is:

$$\overline{\theta} > \frac{2\left(4-3\beta^2+\beta^4\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)} \equiv \theta^{\text{SOC}}(\alpha,\beta) \equiv \theta^{\text{SOC}}. \tag{25}$$

We consider in the following that $\overline{\theta}$ is large enough so that (25) is satisfied. Cases for which equation (25) is not satisfied are discussed below.

We now explore the possible corner equilibria. We have to check first that net strategic wages are positive. From equation (19), $\widehat{\omega}^P \geq 0$ and $\widehat{\omega}^R \geq 0$ are equivalent to

$$\overline{\theta} \geq \frac{2(1-\beta)}{(1+\beta)(2-\beta)^2}. \tag{26}$$

This condition holds if condition (25) is satisfied, which we assume. Consequently, the net strategic wage of all poached workers (equal to $\widehat{\omega}^R$) is positive. Turning to retained workers (of type $\theta \in [\widehat{\theta},\overline{\theta}]$), their net strategic wage (equal to $\widehat{\omega}^P - \theta$) is positive if $\widehat{\omega}^P - \theta \geqslant 0$. From (16), $\widehat{\omega}^P - \widehat{\theta} \geqslant 0$ is equivalent to $\widehat{\omega}^R \geqslant 0$, which is satisfied. Consequently, the net strategic wage of the retained worker of the lowest type is always positive. Turning to the strategic worker of the highest type, direct calculations show that $\widehat{\omega}^P - \overline{\theta} \geqslant 0$ is equivalent to

$$\overline{\theta} \leqslant \frac{2\left((1+\alpha)\left(2-\beta^2\right)-\beta\right)}{(2+3\beta+\beta^2)(2-\beta)^2} \equiv \theta^{\text{PPC}}(\alpha,\beta) \equiv \theta^{\text{PPC}}. \tag{27}$$

Thus, if condition (27) is satisfied, the net strategic wages $\widehat{\omega}^R$ and $\widehat{\omega}^P - \theta$, where $\widehat{\omega}^P$ and $\widehat{\omega}^R$ are defined in equation (19), are positive for all strategic workers regardless of their type. If condition (27) is not satisfied, workers of type $\theta \in [\widehat{\theta},\theta^{\text{PPC}}]$ are retained with a strategic wage equal to $\widehat{\omega}^P - \theta$ and workers of type $\theta \in [\theta^{\text{PPC}},\overline{\theta}]$ are retained with a strategic wage equal to zero.

Finally, we need to check under which conditions the share of poached workers belongs to [0,1]. We can first note that $\lambda^P > 0$. This is because from equation (20), this condition is equivalent to satisfying equation (26). Then from equation (20) again, the condition $\lambda^P \leq 1$ can be re-written:

$$\overline{\theta} > \frac{2(1+\alpha)(1-\beta)}{(1+\beta)(2-\beta)^2} \equiv \theta^{\text{FP}}(\alpha,\beta) \equiv \theta^{\text{FP}}. \tag{28}$$

Hence, depending on parameter values, we have one of three different symmetric equilibria:

- Ω^{FP}, the 'Full-Poaching' equilibrium:

$$\begin{cases} \lambda^{P*} = 1 \quad \text{and} \quad \omega^{P*}(\theta) = \frac{2\beta(1+\alpha)}{(1+\beta)(2+\beta)(2-\beta)^2} + \theta, \\ \lambda^{R*} = 0. \end{cases} \tag{29}$$

- Ω^{PPI}, the 'Partial-Poaching Interior' equilibrium:

$$\begin{cases} \lambda^{P*} = \lambda^P \quad \text{and} \quad \omega^{P*}(\theta) = \widehat{\omega}^R + \theta \text{ for the poached workers } \theta \in \left[0,\widehat{\theta}\right] \\ \lambda^{R*} = 1-\lambda^P \quad \text{and} \quad \omega^{R*}(\theta) = \widehat{\omega}^P - \theta \text{ for the retained workers } \theta \in \left[\widehat{\theta},\overline{\theta}\right]. \end{cases} \tag{30}$$

- Ω^{PPC}, the 'Partial-Poaching Corner' equilibrium:

$$\begin{cases} \lambda^{P*} = \lambda^P \quad \text{and} \quad \omega^{P*}(\theta) = \widehat{\omega}^R + \theta \text{ for the poached workers } \theta \in \left[0,\widehat{\theta}\right] \\ \lambda^{R*} = 1-\lambda^P \quad \text{and} \quad \begin{cases} \omega^{R*}(\theta) = \widehat{\omega}^P - \theta \text{ for the retained workers } \theta \in \left[\widehat{\theta},\theta^{\text{PPC}}\right] \\ \omega^{R*}(\theta) = 0 \text{ for the retained workers } \theta \in \left[\theta^{\text{PPC}},\overline{\theta}\right]. \end{cases} \end{cases} \tag{31}$$

From equations (27) and (28), direct calculations show that $\theta^{\text{FP}} \leq \theta^{\text{PPC}}$, while θ^{SOC} can be either lower than both θ^{FP} and θ^{PPC} (for high α) or in between the two (for intermediate α) or higher than both θ^{FP} and θ^{PPC} (for low α). Proposition 1 summarises all this:

Proposition 1 - *Equilibrium*

Under co-location, the sub-game perfect equilibria in Stage 2 are:

- Ω^{FP}, *if* $\theta^{\text{SOC}} \leq \overline{\theta} \leq \theta^{\text{FP}}$,
- Ω^{PPI}, *if* $\max\left(\theta^{\text{SOC}}, \theta^{\text{FP}}\right) < \overline{\theta} < \theta^{\text{PPC}}$,
- Ω^{PPC}, *if* $\max\left(\theta^{\text{SOC}}, \theta^{\text{PPC}}\right) \leq \overline{\theta}$.

Comparative statics results proved in Appendix A are summarised in Proposition 2:

Proposition 2 - *Comparative statics*

- *The wages of poached and retained workers increase in α and decrease with $\overline{\theta}$. The wage of poached workers increases with β, while that of retained workers decreases with β.*
- *The number of poached (resp. retained) workers increases (resp. decreases) with α and decreases (resp. increases) with $\overline{\theta}$ and β.*
- θ^{SOC} *does not depend on α and increases with β. θ^{FP} and θ^{PPC} both increase with α and decrease with β.*

To understand these results, start by noting that when firm i poaches a worker, it lowers its absolute marginal cost (which increases the demand for its good regardless of the other firms' costs) as well as its relative cost (which makes it more competitive and allows it to grab some of firm j's customers). By contrast, when firm i retains a strategic worker, it only improves its marginal cost relative to the other firm. Thus, as we noted above the *gross* incentive to poach a worker is stronger than the *gross* incentive to retain a worker (equations 14 and 15). Then note that when the size of the market increases (higher α), both the *gross* incentive to poach and the *gross* incentive to retain workers become stronger because any cost reduction or any cost advantage is spread over a larger output. This implies that the wages of all strategic workers (poached and retained) should increase with market size. At the same time however, the incentive to poach increases more than the incentive to retain workers because poaching lowers both relative *and* absolute costs. Consequently and despite higher wages, more workers are poached in equilibrium as market size increases.

As final goods become less differentiated (higher β), the *gross* incentive to poach also becomes stronger (equation 14). This is because a cost advantage yields a higher extra-revenue when goods are more substitutable. For the same reasons, the *gross* incentive to retain workers also increases with β (equation 15). This makes poaching workers more expensive. As a matter of fact, the *gross* incentive to retain workers increases even faster with β than the *gross* incentive to poach workers. This is because the importance of relative costs (as opposed to that of absolute costs) increases as rivalry between firms intensifies. Thus, as goods become less differentiated, it becomes relatively more attractive to retain rather than poach workers. This implies that the number of poached workers decreases as β increases. Then note from equation (14) that the incentive to poach increases with the number of workers poached since $\partial^2\Pi_i/\partial(\lambda_i^P)^2 > 0$. Hence there is an indirect effect whereby a lower quantity of poached workers (caused by higher wages offered by the initial employer) reduces the *gross* incentive to poach workers. With respect to the wage of retained workers, this indirect effect more than offsets the direct rivalry effect highlighted previously so that firms are able to retain workers at a lower wage. Consequently, the wage of retained workers decreases when the degree of differentiation between final goods decreases.

Turning to the effect of worker heterogeneity ($\overline{\theta}$), note that a greater heterogeneity does not change the *gross* incentives to poach or retain workers since it does not enter into the revenue function (13). However note from equation (17) that a higher $\overline{\theta}$ makes poaching more expensive and thus reduces the *net* incentive to poach. As a result, a higher heterogeneity also makes it easier for firms to prevent poaching. Consequently, the wages of strategic workers (both poached and retained) and poaching decrease with rising worker heterogeneity.

We can now understand why there are different types of equilibrium. When poaching is easy (low $\overline{\theta}$), the *net* incentive to poach is much stronger than the *net* incentive to retain workers. For a large enough market and sufficiently differentiated goods all workers may end up being poached and the equilibrium is in a corner in this case (Ω^{FP}). As worker heterogeneity increases (intermediate $\overline{\theta}$), some workers become fairly costly to move between firms. They can now be retained by their original employer. We are thus in an interior equilibrium where some workers are poached while others are retained (Ω^{PPI}). As heterogeneity increases even further (high $\overline{\theta}$), some workers becomes prohibitively costly to poach. Their initial employer can retain them at no cost (Ω^{PPC}). Alternatively, for the full-poaching equilibrium, decreasing market size or increasing rivalry at a given level of heterogeneity makes poaching more and more difficult and therefore one moves first to the interior equilibrium and then to the partial-poaching corner one.

Finally, we can also understand why the equilibrium fails to exist when condition (25) is not satisfied. When worker heterogeneity is small, a large fraction of strategic workers is poached (possibly all of them at the full-poaching candidate equilibrium). As noted above for the incentive to poach, the incentive to retain workers increases with the number of workers retained ($\partial^2\Pi_i/\partial(\lambda_i^R)^2 > 0$). The more workers a firm retains, the more it is willing to pay to retain them. Hence, for a low enough $\overline{\theta}$, a firm may find it worth deviating from the candidate equilibrium and significantly raise the wage it offers to its strategic workers to retain most (or all) of them. Similarly, it is also willing to pay more for the workers it poaches (if full poaching does not already occurs). Put differently, in this case the candidate is not robust to unilateral deviations. There is thus no equilibrium when $\overline{\theta}$ falls below a certain threshold, θ^{SOC}.

It interesting to note that this threshold increases when the degree of differentiation between final goods decreases, i.e., a Nash-equilibrium (in pure strategy) fails to exist when β is high. In such a case, rivalry between firms is very strong. At the candidate symmetric equilibrium, a firm will find it profitable to deviate and increase the wage of its strategic workers to retain them as well as increase the wage of the other firm's strategic workers to poach them in much larger numbers. This will lead to a significant cost difference between the two firms. Generating such a difference will be profitable since it allows the firm that deviates to grab a much larger market (since the degree of differentiation between the two goods is low).[14]

5. Location and Welfare Issues

We now turn to the location decision. When firms locate separately, they cannot poach on each other's workforce due to the immobility of strategic workers. This implies $\lambda^{P*} = 0$ and $\lambda^{R*} = 1$. Profit maximisation in this case also implies $\omega^{P*} = 0$ and $\omega^{R*} = 0$. From equations (12) and (13), the firms' profit when they locate separately is:

$$\pi^{\mathrm{S}} = \frac{(1-\beta)\,\alpha^2}{(1+\beta)\,(2-\beta)^2}. \tag{32}$$

Location

We can now define for $\mathrm{C} = \mathrm{FP}, \mathrm{PPI}, \mathrm{PPC}$, $\Delta^{\mathrm{C}}\left(\alpha,\beta,\overline{\theta}\right) \equiv \pi^{\mathrm{C}}\left(\alpha,\beta,\overline{\theta}\right) - \pi^{\mathrm{S}}$ where π^{C} is the profit when firms co-locate, i.e. under the full-poaching, the partial-poaching interior and the partial-poaching corner equilibrium of stage 2, respectively. When $\Delta^{\mathrm{C}}\left(\alpha,\beta,\overline{\theta}\right) \geq 0$, firms want to co-locate and do so in equilibrium. When $\Delta^{\mathrm{C}}\left(\alpha,\beta,\overline{\theta}\right) < 0$, firms do not want to co-locate and end up in separate locations.

We turn to the determination of the sign of $\Delta^{\mathrm{C}}\left(\alpha,\beta,\overline{\theta}\right)$ depending on the sub-game equilibrium at stage 2. Under full poaching, from equations (12), (13), (21), (29), and (32), we obtain:

$$\Delta^{\mathrm{FP}}\left(\alpha,\beta,\overline{\theta}\right) = \frac{1}{2}\left(\theta^{\mathrm{SFP}} - \overline{\theta}\right), \tag{33}$$

where

$$\theta^{\mathrm{SFP}} \equiv \frac{2\left[(2-2\beta-\beta^2)(1+2\alpha)-\beta\right]}{(1+\beta)\,(2+\beta)\,(2-\beta)^2}. \tag{34}$$

Recall that the full-poaching equilibrium occurs when $\theta^{\mathrm{SOC}} \leq \overline{\theta} \leq \theta^{\mathrm{FP}}$. One can show that θ^{SFP} can be either greater or smaller than θ^{SOC} and than θ^{FP}. Hence, when $\theta^{\mathrm{SFP}} < \theta^{\mathrm{SOC}}$, firms never locate together at the full-poaching equilibrium. At the other extreme, for $\theta^{\mathrm{SFP}} > \theta^{\mathrm{FP}}$, firms always co-locate at the full-poaching equilibrium. Last, when $\theta^{\mathrm{SOC}} \leq \theta^{\mathrm{SFP}} \leq \theta^{\mathrm{FP}}$, firms co-locate for low $\overline{\theta}$ and disperse for high $\overline{\theta}$. Furthermore, $\left(2-2\beta-\beta^2\right) > 0$ is satisfied in this case, hence θ^{SFP} increases with α. It can also be verified that θ^{SFP} decreases with β. Therefore, when the full-poaching equilibrium is reached in stage 2, firms co-locate for high α and low β or $\overline{\theta}$. They choose different locations otherwise.

We now study the location decision under the partial-poaching interior equilibrium. In this case, from equations (19) and (20), the strategic wages and numbers of poached and retained workers are linear in α. Hence, $\Delta^{\mathrm{PPI}}\left(\alpha,\beta,\overline{\theta}\right)$ is quadratic in α. Calculations lead to:

$$\Delta^{\mathrm{PPI}}\left(\alpha,\beta,\overline{\theta}\right) = \frac{\overline{\theta}}{2} - \frac{2(2-\beta^2)\overline{\theta}}{(2+\beta)\left[\overline{\theta}(1+\beta)(2-\beta)^2 - 2(1-\beta)\right]}\alpha \tag{35}$$

[14] This existence problem is a standard feature of Bertrand games with variable marginal costs. See Gabszewicz and Thisse (1999) for a general discussion on this issue. Note that in our model, introducing strongly decreasing returns in the cost reduction achieved by poaching (in equation 5) would alleviate considerably this existence problem. Such decreasing returns may even be more realistic but they would also prevent us from deriving closed-form solutions.

$$+\frac{4(1-\beta)^2\left[\overline{\theta}(1+\beta)(2-\beta)^2-(1-\beta)\right]}{(1+\beta)(2-\beta)^2\left[\overline{\theta}(1+\beta)(2-\beta)^2-2(1-\beta)\right]^2}\alpha^2.$$

The coefficients of order 0 and 2 are positive, and the coefficient of order 1 is negative. Hence, $\Delta^{\text{PPI}}\left(\alpha,\beta,\overline{\theta}\right)=0$ has either no positive root in α or two positive ones. From the expression of the determinant, one can show that, if $\beta<\sqrt{14+4\sqrt{2}}/2-1-\sqrt{2}/2\approx 0.51$ and $\overline{\theta}<\frac{(1+\beta)(2-\beta)^2\left(4-8\beta-2\beta^2+4\beta^3+\beta^4\right)}{8(2+\beta)^2(1-\beta)^3}$, then $\Delta^{\text{PPI}}\left(\alpha,\beta,\overline{\theta}\right)\geq 0$. In this case, firms co-locate. Otherwise, $\Delta^{\text{PPI}}\left(\alpha,\beta,\overline{\theta}\right)=0$ has two roots in α, but it can be shown that α lower than the lowest one is incompatible with the existence of Ω^{PPI}. Therefore, either α is lower than the highest root and firm choose different locations; or α is higher and they co-locate. Finally, this root can be shown to be increasing with β and $\overline{\theta}$. To sum up, the comparative statics works as in the full-poaching case and firms co-locate when rivalry and worker heterogeneity are not too strong and when the market is large.

Under the partial-poaching corner equilibrium in stage 2, $\Delta^{\text{PPC}}\left(\alpha,\beta,\overline{\theta}\right)$ is also quadratic in α (for the same reasons as for Δ^{PPC}). Then tedious calculations show again that either $\Delta^{\text{PPC}}\left(\alpha,\beta,\overline{\theta}\right)=0$ has no positive root in α or has two positive ones. When there is no positive root, $\Delta^{\text{PPC}}\left(\alpha,\beta,\overline{\theta}\right)$ is always positive. This implies co-location. When there are two roots (which happens for high β and $\overline{\theta}$), α greater than the highest root is incompatible with the existence of this equilibrium. Hence, for low α firms co-locate. For high α, they choose different locations.[15] Similarly, the smallest root is not monotonous in β and $\overline{\theta}$, and thus firms may also co-locate for high β and $\overline{\theta}$.

The results regarding the first stage of the game are summarised in Proposition 3:

Proposition 3 - ***Location choices***

Assuming that the second-order conditions are met in stage 2 ($\theta^{\text{SOC}}\leq\overline{\theta}$):

- *If β and $\overline{\theta}$ are sufficiently low, firms always co-locate.*
- *If β is sufficiently high, the location decision depends on the nature of the stage 2 equilibrium:*
  - *Under the full-poaching equilibrium or the partial-poaching interior equilibrium, firms co-locate for high α and low $\overline{\theta}$.*
  - *Under the partial-poaching corner equilibrium, firms co-locate for low α and high $\overline{\theta}$.*

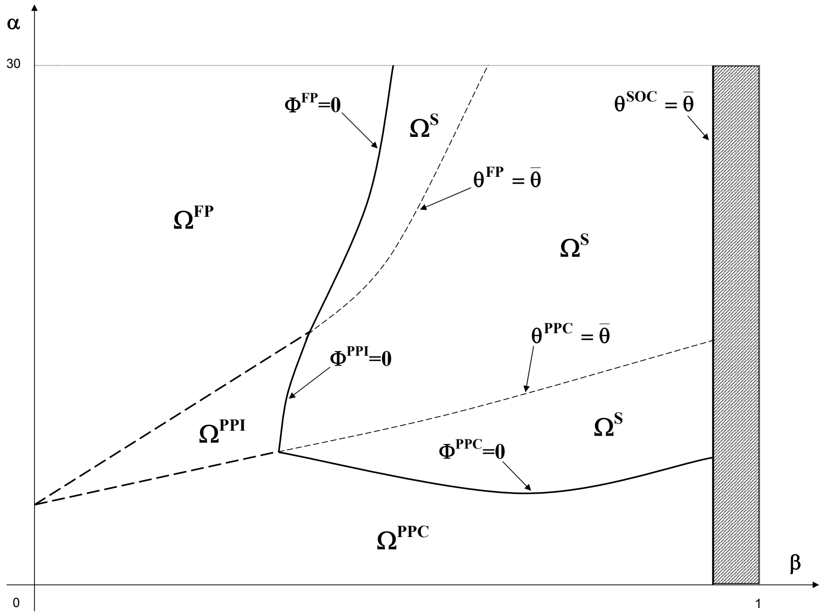
As an example, Figure 1 represents the areas of existence of the different equilibria for $\overline{\theta}=5$ in the (β,α) plane. The dashed lines delineate the areas of existence of the different types of stage 2 sub-game equilibria. The continuous lines represent the co-location conditions.

To understand these results better, it is worth noting first that co-location implies some benefits (i.e., the cost reduction accruing from poaching), which are captured by the net revenue function (equation 13), and some costs, which are captured by the cost of poaching and the cost of retaining workers (equations 21 and 22). At the symmetric equilibrium, the difference in net revenue between co-location and separation is equal to:

$$\Delta R=\frac{(1-\beta)(2\alpha+\lambda^{P*})\lambda^{P*}}{(1+\beta)(2-\beta)^2}, \tag{36}$$

[15] Note that an even higher α makes the equilibrium move to either full-poaching or a partial-poaching interior situation. From then on the comparative statics in α is reversed.

Figure 1. Equilibrium configurations



where λ^{P*}, the quantity of poached workers, depends on the type of equilibrium. For interior equilibria, λ^{P*} is given by equation (20). From equations (21) and (22) and after simplification, the costs of co-location are equal to:

$$\Delta C = \widehat{\omega}^R \lambda^{P*} + \widehat{\omega}^P (1 - \lambda^{P*}) + \overline{\theta}/2. \tag{37}$$

Consider first an increase in β (a decline in the degree of differentiation between final goods). On the revenue front, this implies a lower revenue in case of co-location relative to separation (equation 36) because of fewer workers being poached. Turning to the costs of co-location, recall that a higher β implies a lower $\widehat{\omega}^P$, a higher $\widehat{\omega}^R$, and less poaching, λ^{P*}. The overall effect of a higher β on the cost of co-location is ambiguous.

Under full-poaching, only the strategic wage $\widehat{\omega}^R$ is relevant in equation (37) since the other strategic wage does not apply to any worker. Thus under full-poaching, the cost of co-location increases with β. Hence, as β increases, the gain from co-location declines whereas its cost increases fast. This implies that starting from a low β, an increase in β implies a prompt separation between the firms.

By contrast, in the partial-poaching corner situation, few workers are poached. An increase in β still reduces the relative revenue of co-location in equation (36). But it increases the costs of co-location far less than in the full-poaching case since now the strategic wage of retained workers $\widehat{\omega}^P$ (which decreases with β) is an important part of the costs of co-location in equation (37). For a high enough β, it can even be the case that the change in the strategic wage of retained workers $\widehat{\omega}^P$ plays a dominant role so that the cost of co-location falls with β in equation (37). In such a case, co-location may even become more likely as β decline as illustrated by the dotted line at the bottom right of Figure 1. The effects at work at the interior equilibrium are similar to the case of the partial-poaching corner equilibrium, but the fact that poaching is higher in the interior case prevents the reemergence of the co-location equilibrium for high β.

Consider now an increase in α, the market size. The gain from co-locating increases through the increase in poaching, λ^{P*} (which itself increases linearly with α) and through a larger market size making existing cost reductions more worthwhile. From equation (36), the gains from co-location increase quadratically with α. At the same time, strategic wages also increase linearly with α. Hence with both wages and the number of poached workers linear in α, the cost of co-location (equation 37) includes a quadratic and a linear term in α. However, since $\widehat{\omega}^P - \widehat{\omega}^R \geq 0$, this quadratic term enters with a negative sign. From here, the overall effect of α on location can be understood since it is the sum of two quadratic terms in α minus a linear term in α. For a small market size, the costs of co-location increase faster than the gains (the linear term dominates the quadratic terms) whereas for a large market, the reverse occurs. This is because the cost reduction generated by the extra cost of poaching can be spread across a larger market.

Consider finally an increase in worker heterogeneity, $\overline{\theta}$. Because a higher $\overline{\theta}$ reduces poaching, it leads to lower gains from co-location in equation (36). At the same time, it also leads to lower strategic wages. This alone would reduce the cost of co-location in equation (37). However, a higher $\overline{\theta}$ also implies less poaching and a higher direct cost of poaching. These effects dominate so that an increase in worker heterogeneity increases the relative cost of co-location. Hence, a higher $\overline{\theta}$ leads to both higher costs and lower gains from co-location, which makes it less attractive.

Another way to interpret these results is to think in terms of force of agglomeration versus force of dispersion. Our force of agglomeration is the opportunity for firms to improve their technology and lower their costs of production through the poaching of strategic workers from another firm. To our knowledge, this is a novelty with respect to the existing literature where the agglomeration forces are either driven by spill-overs for which no microeconomic foundations are given or, when there is a labour market, by a better or safer matching between firms and workers. Our agglomeration force is strong when the costs of transferring knowledge are low (because of cheaper cost reductions), when the final goods are very differentiated (because firms can capture a large fraction of the surplus accruing from lower costs as a result of a weak rivalry), and when the market is large (because cost reduction takes place over a larger quantity of output).

Our dispersion force stems from strategic interactions between rival firms who have incentives to push up their strategic wages to discourage the other firms from poaching from their workforce. When the dispersion force dominates the agglomeration force, firms prefer to locate separately.

Welfare

We can now look at the welfare properties of our equilibria in order to assess if all possible benefits of knowledge exchanges are captured or not. Total surplus is the sum of consumers', workers' and producers' surpluses:

$$\begin{aligned} TS = (1+\alpha)\left(q_i+q_j\right) - \beta q_i q_j - \tfrac{1}{2}\left(q_i^2+q_j^2\right) - p_i q_i - p_j q_j + L_i + L_j \\ + \tfrac{1}{\overline{\theta}}\left[\int_{\Theta_i^P}\omega_i^P(\theta)d\theta + \int_{\Theta_i^R}\omega_i^R(\theta)d\theta + \int_{\Theta_j^P}\omega_j^P(\theta)\theta + \int_{\Theta_j^R}\omega_j^R(\theta)d\theta\right] + \pi_i + \pi_j \end{aligned} \tag{38}$$

where firm profits are given in equation (6). Note that if worker θ is worth being moved from one firm to another, it is the case for any worker of lower type. Thus, total surplus reduces to:

$$TS = (1+\alpha)(q_i + q_j) - \beta q_i q_j - \frac{1}{2}(q_i^2 + q_j^2) - \left(1 - \lambda_i^P\right) q_i - \left(1 - \lambda_j^P\right) q_j - \frac{\overline{\theta}}{2}\left[\left(\lambda_i^P\right)^2 + \left(\lambda_j^P\right)^2\right]. \tag{39}$$

The first-order conditions in $\left(q_i, q_j\right)$ imply:

$$q_i = \frac{\alpha}{1+\beta} - \frac{\beta \lambda_j^P}{1-\beta^2} + \frac{\lambda_i^P}{1-\beta^2}. \tag{40}$$

It is immediate that equation (40) is equivalent to marginal cost pricing. Insert equation (40) in equation (39) and take the first-order conditions with respect to λ_i^P to get:

$$\frac{\partial TS}{\partial \lambda_i^P} = \frac{\alpha}{1+\beta} - \frac{\beta}{1-\beta^2}\lambda_j^P + \frac{1 - \overline{\theta}\left(1-\beta^2\right)}{1-\beta^2}\lambda_i^P = 0. \tag{41}$$

The optimal poaching implied by equation (41) is given by:

$$\lambda^{P**} = \frac{\alpha}{\overline{\theta}\left(1+\beta\right) - 1}. \tag{42}$$

Then $\lambda^{P**} \leq 1$ is equivalent to:

$$\overline{\theta} \geq \theta^{\mathrm{OP}} \equiv \frac{1+\alpha}{1+\beta}. \tag{43}$$

A sufficient second-order condition is for the Hessian matrix of its second derivatives to be negative definite. This simplifies into $\overline{\theta} \geq \frac{1}{1-\beta}$, which we assume.[16] This also implies $\lambda^{P**} > 0$. The characterisation of optimal choices is given in Proposition 4.

Proposition 4 - ***Optimal poaching*** *Assuming $\overline{\theta} \geq \frac{1}{1-\beta}$, the optimum implies at*

- *Stage 1: common location,*
- *Stage 2: any wages and symmetric poaching given by:* $\begin{cases} \lambda^{P**} = 1 & \text{if} \quad \overline{\theta} \leq \theta^{\mathrm{OP}} \\ \lambda^{P**} = \frac{\alpha}{\overline{\theta}(1+\beta)-1} & \text{if} \quad \theta^{\mathrm{OP}} < \overline{\theta} \end{cases}$
- *Stage 3: marginal cost pricing.*

Finally, we can verify that $\theta^{\mathrm{OP}} > \theta^{\mathrm{PPC}}$ and $\lambda^{P**} \geq \lambda^{P*}$. This leads to Proposition 5:

Proposition 5 - ***Comparison of optimal and non-cooperative poaching***

- *Equilibrium dispersion is always sub-optimal.*
- *Optimal poaching is never smaller than equilibrium poaching.*

[16] Unfortunately, it is more constraining than the second-order condition for the market equilibrium, $\overline{\theta} \geq \theta^{\mathrm{SOC}}$. When this condition is not satisfied, the optimum implies some asymmetry between firms. This is because when the degree of differentiation between the two goods is low, it is not worthwhile duplicating the cost reduction for both of them.

To avoid any deadweight loss, the optimum obviously involves marginal cost pricing. Since strategic wages only change the distribution of the surplus, they are irrelevant here. Furthermore, due to the cost-reduction arising from exchanging workers, the optimum also involves co-location. The comparison between the optimum and the equilibrium reveals that there is not enough poaching in equilibrium. The equilibrium can also involves some inefficiencies at the location stage and insufficient clustering.

To understand these results better, note first that due to imperfect competition the equilibrium price given by equation (10) is too high with respect to the optimum. This reduces demand and thus the incentive for cost reduction (i.e., poaching). Then, conditional on the firms co-locating, there is too little poaching at stage 2. Apart from the effect of the price distortion already described, two other inefficiencies are at work. The first one is the possibility for firms to raise the wage of their own strategic workers. This makes costs reduction more expensive to achieve for the other firm. This second inefficiency also pushes towards too little poaching. However, there is also a rivalry effect whereby firms try to lower their costs relative to those of their competitors. Because of this standard market stealing effect, firms are willing to engage into socially wasteful cost reductions. This second effect pushes towards too much poaching. However it is dominated in equilibrium by the other two forces so that too little poaching occurs. Finally, when the cost of poaching and retaining workers are high, firms may choose to locate separately in equilibrium. This is a very inefficient outcome since it prevents any form of poaching.

6. Conclusions

To explore some of the issues raised by the labour market pooling argument, we proposed a model where firms, which ultimately compete on a differentiated product market, choose first a location. Then firms compete to poach / retain their strategic workers under co-location. Our results show that co-location, although it is always efficient, is not in general the equilibrium outcome. In particular, for large enough markets it is when the conditions of perfect competition are approached that firms separate. As rivalry intensifies, poaching decreases while firms raise the wage of their strategic workers. This means a higher cost of co-location because of higher wages, as well as lower benefits from co-location because of smaller flows of workers and knowledge across firms. When the costs of poaching are higher than the benefits of pooling, firms choose to locate separately.

This model allows us to propose some alternative explanations regarding the functioning of some well-known clusters, namely Silicon-Valley and Route 128. Saxenian (1994) attributes the success of the Valley and the relative decline of Route 128 to cultural differences between East and West in the US. In a nutshell, she claims that more open-minded Californians let their workforce hop from firm to firm, which yields important benefits for the Valley as a whole. By contrast, the 'culture' in the East is to try to retain workers as much as possible. Our model also accepts the premise that workers' mobility across firms is socially beneficial but it suggests a different explanation. Firms in Route 128 are mostly in the market for mainframes/mini-computers where the degree of differentiation is low, whereas software/internet activities, which dominate in the

Valley, are intrinsically more differentiated (high versus low β). Furthermore, demand over the last 15 years has been much stronger in the software market than in the market for mini-computers (high versus low α). Consequently, in the light of our model, it may be optimal for firms in Route 128 to prevent poaching and for firms in the Valley not to prevent poaching.

Beyond this suggestive re-interpretation of a famous case, our model generates a set of predictions that may guide future empirical work. The first prediction is that wages for 'strategic' workers should be higher in areas where firms are in the same industry cluster.[17] Second, firms' productivity and productivity growth are predicted to increase with equilibrium workers' flows across firms.[18] Third, the model also predicts that the flows of workers between firms should be more important when firms cluster and then should increase within clusters when the cost of changing firm declines.[19] Fourth, the comparative statics on market size also indicates that when a sector is booming, flows of workers across firms within the sector should be higher. Fifth, the comparative statics on product differentiation also indicates that the tendency for firms to cluster should increase with the degree of product differentiation within the industry. Sixth, like in human capital models, the wage is also predicted to increase steeply over time for key strategic workers.[20] This latter effect is not due to any form of general human capital accumulation, but on the contrary, it is caused by knowledge that one firm tries to protect and that others may obtain by hiring key workers. We hope these predictions will be subject to empirical scrutiny in the future.

A few unresolved issues and caveats are left for future theoretical work. Our model so far considers only two firms. The extension to many firms is important as a greater number of firms may change the terms of the trade-off between pooling and poaching. In particular the benefits to pooling may increase with the number of firms (more opportunities for firms to learn when there are more firms) whereas the cost of poaching may also decrease with the number of firms (through a dilution of the rivalry effect as workers leave to different firms). A second important extension regards viewing the initial recruitment of strategic workers as an endogenous investment. This paper views this recruitment as a fixed set-up cost and considers that only the diffusion of knowledge is endogenous, whereas of course it is both its generation and its diffusion that must ultimately be understood in the same framework.

[17]By contrast, the traditional insurance interpretation of labour market pooling implies that workers are happy to accept lower wages where there are more potential employers.

[18]Davis and Haltiwanger (1998) indicate that a positive correlation between workers flows and productivity growth is observed in US data but the direction of causality remains unclear.

[19]See Franks (2003) for preliminary evidence from the German movie industry.

[20]See Møen (2000) for evidence on this point.

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Appendix A. Comparative statics, proof of Proposition2

We first look at the comparative statics of the boundaries between the different types of equilibrium, θ^{SOC}, θ^{FP}, and θ^{PPC}. From equation (25), we can verify that: $\partial\theta^{\text{SOC}}/\partial\alpha = 0$ and

$$\frac{\partial\theta^{\text{SOC}}}{\partial\beta} = \frac{4\beta\left(16-7\beta^2+2\beta^4-\beta^6\right)}{\left(4-\beta^2\right)^3\left(1-\beta^2\right)^2} \geq 0. \tag{A 1}$$

From (27), we have:

$$\frac{\partial\theta^{\text{PPC}}}{\partial\alpha} = \frac{2\left(2-\beta^2\right)}{\left(2-\beta\right)^2\left(2+3\beta+\beta^2\right)} \geq 0 \tag{A 2}$$

and

$$\frac{\partial\theta^{\text{PPC}}}{\partial\beta} = -\frac{2\left(\alpha\left(4-2\beta-2\beta^2+3\beta^3+2\beta^4\right)+2\left(4+\beta^2+3\beta^3+\beta^4\right)\right)}{\left(1+\beta\right)^2\left(2+\beta\right)^2\left(2-\beta\right)^3} \leq 0. \tag{A 3}$$

Finally, from (28), we can check that

$$\frac{\partial\theta^{\text{FP}}}{\partial\alpha} = \frac{2\left(1-\beta\right)}{\left(1+\beta\right)\left(2-\beta\right)^2} \geq 0 \tag{A 4}$$

and

$$\frac{\partial\theta^{\text{FP}}}{\partial\beta} = -\frac{4\left(1+\alpha\right)\left(1-\beta+\beta^2\right)}{\left(1+\beta\right)^2\left(2-\beta\right)^3} \leq 0 \tag{A 5}$$

We now turn to the comparative statics of λ^P at the Ω^{PPI} equilibrium. From equation (20), we get:

$$\frac{\partial\lambda^P}{\partial\alpha} = \frac{2\left(1-\beta\right)}{\overline{\theta}\left(1+\beta\right)\left(2-\beta\right)^2-2\left(1-\beta\right)} \geq 0, \tag{A 6}$$

$$\frac{\partial\lambda^P}{\partial\overline{\theta}} = -\frac{2\alpha\left(1-\beta\right)\left(1+\beta\right)\left(2-\beta\right)^2}{\left(\overline{\theta}\left(1+\beta\right)\left(2-\beta\right)^2-2\left(1-\beta\right)\right)^2} \leq 0, \tag{A 7}$$

and

$$\frac{\partial\lambda^P}{\partial\beta} = -\frac{4\alpha\left(2-\beta\right)\left(1-\beta+\beta^2\right)\overline{\theta}}{\left(\overline{\theta}\left(1+\beta\right)\left(2-\beta\right)^2-2\left(1-\beta\right)\right)^2} \leq 0. \tag{A 8}$$

Comparative statics for λ^R are reversed since $\lambda^P = 1-\lambda^R$.

The comparative statics of wages at the Ω^{PPI} equilibrium is as follows. From equation (19), for poached workers we obtain:

$$\frac{\partial\widehat{\omega}^R}{\partial\alpha} = \frac{2\beta\overline{\theta}}{\left(2+\beta\right)\left(\overline{\theta}\left(1+\beta\right)\left(2-\beta\right)^2-2\left(1-\beta\right)\right)} \geq 0 \tag{A 9}$$

and $\partial\widehat{\omega}^P/\partial\alpha \geq 0$ for retained workers. Also from equation (19), for poached workers we get:

$$\frac{\partial\widehat{\omega}^R}{\partial\overline{\theta}} = -\frac{4\alpha\beta\left(1-\beta\right)}{\left(2+\beta\right)\left(\overline{\theta}\left(1+\beta\right)\left(2-\beta\right)^2-2\left(1-\beta\right)\right)^2} \leq 0 \tag{A 10}$$

and $\partial\widehat{\omega}^P/\partial\overline{\theta} \leq 0$ for retained workers. By the same token, for poached workers we have:

$$\frac{\partial\widehat{\omega}^R}{\partial\beta} = \frac{2\alpha\left(\overline{\theta}(2-\beta)\left(4+2\beta+4\beta^2+3\beta^3\right)-2\left(2+\beta^2\right)\right)\overline{\theta}}{(2+\beta)^2\left(\overline{\theta}\,(1+\beta)\,(2-\beta)^2-2\,(1-\beta)\right)^2} \tag{A 11}$$

which is positive if $\overline{\theta} \geq \frac{2(2+\beta^2)}{(2-\beta)(4+2\beta+4\beta^2+3\beta^3)}$. This latter condition is satisfied when $\overline{\theta} \geq \theta^{SOC}$, which we assume. Finally, for retained workers we get:

$$\frac{\partial\widehat{\omega}^P}{\partial\beta} = -\frac{2\alpha\left(\overline{\theta}(2-\beta)\left(4-2\beta-2\beta^2+3\beta^3+2\beta^4\right)+2\left(2+\beta^2\right)\right)\overline{\theta}}{(2+\beta)^2\left(\overline{\theta}\,(1+\beta)\,(2-\beta)^2-2\,(1-\beta)\right)^2} \leq 0. \tag{A 12}$$

The only differences for the other equilibria relate to the wage for poached workers at the Ω^{FP} equilibrium. In this case:

$$\frac{\partial\widehat{\omega}^R}{\partial\beta} = \frac{2\,(1+\alpha)\left(4+2\beta+4\beta^2+3\beta^3\right)}{(1+\beta)^2\,(2+\beta)^2\,(2-\beta)^3} \geq 0. \tag{A 13}$$