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# "A MATCHING MODEL OF UNIVERSITY-INDUSTRY COLLABORATIONS"


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# A Matching Model of University-Industry Collaborations

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**Abstract**

In this paper we present a simple model of university-industry collaborations with heterogeneous agents, which is the standard case of technology transfer. We study the characteristics of the matching process, that makes this exchange in technology transfer either efficient or unfeasible. We show that the functioning of the technology transfer market implies dual-trading externalities. We refer to these externalities as *congestion* because they are caused by the tightness that searching firms and researchers cause to each other during trade.

Keywords: Technology transfer; Matching; Externalities.

JEL Code: O31 O32 O38 L23 M38.

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## 1 Introduction

In this paper we study a Technology Transfer (TT) market where heterogeneous university researchers and heterogeneous firms meet each others to exchange knowledge and technology by collaborating. When agents are highly heterogeneous, any market has little resemblance to a Walrasian market. Indeed, in the presence of heterogeneity, agents meet in a decentralized one-to-one fashion and engage in a costly process of trying to match up idiosyncratic technologies, skills and needs.

Currently, a debate is going on within academic circles on the determinants and obstacles affecting University-Industry (U–I) collaborations. On one hand, many empirical studies focused on the role of basic research in technology and innovation - namely, research and development, university research and human capital - in affecting economic growth (Mueller, 2006). On the other hand, the links between industry and science (i.e. the types of interactions between industry and science sectors that foster the exchange of knowledge and technology) play a central role for the innovation process and the commercialization of innovative products and, therefore, for economic growth emanating from knowledge investments, as well (Debackere and Veugelers, 2005). Therefore, the incentives and the mechanisms at the core of collaborations between universities and industries are worth studying to shape the appropriate policies aimed at promoting this form of productive relationships.

As recently pointed out in the EENEE analytical report of the European Commission (Veugelers and Del Rey, 2014), the university contribution to successful economies is quite evident, and the collaborations between the scientific research community and markets allowed the achievement of better outcomes in terms of economic value and new jobs (Audresch and Lehmann, 2005).

However, many exogenous and endogenous factors, such as the functioning and regulation of the innovation system, affect the strength of these collaborations that, often, follow nonlinear patterns. Indeed, the intensity to which academic institutions collaborate with industry varies enormously among sectors and products (Muscio *et al.*, 2014). Further, institutional differences among universities are a crucial aspect of both spillover processes (Calcagnini *et al.*, 2014) and the commercialization of knowledge and basic researches (Audresch *et al.*, 2005).

Perkmann *et al.* (2013) classify knowledge transfer channels as commercialization or academic engagement. The former label includes patenting and licensing, and forms of academic entrepreneurship (e.g. spin-offs, incubators). The latter refers to knowledge-related collaborations (collaborative research, contract research, consulting) between academic researchers and non-academic entities.

There are many drivers and obstacles which affect U-I collaborations. Muscio *et al.* (2014) have recently shown that four main factors are usually perceived by researchers as reducing the success and productivity of U–I collaborations, namely: (1) misalignment of incentives between researchers and firms (conflicts with companies); (2) lack of academic procedures or intermediaries to ease the interaction with businesses (academic networking problems); (3) misalignment between academic goals and technological transfer activity (conflicts with academic goals); and (4) distance between academic research and business needs (nature of research).

Notwithstanding the aforementioned problems, universities may gain several benefits from engagement in collaborations with firms and knowledge transfer activities (Muscio and Vallanti, forthcoming) such as the reinforcement of academic reputation, the establishment of communication channels with firms, and the increase in financial earnings from patenting and licensing. In addition, even though the main historical role of university–base researchers has not always generated innovations, the transfer and commercialization of discoveries and base research helps to improve the quality of technology, the environment and human health, beside providing returns to private investors. These positive externalities may arise through university activities that affect private or public research and graduates employed in widespread economic activities (See Litan *et al.* , 2008). To improve the quality of collaborations, the authors suggest to move from "licensing models" which seek to maximize patent licensing income, to "volume models" that emphasize the number of university innovations and the speed with which they are brought into the marketplace.

However, some questions are still open. Among these: What are the economic factors that affect the stability of U–I collaborations? Can the relationship between universities and industries generate negative unintended externalities that weaken such collaborations? How does the tightness of the TT market affect the duration and the productivity of any collaboration? These are the main issues addressed in this paper. To this aim, we present a theoretical model of matching between university researchers and industrial firms. Notice that, because this process of matching and searching is not instantaneous, it results in some inefficiency and costs. That is, some researchers and firms can result "unemployed" at any time even if they have knowledge and skills to realize profitable trades in the technology transfer market. In addition, this market friction can have implications on the way university-firm collaborations respond to alternative shocks and policies.

In this paper we present a simple model of U–I collaborations with heterogeneous agents, which is the standard case of TT. We study the characteristics of the matching process that makes this exchange in TT either efficient or unfeasible (Pissarides, 2000). Our results show that: (1) the functioning of the TT market implies a *dual-trading externality.* The latter arises because there is a high probability that a firm searching for an university collaboration does not meet the suitable researcher, and another positive probability that an unemployed researcher will not find a suitable firm project, whatever the market prices and the costs are. As for the labor market, we refer to these externalities as *congestion* because they are generated by the tightness that firms and researchers cause to each other during trade; (2) changes in expected profits (aggregate shock) do affect the cutoffs that induce firms to look for new collaborations or quit the existing ones. thus, project reallocation can vary over the business cycle, even if the matching processes that caused it do not; (3) when the separation rate of collaboration increases (idiosyncratic shock), the researcher search rate also increases. However, our model is unable to determine the effect of the increase in the search rate on the number of vacant projects the firms are willing to offer in the TT market.

Overall, our results show that the functioning of the TT market is more complex than the standard representation of it. The trading externalities create both incentives and (implicit) costs that affect the characteristics of the matching and the success of any collaborations. Leaving out such salient features may cause an important loss of information about the nature, duration and productivity of knowledge and technology exchanges between universities and firms.

The paper is organized as follows. In the next Section we describe the model, while in Section 3 we study its properties in the steady state equilibrium. In Section 4 we discuss the comparative statics of the model. Section 5 concludes.

# 2 The model

The transfer of knowledge and technologies from universities to firms may take different forms. In addition to patents and licensing of research products, technology and knowledge transfer also occurs by means of technology-based start–ups (i.e., mostly spin–offs), collaborative research, contract research, consulting and others activities (training courses, meeting and conferences) (Muscio and Pozzali, 2013).

There are several reasons for which universities and firms are willing to collaborate. They depend on the institutional environment and on individual perceptions of potential benefits and costs deriving from such collaborations. The choice of academic researcher to collaborate with firms is positively affected by the possibility of acquiring additional resources (funding, ideas, equipment, new opportunities), and negatively by their perception of the potential threat to their research freedom seems (Tartari and Breschi, 2012).

As for firms, the engagement in collaborative activities with academia is motivated by many factors such as the reduction of the risk associated with the innovative activity, the access to technological knowledge, research infrastructures and research skills (Muscio and Vallanti, forthcoming).

In what follows we will take into account all these elements to build up a simple model of University–Firms relationships that describes the creation and destruction of collaborations.

## 2.1 University–Industry collaborations

The economy consists of a matching between university researchers and technology projects provided by firms. Any firm has potential projects. These can be either active at time $t$ (i.e., a collaboration with universities already exists), or inactive (vacanct) (i.e., the firm is still searching for a skilled researcher in the TT market).

At time $t$ there are $N$ researchers who can be can either be employed in collaborations ($n$) or still in search ($s$) for new collaborations. The total number of researchers is $N = n + s$, with $N$ given.

The numbers of vacant collaborations offered by firms are denoted by $v$. Any *matching* between researchers and firms gives rise to a *collaboration*, that is a *technology transfer*. We assume that any collaboration can have at most one researcher.

A key assumption of the model concerns how the TT occurs, that is when a researcher meets a suitable firm. Thus, positive levels of unemployed researchers and vacancies can coexist without being immediately eliminated from the market.

Unemployed researchers and vacant projects are, instead, assumed to yield a flow of new collaborations at some rate per unit of time:

$$T = M(s, v) \quad (1)$$

$$= M_0 v^{\alpha} s^{\beta} \quad (2)$$

where $T$ is one collaboration, or one technology transfer. The matching function $M$ (equation 1) proxies for the complex process that generates the technology transfer. We assume that it takes the form of a Cobb-Douglas function with exogenous parameters $M_0$, $\alpha$ and $\beta$. $M_0$ is a *policy* parameter, while $\alpha$ and $\beta$ determine the returns of the matching process.

If $\alpha + \beta > 1$ there are *thick market effects* i.e.: increasing the level of search makes the matching process to operate more effectively, in the sense that it yields more output (technology transfer $T$) per unit of input (researchers, $s$, and vacancies, $v$).

If $\alpha + \beta < 1$ the matching function has decreasing returns, and there are *crowding effects*, i.e.: current collaborations reduce, given knowledge and skill levels, the number of future collaborations.

In the paper we focus on the case of constant returns to scale where $\alpha + \beta = 1$. In this case the $T$ function can be written as

$$T = M_0 s^{1-\alpha} v^{\alpha} \tag{3}$$

**Probability to meet a firm** Let $m(x)$ denote the rate per unit of time that a researcher $s$ employs to find a suitable firm, that is:

$$m(x) = \frac{M(s,v)}{s} = \frac{M_0 s^{1-\alpha} v^{\alpha}}{s} = M_0 x^{\alpha} \tag{4}$$

where $x = \frac{v}{s}$ is the ratio between vacant projects and researchers in search. By definition, $1/m(x)$ is the average search duration. Further, note that $m_x > 0$.

**Probability to meet a researcher** Let $q(x)$ denote the rate per unit of time that vacant projects $v$ are filled by suitable researchers, that is:

$$q(x) = \frac{M(s,v)}{v} = \frac{M_0 s^{1-\alpha} v^{\alpha}}{v} = M_0 x^{\alpha-1} = \frac{m(x)}{x} \tag{5}$$

and

$$m(x) = q(x)x \tag{6}$$

By definition, $1/q(x)$ is the average vacancy duration. Further note that $q_x < 0$.

Both probabilities depend on $x$, which measures the *tightness* in the TT market, that is the excess of potential projects with respect to the number of researchers in search. Therefore, on one hand, the rate $x$ shows that researchers find suitable firms more easily when there are more projects relative to the available researchers and, on the other, that firms with potential projects find researchers more easily when there are more universities and researchers relative to the available projects.

This is an example of *trading externality* that plays a central role in our analysis. The trading externality arises because, during search, the cost of collaboration is not the only allocative mechanism that determines the number of collaborations.

During search, any researcher and firm have a probability $m(x)$ and $q(x)$ to be employed and filled, respectively. Anytime a new project arrives into the market it rises $v$ and thus $x$, the ratio of the number of vacancies to unemployed researchers and, therefore, the probability $m(x)$ a researcher has to find a firm for any given $s$. At the same time, as long as $v$ increases, the probability $q(x)$ a firm has to fill a vacant project decreases.

We refer to these externalities as search or *congestion* externalities because they are caused by the congestion that searching firms and researchers cause to each other during search. Hence, the dependence of $m$ and $q$ on $x$ captures the dual externality between agents in the market: an increase in the number of vacancies $v$ relative to unemployed researchers increases the probability that a researcher finds a collaboration ($m_v > 0$), but at the same time it reduces the probability that a vacancy is filled ($q_v < 0$).

### 2.2 The researcher dynamics

The outcome from active collaborations is determined by the "separation rate" $\theta$ that we take as given: at each point of time a fraction $\theta$ of collaborations is hit by a shock. Following the shock, the researcher loses his/her collaboration, while the firm is free to advertise the vacant project in order to find a new researcher. Therefore, given $\theta$, collaborations remain productive for an average period of $1/\theta$. Thus, we can describe the dynamics of the number of researchers in collaboration as:

$$\dot{n} = m(x)s - \theta n \tag{7}$$

The change in the number of researchers at $t$ depends on the tightness $x$ of the TT market: researchers easily find collaborations for larger values of $x$. From equation (7) we can immediately derive the steady-state relationship as:

$$n_0 = \frac{m(x_0)s}{\theta} \tag{8}$$

Since $m_x > 0$, the properties of the matching function determine a positive relation between $x$ and $n$: higher values of $x$ correspond to larger flows of newly vacant projects. To fill these new potential collaborations, the number of employed researchers increases to match the flow of vacant projects. The steady-state relationship (8) is shown in panel (a) of Figure 1: to each value of $x$ corresponds a unique value of researchers already employed in collaborations. Moreover, the same properties of $m(x)$ ensure that this curve is concave with respect to the ratio $x$.

For points above or below $\dot{n} = 0$, the number of employed researchers move towards the steady state: keeping $x$ constant at $x_0$, a value $n > n_0$ causes a decrease in the flow out of searching and an increase in the flow of separations, bringing $n$ back to $n_0$. The opposite occurs when $n < n_0$. Moreover, given $n$ and $x$, we obtain $s = N - n$, so that the number of vacant projects is uniquely determined by:

$$v = x_0 s \tag{9}$$

where $v$ denotes the number of vacancies as a proportion of $N$.

Panel (b) of Figure 1 shows the curve (8) in the space $[s, v]$. We call this locus as the *Vacancy Projects* curve (VP) since it identifies the number of vacant projects $v_0$ corresponding to the pair $(x_0, n_0)$ of panel (a). The relationship for VP is obtained by substituting $n = N - s$ in equation (8) and rearranging the expression to obtain:

$$s = \frac{\theta N}{1 + m(x)} \tag{10}$$

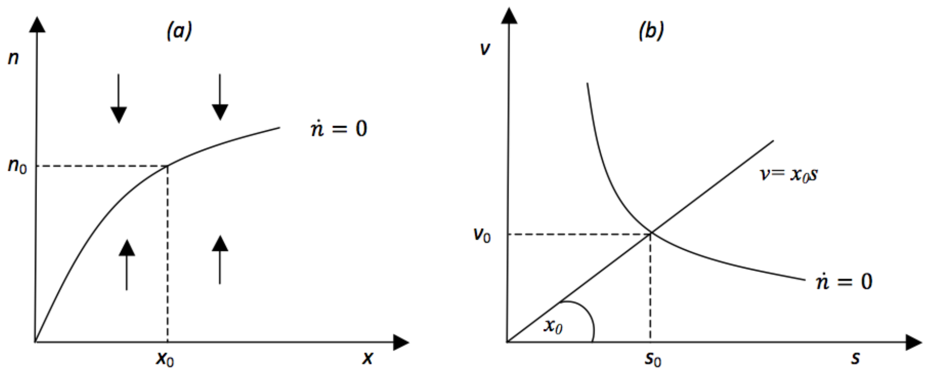


Figure 1: Dynamics of researchers

that is the downward sloping curve depicted in panel (b) of Figure 1. Given that $x = v/s$, and deriving the equation (10) with respect to $v$, we obtain the slope of the downward sloping curve as:

$$\frac{dv}{ds} = -\frac{(1+m(x))^2}{(\theta N/s)\, m_x} < 0 \tag{11}$$

since $m_x > 0$. In Section (4) both curves of Figure 1 will be used to illustrate the comparative statics of the model. At this stage it is important to note that changes in the tightness $x$ are associated with movements along the curve $\dot{n} = 0$, while those in the separation rate $\theta$ correspond to shifts of the curve $\dot{n} = 0$. For example, an increase in $\theta$ causes an upward shift of $\dot{n} = 0$ in the space $[s, v]$ which rises both $s$ and $v$ along the straight line $v = x_0 s$. Correspondingly, in equilibrium, increases in $\theta$ reduce the number $n$ of active researchers for any value of $x$. Thus, equations (8) and (10) describe the steady-state relationships between $n, s, v$ and $x$. However, to find equilibrium values for the aforementioned variables we need a further relationship that is derived from the behavior of firms and researchers in the TT market. This relationship describes the determination of the *fee rate* paid by firms to engage university researchers in new collaborations.

### 2.3 Firms

The crucial decision of firms concerns the opening of new collaborations. This decision depends on the current value of the expected future profits. We assume the time horizon is infinite. Each industrial firm solves an intertemporal optimization problem taking as given the aggregate conditions prevailing in the TT market, which are summarized by the ratio $x$. Therefore, individual firms disregard the effect of their decisions on $x$, and consequently on the probabilities $m(x)$ and $q(x)$.

For sake of simplicity, let's assume that each firm can offer at most one project. On one hand, if the project is matched, the collaboration starts and technology transfer occurs. The latter provides the firm with a constant flow of real profits (in terms of output) equal to $\pi$. Further, the firm pays a fee rate $k$ as an incentive for the suitable researcher to collaborate. The determination of $k$ is described below.

On the other hand, if the project is not filled the firm bears a flow cost $c\pi$, where $0 < c < 1$. The flow cost measures time and resources invested in the search for researchers and is a percentage loss of real profits. Therefore, firms find it attractive to offer a vacant project as long as its value, measured in terms of expected profits, is positive. The value that a firm assigns to a vacant project ($V$) and to a matched project ($Y$) can be obtained by means of the Bellman Equation. Given a constant real interest rate $r$, we can write the value functions in the two states of positive expected profits and unfilled project, respectively, as:

$$rY = (\pi - k) + \theta (V - Y) + \dot{Y} \tag{12}$$
$$rV = -c\pi + q(x)(Y - V) + \dot{V} \tag{13}$$

Equation (12) describes the flow return of a collaboration, which is given by: the value of the additional output flow minus the fee rate ($\pi - k$), plus the capital loss ($V - Y$) in case the collaboration is destroyed with probability $\theta$, plus the change in the value of the collaboration ($\dot{Y}$).

Similarly, equation (13) states that the flow return of a vacant project is equal to: a negative cost term ($-c\pi$) plus the capital gain in case the collaboration starts ($Y - V$), which occurs with probability $q(x)$, plus the change in the value of the vacant project $\left(\dot{V}\right)$.

Let's focus on the steady state of these relationships. In steady state, by definition, $\dot{Y} = \dot{V} = 0$ in equations (12) and (13). Moreover, under the assumption that firms continue to offer new projects until the value of the marginal vacant collaboration is reduced to zero, we may set $V = 0$ in (12) and (13) to obtain the following equilibrium conditions:

$$\begin{cases} Y = \frac{\pi-k}{r+\theta} \\ Y = \frac{c\pi}{q(x)} \end{cases} \Longrightarrow \pi = k + (r+\theta)\frac{c\pi}{q(x)} \tag{14}$$

The first equation of (14) states that the value of already active collaborations is equal to the constant value of the marginal profit flow $\pi - k$ discounted at rate $r + \theta$, to account for both impatience and the risk that the match breaks down. The second condition for $Y$ says that the equilibrium value of a vacant collaboration is equal to the expected costs of a vacant project, that is the flow cost of a vacancy $c\pi$ times the average duration of a vacant project $1/q(x)$. Equating these two expressions yields the final steady state solution (14): the marginal productivity of the project $\pi$ needs to compensate the firm for the direct marginal fee $k$ and for the indirect flow cost of opening a vacancy. The latter is equal to the product of the discount rate $r + \theta$ and the expected costs of a vacancy $\frac{c\pi}{q(x)}$. This last term is an indirect cost caused by the externality $x$ that generates a wedge between the marginal product of the collaboration and the fee rate. We label expression (14) as the *Collaboration Creating* condition (CC) and, in what follows, we prefer to write it as:

$$k = \pi - (r+\theta)\frac{c\pi}{q(x)} \tag{15}$$

Since $q_x < 0$, this expression shows the existence of a negative relationship between the tightness $x$ and the fee rate $k$: the higher $x$ is, the higher is the firm's indirect cost of searching for a collaboration, the smaller the fee rate that the firm is willing to pay in order to create a new collaboration is, given the additional profit $\pi$ provided by the the new project. Note that the size of the indirect cost is endogenous because it depends on the aggregate conditions $x$ prevailing in the TT market. For example, if the value of the marginal profit $\pi$ increases, then the collaboration will become profitable ($Y > 0$) and more firms will offer new projects. As a result, $x$ will increase, leading to a reduction in the matching rate for firms, and an increase in the average cost of a vacancy. Both these effects bring the value of a vacancy back to zero. Importantly, the marginal product of a new collaboration must exceed the fee rate to compensate the firm of the indirect cost. If $\pi = k$, as in a perfect-competition market, the shadow value of an additional project would be negative in the steady state, because the indirect cost would still remain uncover. The main implication of this result is that, in equilibrium, the firm needs the surplus $\pi - k > 0$ to create a collaboration with the university.

Finally, equation (14) still contains the fee rate $k$. This is an endogenous variable. Hence, the CC condition is not yet the steady-state condition that, together with (8), would allow us to solve for the equilibrium values of $n$ and $x$. To complete the model, we need to analyze the process of the fee rate determination.

## 3 Fee determination

In equilibrium any collaboration must generate a surplus. This surplus is shared during negotiations between the firm and university researchers. The negotiation determines the total surplus distribution and the fee rate value $k$.

Let us describe the university researchers' surplus. $W$ and $U$ denote the value that any researcher assigns to collaboration and search, respectively. As for firms, we express the values $W$ and $U$ by using the Bellman equations as:

$$rW = k + \theta (U - W) + \dot{W} \tag{16}$$

$$rU = \sigma + m(x) (W - U) + \dot{U} \tag{17}$$

For researchers the return on collaboration is equal to the fee rate $k$ plus the loss in value, if the researcher and the firm separate The latter occurs with probability $\theta$, plus any change in the $W$ value. The return on search is given by the subsidy $\sigma$ paid to the researcher not in a collaboration (that is his/her university salary), plus the gain if (s)he finds a new collaboration, plus the change in the value of $U$.

In steady state, i.e., when $\dot{W} = \dot{U} = 0$, we derive the surplus of the university researchers by subtracting (16) from (17):

$$W - U = \frac{k - \sigma}{r + \theta + m(x)} \tag{18}$$

Condition (18) states that the researchers' surplus positively depends on the difference between the fee rate and the subsidy ($k - \sigma$), and negatively on the separation rate $\theta$ and $x$: an increase in tightness $x$ (that is a higher probability to find a collaboration) increases the exit rate of searching and reduces the average search duration of researchers.

Therefore, the total surplus of the match between researchers and firms is equal to the sum of the firm's surplus ($Y - V$) and the researcher's surplus, ($W - U$).

Total surplus is divided between agents through a bargaining process. We take their relative bargaining strength to be exogenously given. Further, we adopt the assumption of Nash bargaining, which is a common assumption in models of bilateral negotiations. It can be written as:

$$\max_k (Y - V)^{1-\beta} (W - U)^{\beta} \tag{19}$$

where $0 \leq \beta \leq 1$ denotes the university's relative bargaining strength. From the FOCs we obtain:

$$(W-U) = \frac{\beta}{1-\beta}(Y-V) \tag{20}$$

or

$$(W-U) = \beta[(Y-V)+(W-U)] \tag{21}$$

that is, the surplus $(W-U)$ that the university appropriates in the negotiation is equal to a fraction $\beta$ of the collaboration total surplus. In steady state $(Y-V)$ is equal to $Y = \frac{\pi-k}{r+\theta}$ since $V=0$, therefore, by (18), we can write (20) as:

$$\frac{k-\sigma}{r+\theta+m(x)} = \frac{\beta}{1-\beta}\frac{\pi-k}{r+\theta} \tag{22}$$

Rearranging terms, using (14) and because $m(x) = q(x)x$, we obtain the following expression for the fee rate $k$ required by the university to enter into a new collaboration:

$$k = \beta(\pi-\sigma+cx) \tag{23}$$

It can be verified that the only influence of the TT market conditions on the fee rate occurs *via* $x$. This variable determines the average duration of a vacant project and, hence, the firm's expected costs in the case it continues to search for a collaboration.

The description of the model is completed by the equilibrium fee determination in the TT market and it can be summarized by equations (15), (23) (8) and (10), which we refer to as $CC$ (*Collaboration Creation* condition), $KK$ (fee rate equation), $ER$ (employed researchers) and $VP$ (vacancy projects):

$$\begin{aligned}
CC: &\qquad k = \pi - (r+\theta)\frac{\pi c}{q(x)} \\
KK: &\qquad k = \beta(\pi-\sigma+cx) \\
VP: &\qquad s = \frac{\theta N}{\theta+m(x_0)} \\
ER: &\qquad n_0 = \frac{m(x_0)s}{\theta}
\end{aligned}$$

The above system can be recursively solved for the endogenous variables $k, x$ and $s$. Then we can solve for $n$, knowing the definition for $N = s+n$. The first two equations ($CC$ and $KK$) jointly determine the equilibrium fee rate $k$ and the ratio $x$, as shown in the upper left-hand panel (a) of Figure 2. Given $x$, and using the $VP$ condition, we can determine the number $s$ of researchers in collaborations (panel (b)) and, consequently, the number $v$ of vacant projects, since $v = x_0 s$. Finally, we obtain the value $n_0$ compatible with the equilibrium ratio $x_0$ (panel (d)) using the identity $N = s+n$ (panel (c)).

The $CC$ curve slopes down in the $[x,k]$ space: higher values of $k$ make collaboration creation less profitable for firms that leads to a lower equilibrium ratio between collaborations $n$ and total researchers $N$. The $CC$ curve replaces the standard demand curve of the Walrasian model. Equation $KK$ is the fee rate required from the university for any researcher engaged in collaborations: the relative bargaining strength of TT market participants shifts in favor of universities at a higher values of $x$. The $KK$ function replaces the standard supply curve. Equilibrium $(x,k)$, which is unique, is reached at the crossing of the two curves $CC$ and $KK$. Further, panel (b) shows that the equilibrium $v$ mainly depends on the congestion $x$ prevailing in the TT market: any change in $x$ influences both $s$ and $n$ (panel (b) and (c)) and also affects the slope of the $v = xs$ curve.

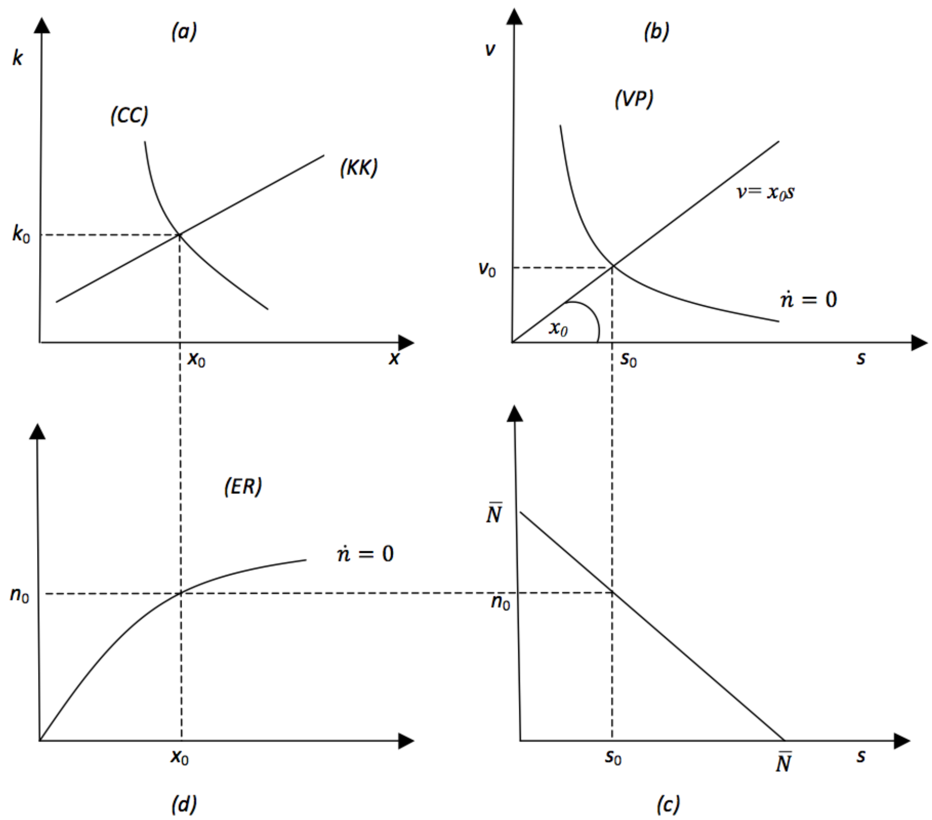


Figure 2: Equilibrium in the technology transfer market

## 4 Comparative statics

The above graphical representation allows us to develop the comparative static analysis of the model in the steady-state equilibrium.

In some cases, parameter changes have an unambiguous effect on all the endogenous variables. This occurs in the presence of an increase in the relative bargaining strength $\beta$ or in subsidies $\sigma$ (reservation wage): the only effect of these changes is an upward shift of $KK$ that causes an increase in the fee rate $k$ and a decrease in $x$. This change is accompanied by a decrease in $v$ along the $VP$ curve, with a corresponding increase in $s$ and a decrease in $n$ along the $ER$ curve. These movements are shown in Figure 3. The final effects of these changes is a destruction of collaborations, together with a rise in the number of researchers in search for new projects, and a decrease in vacant projects offered by firms.

In other cases, the effects are more complex to describe and not always of unambiguously signed. Consider, for example, the effects of the following two shocks. The first is

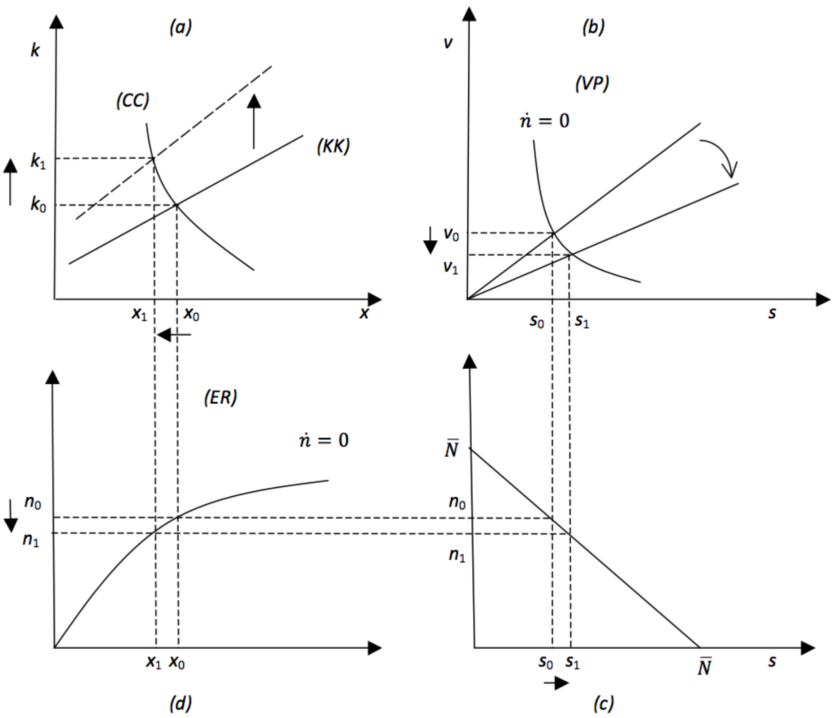


Figure 3: The effect of a rise in $\beta$ and $\sigma$

an "aggregate" disturbance that, in our set up, is natural to model as a change in the real profit $\pi$. The second disturbance is a "idiosyncratic" shock represented by a change in the separation rate $\theta$.

A reduction in real profit $\pi$ shifts both the $CC$ and $KK$ curves downwards. This change results in a reduction of the fee rate, but may have an ambiguous effect on $x$ according to the values of $\beta$. In the extreme case of $\beta = 1$, the whole matching surplus is captured by universities, and changes in productivity will affect only the fee rate $k$ with no effects on $x$. If we assume that $\beta < 1$, as in Figure 4, then our analysis shows that also the ratio $x$ decreases in steady state because along the $CC$ curve it holds that $\frac{\partial k}{\partial \pi} = 1$, whereas along the $KK$ curve $\frac{\partial k}{\partial \pi} = \beta$. In other words, when $\beta < 1$, lower productivity is associated with a lower vacancy-to-search ratio in the new steady state. In this scenario, the tightness decreases because both firms and researchers withdraw from the TT market. Afterwards, since the $VP$ curve does not shift, the rate $s$ increases while the number of vacant collaborations decreases, together with the number of researchers active in collaborations. Hence, the negative (positive) aggregate productivity shock destroys (creates) technology transfer in the steady-state equilibrium.

How should the TT market operate to avoid this mismatching? One strategic variable in our model is the policy parameter $M_0$. It represents public policies that promote collaborations between firms and universities by establishing, for example, efficient TT offices. Notice that, when $M_0$ increases, also the matching efficiency increases, with a positive long run effect on $n$ and a corresponding negative effect on $s$. Hence, public policies aimed at reinforcing the efficiency of TT offices must, at the same time, pursue an increase in the number of technology transfer matchings and reduce the distortionary effects of externalities that alter the relationship between universities and firms.

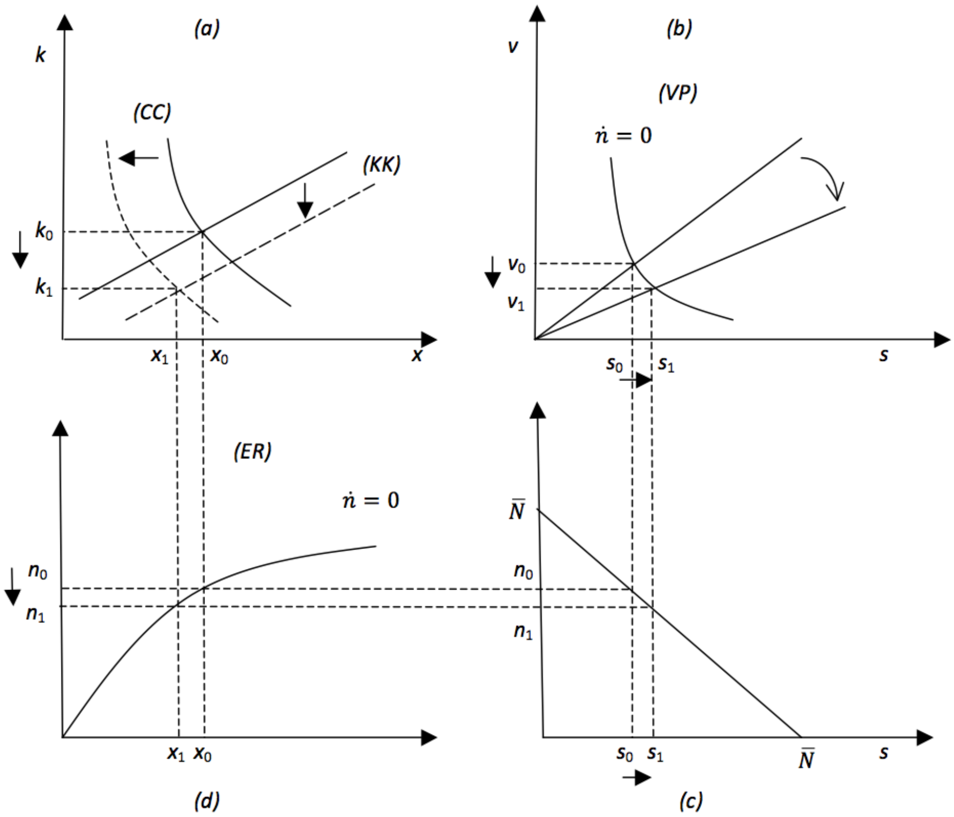


Figure 4: The effect of a decrease in profit $\pi$ with $\beta < 1$

Finally, in the case of negative idiosyncratic shocks, proxied by a rise in the separation rate $\theta$, we observe an inward shift of $CC$ along the $KK$ curve as in Figure 5. This shift results in a joint decrease of the fee rate and the tightness $x$, as in the case of the aggregate shock. At the same time, however, the curve $ER$ shifts to the right. The latter also implies a change in the $VP$ curve that shifts upwards along the new $v = xs$ curve. Hence, in general, while the level of $n$ and $s$ increase unambiguously, it is impossible to determine the effect of a change in $\theta$ on the number of vacant projects $v$. The result depends on the relative changes and shifts of both $VP$ and $v = xs$, in the space $[v, s]$.

Therefore, the effects on collaborations of shocks in the TT market occur as a result of either creation or destruction of vacant projects. But the fact that the fee rate $k$ responds substantially to shifts in $CC$ (the implicit demand curve) does not incentive firms to offer new vacant projects. As a result, search and matching models of technology transfer, as the one considered here, can only imply small effects on technology transfer in the presence of shifts in collaboration demand.

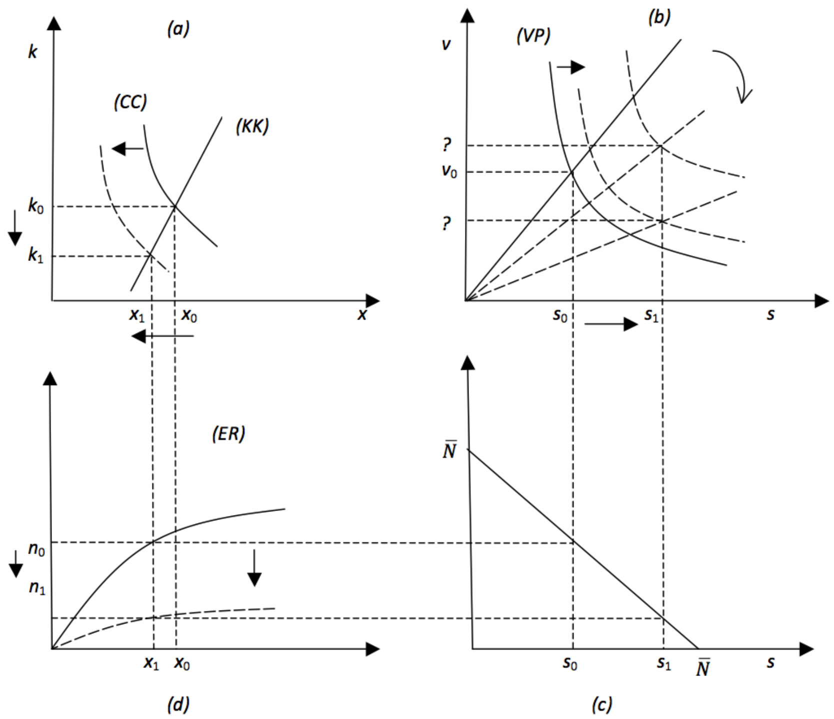


Figure 5: The ambiguous effect of a rise in the separation rate $\theta$

## 5 Conclusions and policy remarks

The model outlined in this paper is a first attempt to focus on the main features that characterize the technology transfer process between universities and firms. Our basic model studies the impact on collaboration creation and destruction of some variables traditionally involved in this process namely, the expected profit, the cost of researchers, the relative bargaining strength of agents, and the separation rate that determines the duration of a collaboration. We were able to obtain endogenous collaboration creation and destruction processes, and study their properties in the steady state.

A first result shows that the functioning of the TT market implies a trading externality. It arises because of the probabilities that a firm searching for a collaboration does not meet a suitable researcher, and an unemployed researcher does not find a suitable firm, whatever the level of market prices. However, the tightness of the TT market, and the corresponding probabilities of researchers and firms, can change by changes in the relative number of agents in the market. If the ratio of firms to searching researchers increases, the probability of rationing is higher for the average firm and lower for the average researcher, and conversely when the ratio decreases. We have referred to these dual externalities as *congestion* because they are caused by the tightness that searching firms and researchers produce to each other during trade.

As discussed above, creation and collaboration destruction are due to aggregate and idiosyncratic shocks that take place independently of the matching process, which determines the collaboration creation.

Changes in aggregate conditions, that is changes in profits, do affect the cutoffs that induce firms to look for new collaborations or close existing ones. So, projects reallocation can vary over the business cycle, even if the matching processes that cause it do not. Then, we have shown that, at higher profits, the probability that a researcher finds a collaboration is higher, and the probability that a collaboration is destroyed is lower. At the same time, an increase in the vacancy–search ratio reduces the firm probability that a vacancy is filled, but rises the probability that a researcher finds a suitable vacant collaboration.

Further, the dynamic analysis of collaboration creation and destruction, in the presence of random separation rates, has revealed that the final effect on vacant projects is ambiguous and depends on the supply elasticity of firms offering new collaborations. When the separation rate rises, the search rate rises unambiguously, but it is not possible to determine the effect of this change on the number of vacant projects. They depend on the relative variations of collaboration creation and destruction probabilities, that is on trading externalities.

The latter result suggests that a non negligible portion of researchers in search for collaborations is largely inevitable and results from the functioning of the economy and the complexity of the TT market.

Our is a basic model with a few crucial variables at work. Indeed, some important aspects remain still unexplored. Among these, we number the role of capital accumulation in affecting productivity, the quality of capital employed, the endogeneity of the separation rate, the existence of a reservation productivity for which firms prefer to destroy old collaborations, the role of researchers' search intensity, the collaboration advertising by firms and the role of policies aimed at promoting technology and knowledge transfer from universities to firms. All these aspects are crucial to improve the quality of collaborations and will be incorporate in our future models.

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