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"Technology transfer with search intensity and project advertising"

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Technology transfer with search intensity and project advertising

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Abstract

In this paper we present a model where technology transfer is embedded into a competitive model of utility and profit maximization and is the result of a matching process between heterogeneous Knowledge Transfer Offices (KTOs) and innovative firms. Our model improves on previous literature by endogenizing the process that drives the dynamics of university researchers in search and firm vacant projects. We are able to show that the KTOs' reservation fee rate must be greater than the ratio between the marginal researcher cost and the marginal utility of matched projects, and that technology transfer strictly depends on the efficiency units of searching researchers and vacant projects. Further, we show that firm technological progress might be too low when KTOs too much intensively search for project matches. This occurs because both sides of the market ignore the externalities of their decisions. Finally, behavioral complementarity, substitutability, and free riding are all potential equilibrium outcomes.

Keywords: Technology transfer; Matching; Externalities.
JEL Code: O31 O32

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1 Introduction

In this paper we study the functioning of a decentralized and heterogeneous Technology Transfer (TT) market, in which technology transfer is the result of a matching process between heterogeneous universities' Knowledge Transfer Offices (KTOs) and innovative firms. We improve previous microfounded theoretical literature on university-industry (U-I) collaborations (Leyden and Link 2013b; Calcagnini et al. 2015b) by embedding TT into a competitive model of utility and profit maximization (Shi and Wen 1997). In other words, our model endogenizes the process that drives the dynamics of university researchers in search and firm vacant projects by assuming that unemployed researchers choose their search intensity and firms their projects' advertising expenditure.

We provide a microfoundation of U-I collaborations by adding some additional features that characterize the actual functioning of the TT market. Specifically, in our model unemployed researchers decide their optimal search intensity on the basis of their search costs and the fee rate they expect to receive once entered in a TT project. This assumption is strictly related to the concept of academic engagement, namely, a '*knowledge-related collaboration by academic researchers with non-academic organizations*' (Perkmann et al. 2013 p. 424). These collaborations are often driven by the personal effort of individual researchers (Link et al. 2007)

Firms also search for researchers by advertising their vacant projects. In this perspective, among the factors that affect the intensity of firms' collaborative effort in innovative projects, it has been shown that internal knowledge, appropriability conditions and incoming spillovers explain a large variation of the probability and intensity of R&D collaborations of European firms with universities (Aristei et al. 2015).

Thus, researchers and firms influence the matching outcome through their choice of search intensity and project advertising. The matching between researchers and firms requires that both monetary and implicit costs must be covered in equilibrium to provide a positive surplus that satisfies their objective functions.

We then investigate whether the steady state equilibrium in the TT market is efficient, and focus on the optimal steady state allocations. We show that if both firms and KTOs search the other side of the market there will be either too much or too low technology transfer in equilibrium. This occurs because both firms and KTOs ignore the externalities of their decisions, so they can search either too little or too much. In general, the project-matching probability is an increasing function of the search intensity of the other side of the market, but this dependence is ignored by single agents. We refer to these externalities as congestion because they are generated by the tightness – as measured by the ratio between vacant projects and researchers in search – that firms and researchers cause to each other during search (Pissarides 2000; Calcagnini et al. 2015b).

Our paper is also related to other strands of the TT literature. Theoretical models of TT often referred either to the triple helix approach or to the linear model of innovation. The former uses an evolutionary framework to study the relationship among universities, industry and government at macro level perspective (Leydesdorff 2000). The latter postulates that innovation starts with basic research, followed by applied research and development, and it eventually ends with production and diffusion (Godin 2006). However, also in the managerial literature, this traditional view recently changed in favor of a microfoundation approach of the relationship among the three main actors of innovation. Barney and Felin (2013) focus on the matching between individuals and organizations, while Cunningham et al. (2015) study the factors that induce researchers to become a principal investigator. They labelled the influencing factors as push (project dependencies and institutional pressures) and pull (control, career ambition and advancement) factors. In addition, recent empirical microfounded TT models give a great attention to the analysis of the aggregation, capability development, joint production motivation and value creation (Barney and Felin 2013; Foss and Linbenberg 2013; Winters 2013).

Moreover, other contributions showed that collaborations in innovative projects may help firms to exploit economies of scale, spread the risk of the investment, and acquire specialized knowledge (Link and Scott 2005). Among innovative firms, cooperation in innovation activities with research institutions affect positively a company's involvement in R&D activities (Conte and Vivarelli 2014). Meoli et al. (2013) showed that the affiliation of firms with universities is recognized beneficial by investors because it enhances the firm valuation and the probability of being targeted in subsequent M&As, particularly in cross-border deals.

Finally, the functioning of U-I collaborations is crucial to economic growth and the creation of new jobs (Audresch and Lehmann 2005; Link and Welsh 2013), while university spillovers positively affect the creation of innovative start-ups (Calcagnini et al. 2015a) and the commercialization of knowledge as well as basic research in the long run (Audresch et al. 2005). Hence, U-I collaborations contribute to convert knowledge into economic innovations and affect economic growth over time (Braunerhjelm et al. 2010; Leyden and Link 2013a).

Recent data suggest a close relationship between U-I collaborations, technological progress and country competitiveness. The World Economic Forum (2015) considers innovations as one of the twelve pillars of global competitiveness of countries. Indeed, such technological advancements depend on investment in research and development, and the presence of high-quality scientific research institutions, but also on extensive collaborations in research and technological developments between universities and industries. Scores for some key countries show that the United States is the most competitive and innovative country, and also displays the most intensive U-I collaboration in R&D (World Economic Forum 2015, p. 378-379). Diversely, Italy has the lowest score and the lowest degree of U-I collaborations, consequently it is also the less competitive and innovative country (World Economic Forum 2015, p. 222-223).[1]

Thus, data suggest the presence at country level of heterogenous TT markets characterized by relevant differences in the intensity and the efficacy of U-I collaborations. In fact, KTOs have been considered a priority by the 2008 European Commission's Recommendation that defines knowledge transfer as a strategic mission of public research organizations. However, its implementation shows a significant variability among European countries: the UK and Germany show the highest stage of implementation of the KT Recommendations, followed by France and Italy (European Commission 2013, Exibit A, p. 9). Moreover, other differences also emerge when considering the share of university research funded by firms or the share of firms' R&D expenditure devoted to support university research (Netval 2015 fig 9.1 p. 179). Again, Italy falls behind Germany, UK and France.

Heterogeneity also exists at the university level and is caused by both demand- and supply-side factors, such as the functioning of the KTOs. Interesting, Netval (2015) finds that Italian universities that between 2004-2010 had the lowest income from collaboration agreements with industries, in 2012 invested relatively more resources (per KTO employee) in order to fill the gap

[1]The other countries selected are: France, Germany, Japan, and United Kingdom. See World Economic Forum (2015) for a detailed description of the scores and ranking reported for each country.

with those universities more active in such collaborations (Netval 2015, fig. 9.3, p. 181). Demand factors, such as firm size or firm innovative activity, also affect the actual functioning of the U-I collaborations: small-sized and the less innovative firms have fewer collaboration agreements with universities (Netval 2015, p. 179).

Our model aims at developing a general setup to study the determinants of U-I collaborations and how these collaborations are affected by externalities and policies, often neglected aspects of the economic growth.

We obtain three main results. First, from the micro foundation of the matching process we show that KTOs' reservation fee rate must be greater than the ratio between the marginal researcher cost and the marginal utility of matched projects. Similarly, firms participate to a TT project only if the marginal productivity of an innovative project is greater than the fee rate paid to the KTO in order to engage a new researcher in the project. These conditions generate a global surplus that must be shared among agents. Second, the TT strictly depends on the efficiency costs of searching researchers and vacant projects. This occurs because, for a given number of potential projects and researchers in search, the number of matches increases when KTOs and firms search more intensively. Importantly, the optimal level of search intensity and project advertising is chosen so that the elasticity of their (efficiency) cost is independent of market variables, and only depends on the cost function properties. Finally, our model also considers the stock of technological progress of the economy that affects firm costs and production. We find that in steady state, externalities generate an ambiguous result for the technological progress, which is due to the presence of an endogenous relationship between the tightness and the technological progress. For example, if the KTOs search too intensively the other side of the market for project matches, firms can find optimal to reduce the number of innovative projects in order to fill the current vacant projects. Consequently the stock of technology may decrease.

This endogenous relationship is caused by the externalities of tightness and search efforts. Hence, firms and researchers can influence the equilibrium outcome of the TT market through their choice of search intensity and project advertising and their decision to accept an innovative project or to move out from an active one. This aggregate behavior of the agents also determines the technology stock in steady state. Behavioral complementarity, substitutability, and free riding are all potential equilibrium outcomes.

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

2 Decentralized economy

2.1 KTOs

Consider an economy with many identical KTOs. Each KTO consists of many researchers. At any time, a researcher spends time in two activities: working in a technology transfer project (TTP) or searching for a vacant project. A researcher in searching for a new TTP is termed unemployed and is randomly matched with vacant projects offered by innovative firms according to a matching function described below. Researchers and firms can influence the matching outcome through their choice of search intensity and project advertising. The implications of their decisions for equilibrium technology transfer and technological progress are then analyzed and discussed.

Search intensity and project advertising, which affect utility and profits, can be represented as cost functions. If unemployed researchers or vacant firms search more intensively for a match, for given researchers and vacancies, the number of matched projects rises. However, this effort requires resources and implies costs.

Let $a \geqslant 0$ be a variable measuring the intensity of search and $C(a)$ its corresponding efficiency cost, that is the utility cost that researchers in search bear at each time t. The researchers' cost function is such that $C(a) = 0$ when $a = 0$, and $C_a > 0$ when $a > 0$. As for the KTO's their *cost function* can be written as $h[n_t + s_t(1 + C(a))]$, where n is the number of researchers already employed in TTPs, s the number of the unemployed researchers in search, and h is the weight of the aggregate utility cost of KTOs.

The KTO utility function is

$$U = \int_0^\infty \{u(z_t) - h[n_t + s_t(1 + C(a))]\} e^{-\rho t} dt \tag{1}$$

Here, z_t is the number of TTPs (control variable), in the hand of each KTO, which determines its utility level $u(z_t)$ with $u_z > 0$ and $u_{zz} < 0$. ρ is the rate of time preference, or the subjective discount rate, which is assumed to be constant and strictly positive. We further assume that the number N of researchers is given so that $N = n_t + s_t$.

The composition $n_t + s_t$ gradually changes as researchers find new projects or researchers separate from previous projects.

Now, let m be the rate at which researchers find a TTP, so that ms_t is the flow of matched projects for a KTO that has s_t researchers in search, and $1/m$ is the average duration of search. As explained below, the probability m depends on the aggregate number of vacant projects and researchers in search. However, each individual KTO takes m as given.

Let θ be the separation rate which generates the flow of researchers ending previous collaborations. Given θ, collaborations remain productive for an average period of $1/\theta$. Then, the law of motion of n_t is

$$\dot{n} = ms_t - \theta n_t \tag{2}$$

From equation (2) we can write the steady state as

$$n^* = \frac{ms}{\theta} \tag{3}$$

The maximization problem of the representative KTO can be written as

$$\begin{aligned} &\max_{z,s,a,n} \{U\} \text{ s.t.} \\ &\text{(2) holds} \\ &a \geqslant 0 \end{aligned}$$

with

$$\dot{g} = rg_t + fn_t - \gamma z_t \tag{4}$$

In equation (4), g_t is the KTO financial wealth, which is equal to the holdings of capital k_t minus debts d_t, i.e., $g_t \equiv k_t - d_t$. Here, r is the interest rate, f the fee rate paid by the firm to the KTO for the researchers engaged in TTPs, and γ the (monetary) cost of any project z_t.

At any time t the KTO supplies both researchers and (the share of) capital such that it chooses how many projects participate and researchers engage.

The current Hamiltonian of the problem is

$$\begin{aligned} H_c^{KTO} = \; & \{u(z_t) - h[n_t + s_t(1 + C(a))]\} + \mu_t [ms_t - \theta n_t] + \\ & + \lambda_t (rg_t + fn_t - \gamma z_t) + \psi_t(a) \end{aligned} \tag{5}$$

where μ_t, λ_t and ψ_t are the shadow values of constraints.

Ignoring time subscripts to simplify notation, the optimal solution satisfies the following first order conditions

$$z \quad : \quad \lambda = \frac{u_z}{\gamma} \tag{6}$$

$$s \quad : \quad \mu = \frac{h\left[1 + C\left(a\right)\right]}{m} \tag{7}$$

$$a \quad : \quad \psi = hsC_a \text{ with } a > 0 \tag{8}$$

$$n \quad : \quad \dot{\mu} = \left(\theta + \rho\right)\mu - \left(\lambda f - h\right) \tag{9}$$

$$g \quad : \quad \dot{\lambda} = \left(\rho - r\right)\lambda \tag{10}$$

Equation (6) states that the marginal utility of a TTP (z_t) has to be equal to its marginal costs, while equation (7) characterizes the optimal number of researchers in search so that the marginal benefit of search μ equals the marginal search cost $\frac{h[1+C(a)]}{m}$.

Equation (8) provides the optimal level of search intensity. Integrating this expression by a and substituting the resulting expression back by ψ, we obtain the optimal condition:

$$\frac{aC_a}{C(a)} = 1 \tag{11}$$

Equation (11) states that the optimal level of search intensity a^* is chosen so that the cost elasticity with respect to a is equal to 1. The latter condition is closely connected with the determination of the efficiency–wage of the Solow (1979) model, in which firms control both the effort provided by each worker and the number of workers. Similarly to Solow (1979), here the KTO chooses both the number of researchers in search and their effort in searching a vacant project in order to minimize the searching costs. The optimal level of effort a^* only depends on the properties of the cost function, but is independent of market variables.

An additional feature characterizes the optimal solution that satisfies the system of first order conditions. In equation (9), $\dot{\mu} = 0$ in steady state. Thus, as long as $\mu > 0$, $(\lambda f - h)$ needs to be greater than zero. That is, different from a standard neoclassical model, here the fee rate f must exceed the ratio between the marginal researcher cost and the marginal utility of matched projects. Indeed, if $f = \frac{h}{\lambda}$ the shadow price of researcher's matched project would be zero in steady state and as well as the search effort and the number of researchers employed in technology transfer. Hence, we refer to $\frac{h}{\lambda}$ as the reservation fee rate and the difference $\lambda f - h > 0$ or $f - \frac{h}{\lambda} > 0$ measures the researcher's surplus.

Finally, combining equations (7) and (9) we obtain

$$\frac{f\frac{u_z}{\gamma} - h}{\theta + \rho} = \frac{h\left[1 + C\left(a\right)\right]}{m} \tag{12}$$

that is the actual value of researchers' surplus must equal the actual (marginal) value of their searching costs.

2.2 Firms

Many identical firms operate in the TT market. Each firm has vacant TTPs (v) and aims at realizing new technology transfers. In our model, A is the current stock of technological progress, which is taken as given by each firm. We assume that the cost of filling vacant projects positively depends on the stock of technology and the level of advertising b of vacant projects (Pissarides, 1984). Thus, the cost of maintaining a number v of vacant project is $A\left[1 + B(b)\right]v$, where $B(b)$, with $b \geqslant 0$ and $B_b > 0$, is the additional cost that firms bear for advertising.

Let q be the rate at which a project is matched with researchers in search. As m, the rate q is a probability that depends on the number of aggregate vacant projects and researchers. q is given for an individual firm. Then the evolution of n, given the separation rate θ, might be written as

$$\dot{n} = qv_t - \theta n_t \tag{13}$$

The representative firm maximizes the present value of its (real) profits (π_t)

$$\begin{aligned} &\max_{z,s,a,n} V = \int_0^{\infty} \pi_t e^{-rt} dt \text{ s.t.} \\ &(13) \text{ holds} \\ &b \geqslant 0 \end{aligned}$$

where

$$\pi_t = AF\left(k_t, n_t\right) - \left(r + \delta\right)k_t - fn_t - Av_t\left[1 + B(b)\right] \tag{14}$$

Here, $Y_t = AF\left(k_t, n_t\right)$ is the production function, increasing and concave in both the arguments. r is the constant interest rate, δ the rate of capital depreciation and f the fee rate that is taken as given.

The corresponding current Hamiltonian is

$$H_c^{Firm} = \pi_t + \phi_t \left(qv_t - \theta n_t \right) + \varepsilon_t \left(b \right) \tag{15}$$

where ϕ_t and ε_t are the shadow values of constraints. Ignoring for simplicity time subscripts, the first order conditions are

$$k \; : \; AF_k = r + \delta \tag{16}$$

$$v \; : \; \phi = \frac{A\left(1 + B(b)\right)}{q} \tag{17}$$

$$b \; : \; AvB_b = \varepsilon \tag{18}$$

$$n \; : \; \dot{\phi} = \left(r + \theta\right)\phi - \left(AF_n - f\right) \tag{19}$$

Equation (16) states that capital k is chosen so that its marginal product equals its marginal cost. Equation (17) states that the optimal number of vacant projects is such that the marginal cost $A\left(1 + B(b)\right)$ of a vacancy equals its marginal benefit ϕq.

Further, from equation (18) we find that, as for the optimal search intensity, the optimal advertising b^* is independent of the market variables, but only depends on the properties of the cost function. Indeed, integrating equation (18) by b and substituting the resulting expression back by ε we obtain:

$$\frac{bB_b}{B(b)} = 1 \tag{20}$$

that is, the firm uses the level of advertising to minimize the cost of each vacant project so that the cost elasticity with respect to b is equal to 1. Equation (20) provides the optimal level b^*.

Finally, from equation (19) we obtain the firm surplus from a matching. In steady state, the condition $\left(\dot{\phi} = 0\right)$ implies that $AF_n - f > 0$ in order to compensate the firm for maintaining vacant projects. Otherwise, if $AF_n = f$ then the shadow price ϕ of the vacant project would be zero in steady state, and the firm would not have any incentive to offer new vacant TTPs. We will refer to $\phi = \frac{AF_n - f}{r + \theta}$ as the actual value of a firm's surplus from matching.

Equating the latter expression for ϕ with (17) yields the steady state solution for the firm. We label this solution as the *fee determination* condition (*ff*), which might be written as:

$$f = A\left[F_n - \frac{1 + B(b)}{q}\left(r + \theta\right)\right] \tag{21}$$

Note that the value of the fee rate f is endogenous because it depends on the aggregate conditions prevailing in the TT market. In the following Sections we will show that f affects both the probability q and the number of the employed researchers.

3 Matching and fee rate determination

TTP vacancies and researchers are randomly matched with each other. However, the aggregate flow of TTP matches are deterministic and given by a matching function. Further, the number of actual matches are also determined by researchers' search intensity of and firms' advertising expenditure. The matching function in the TT market is written as

$$M\left(as, bv\right) = M_0 \left(as\right)^{1-\alpha} \left(bv\right)^{\alpha} \tag{22}$$

where as defines the efficiency units of searching workers, bv the efficiency units of TTP vacancies and M_0 is a positive constant that might be interpreted as a policy parameter. M_0 captures public policies that promote collaborations between firms and universities by establishing, for example, efficient TT offices (TTOs). When M_0 increases, the number of matches also increases (Calcagnini et al 2015b).[2]

The variables a and b are market averages. The matching function exhibits constant returns–to–scale, as showed by Pissarides (1986) and Blanchard and Diamond (1989).

Let $x = v/s$ be the the ratio between vacant projects and researchers in search. We define x as the tightness of the TT market, that is, firm vacant projects in excess of the number of researchers in search (Pissarides, 2000). Therefore, smaller x represents a situation characterized by a higher number researchers in search than vacant projects. In other words, researchers would match suitable projects less easily than in the presence of a higher number of vacant projects (i.e., higher x).

The probability of a successful match between researchers and firms are calculated looking at the difference between individual search intensities and

[2]Bozeman (2000) recognizes the active role of governments and universities in technology development and transfer. Governments act as producers of research, supplying applied research and technology to industry, or as brokers who design policies for industrial technology development and innovation. Thus, public policies are crucial to fostering U-I cooperation.

the market average. Let a_i be the intensity of researcher i. The mean probability to find a suitable firm is $M(as, bv)/as$. Therefore, the probability of researcher i is given by

$$m_i \equiv m(x, a, b) = a_i \frac{M_0 (as)^{1-\alpha} (bv)^{\alpha}}{as} \tag{23}$$

In general, the researcher i chooses a_i during search taking all the other variables of probability function m as given.

Similarly, let b_j be the advertising expenditure supplied by the firm j. The mean probability of a firm to find a suitable researcher is $M(as, bv)/bv$. Hence, the probability of firm j is

$$q_j \equiv q(x, a, b) = b_j \frac{M_0 (as)^{1-\alpha} (bv)^{\alpha}}{bv} \tag{24}$$

But, in a symmetric Nash equilibrium all researchers and firms choose the same level of intensity and advertising. Thus, $a_i = a$ and $b_j = b$. Consequently, the previous two expressions become

$$m_i = m(x, a, b) = \frac{M_0 (as)^{1-\alpha} (bv)^{\alpha}}{s} = M_0 a^{1-\alpha} b^{\alpha} x^{\alpha} \qquad \forall i \tag{25}$$

$$q_j = q(x, a, b) = \frac{M_0 (as)^{1-\alpha} (bv)^{\alpha}}{v} = M_0 a^{1-\alpha} b^{\alpha} x^{\alpha-1} \qquad \forall j \tag{26}$$

where $m(x, a, b) = q(x, a, b)x$.

By definition, $1/m(x, a, b)$ is the average search duration and $m_x, m_a, m_b > 0$. Also $1/q(x, a, b)$ is the average vacancy duration. However, note that $q_x < 0$ and $q_a, q_b > 0$. The dependence of m and q on x captures the dual externality between agents in the market (Pissarides, 2000): an increase in the number of vacancies v relatively to researchers s increases x and the probability that a researcher will find a collaboration ($m_x > 0$) for given a and b. However, the probability that a vacancy will also be filled decreases ($q_x < 0$).

3.1 Fee determination

In equilibrium, any TTP must generate a surplus. This surplus is shared between firms and KTOs during negotiation, which determines the total surplus distribution and the fee rate f. As in the previous Sections, we assume that the fee rate is determined by Nash bargaining (bilateral negotiations), which maximizes the product of weighted surplus of researchers and firms. Taking the relative bargaining strength β exogenously given, the maximization problem can be written as

$$\max_f \left(\frac{f\frac{u_z}{\gamma}-h}{\theta+\rho}\right)^{\beta}\left(\frac{AF_n-f}{r+\theta}\right)^{1-\beta} \tag{27}$$

From the FOCs we obtain

$$\frac{f\frac{u_z}{\gamma}-h}{\theta+\rho}=\frac{\beta}{1-\beta}\frac{AF_n-f}{r+\theta} \tag{28}$$

Rearranging terms, using equations (6) and (12) and remembering that $m(x,a,b) = q(x,a,b)x$, we obtain the fee rate f required from KTOs to enter into a new TTP

$$f=\frac{1}{\lambda}\left\{h+\beta\left(\theta+\rho\right)\left[h\left(1+C(a)\right)+A(1+B(b))x\right]\right\} \tag{29}$$

with $\lambda=\frac{u_z}{\gamma}$ from equation (6). Given the Nash negotiation, all researchers require the same fee rate in any symmetric equilibrium. Therefore, as argued above, $f\in\left(\frac{h}{\lambda},AF_n\right)$ to assure the existence of a surplus.

3.2 Equilibrium

Now we consider the steady state equilibrium in the TT market when search intensity a and vacant project advertising b are determined by their respective efficiency conditions (11) and (20). The equation describing the stock of the researchers in search is obtained substituting $n=N-s$ in (3) and rearranging the expression to obtain

$$s=\frac{\theta N}{\theta+m(x,a,b)} \tag{30}$$

As $m_x>0$, the number of researchers in search decreases when the tightness of the TT market x increases. Indeed, the higher x is, the easier researchers will find suitable vacant projects.

Finally, to complete the description of the economy, we need two further equations, one for the fee rate and one for the tightness x. Equation (21) defines the fee rate. The equilibrium condition between the fee rate f and tightness x in the TT market can be obtained from equation (28) by substituting (12) in its LHS, and by combining equations (19) and (17) in its RHS. Rearranging terms, and recalling that $m(x,a,b)$ is equal to $q(x,a,b)x$ we obtain

$$h\left[1+C(a)\right]=\frac{\beta}{1-\beta}A\left[1+B(b)\right]x \tag{31}$$

We underline that (31) is not a behavioral equation but, after solving for the fee rate f, it describes the relationship between A and x given the optimal values of search intensity and advertising expenditure that hold in equilibrium. Hence, (31) describes the link between technology and the tightness in the TT market.

Thus the model can be summarized by Eqs. (11), (20), (31), (30), ($n=N-s$), and (21), which we refer to as aa (optimal search intensity), bb (optimal project advertising), xx (equilibrium tightness), ss (optimal researchers in search), nn (optimal researchers in projects), ff (fee determination), respectively

$$\begin{aligned}
aa &: \quad \frac{aC_a}{C(a)}=1\\
bb &: \quad \frac{bB_b}{B(b)}=1\\
xx &: \quad h\left[1+C(a)\right]=\frac{\beta}{1-\beta}A\left[1+B(b)\right]x\\
ss &: \quad s=\frac{\theta N}{\theta+m(x,a,b)}\\
nn &: \quad n=N-s\\
ff &: \quad f=A\left[F_n-\frac{1+B(b)}{q(x,a,b)}(r+\theta)\right]
\end{aligned}$$

The problem has a recursive structure. From aa and bb we obtain the optimal search intensity a^* and project advertising b^*. From xx, given the stock of technological progress A, we obtain the equilibrium value of the tightness x^*. Once a, b, and x are known, conditions (25) and (26) provide the probabilities that researchers and firms will match in the market, $m(x,a,b)$ and $q(x,a,b)$ respectively. Finally, by substituting these values in equation ss, nn and ff, we obtain the number of researchers in search and, consequently, the number n^* of the researchers already engaged in TTPs and the corresponding equilibrium fee rate f^*.

The properties of the intensity–tightness block (aa–ff) determine the unique steady state of the model. In equilibrium, aggregate private debt d_t is zero, so that $g_t = k_t$. By using this condition and equation (4) we obtain $\dot{k} = rk_t + fn_t - \gamma z_t$ and the steady state value of capital when $\dot{k} = 0$ with the corresponding firm's profit:

$$\begin{cases} k^* = \frac{\gamma z^* - f^* n^*}{r} \\ \pi^* = AF(k^*, n^*) - (r + \delta) k^* - f^* n^* - Av^* [1 + B(b^*)] \end{cases} \tag{32}$$

where $v^* = x^* s^*$.

Furthermore, after the steady state fee rate is calculated, equations (6) and (29) provide the optimal marginal utility value $u_z = \gamma \lambda^*$ in equilibrium, and consequently the number z^* of TTPs together with the utility level $u(z^*)$.

Finally, we can derive further insights into the nature of the optimal solution by examining the KTO's investment path. To this end, we totally differentiate (6) with respect to time and use the result with (10) and (16) to obtain:

$$\dot{z} = -\frac{u_z}{u_{zz}} [(AF_k - \delta) - \rho] \tag{33}$$

where $-\frac{u_z}{u_{zz}} > 0$ given that $u_{zz} < 0$. The latter equation indicates that the optimal flow of TTPs will increase (decrease) if and only if the net marginal rate of return of projects is larger (smaller) than the subjective rate of discount: it pays to have a larger number of higher future TTPs relative to present projects if the cost of postponing them is smaller than the gains they provide through their marginal effect on net capital return. This is a standard efficiency condition that must be satisfied along the optimal path.

4 Matching and technological progress

In this Section we focus on the relationship between x and A in equilibrium, and how this equilibrium relationship is affected by trading externalities. The trading externalities are caused by the congestion that searching firms and researchers cause each other during search (Pissarides 2000, pp. 7–8). 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 s increases the probability that a researcher will find a collaboration ($m_x > 0$), but at the same time it reduces the probability that a vacancy will be filled ($q_x < 0$) (Calcagnini et al. 2015, pp. 4-5).

Thus, the relationship between x and A is not unique. The possibility of non-uniqueness arises because of positive and negative trading externalities that operate in opposite directions, leaving the final impact of the tightness on the stock of technology unsigned *a priori*. Indeed, the tightness x rises because of (a) an increase of the number of firm vacant projects v or (b) a decrease in the number of researchers in search s. In the former scenario, firms affect positively the probability that a researcher will find a collaboration, and thus the number of effective TTPs, by offering more innovative (vacant) projects. This positive externality affects the stock of technology the value of which rises in steady state. In the latter scenario, KTOs reduces the number of researches in search and, consequently, cuts the probability that firms will find a suitable research and the number of matches and TTPs realized. This negative externality negatively affect the aggregate stock of technology in steady state.

Therefore, search externalities may have two opposite effects on the equilibrium relationship between x and A: the positive externality makes A an increasing function of x (for given a and b), and at the same time the negative externality makes A a decreasing function of x. Consequently, different allocations (x, A) may result in steady state. Obviously, this unpredictable relationship opens new perspectives on technology advancements.

To study this crucial issue we focus on the equilibrium conditions (xx) and $(ff\ )$ of our model. It is useful to rewrite these two equations as

$$x(A) \quad : \quad x = \frac{1-\beta}{\beta}\frac{h\,[1+C(a)]}{[1+B(b)]}A^{-1} \tag{34}$$

$$A(x) \quad : \quad A = \frac{f}{F_n - \frac{1+B(b)}{q(x,a,b)}\,(r+\theta)} \tag{35}$$

From equation (34) we see that $x_A < 0$, whereas in equation (35) a positive fee rate f requires that $F_n - \frac{1+B(b)}{q(x,a,b)}\,(r+\theta) > 0$. Then, in the second equation $A_x > 0$, as $q_x < 0$. These equations are depicted in Figure (1) and labelled as $x(A)$ and $A(x)$, respectively. The curve for the equilibrium condition in search and advertising $x(A)$ is convex and decreasing in x, while the collaboration creating condition $A(x)$ is concave and increasing in x, so their intersection is unique.

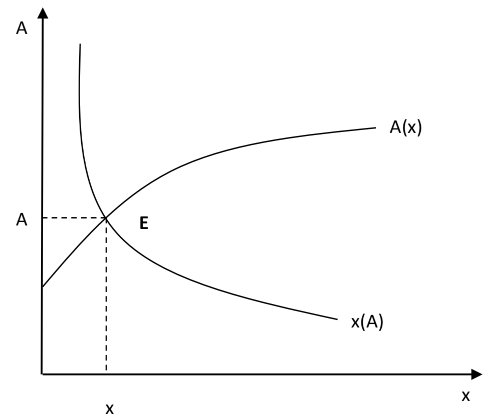

Figure 1: TT-market tightness and technological progress in equilibrium

Equations (34) and (35) suggest that search intensity a and project advertising b have a potentially important role to play in the determination of the long-run equilibrium. These parameters can be thought as "technical change" parameters in the matching technology. A change in the cost structure of researchers or firm in the long run determines different levels of optimal search intensity or project advertising, respectively. Thus, a and b enter the relationship between researchers in search and vacant projects as shift variables so they can actually influence the number of TTPs and the stock of technology in steady state, independently of the effective number of vacant projects in the TT market. In the next Section will show that changes of search intensity and project advertising can have ambiguous effects on the evolution of the technological progress, i.e.: if researchers search more intensively for a match, the aggregate stock of technology could be reduced.

Furthermore, the equilibrium conditions (34) and (35) suggest that the relationship between technological progress and the tightness crucially depends on the assumption that we make about the changes in the relative bargaining power β and the fee rate f.

4.1 Comparative statics

Starting from the equilibrium, exogenous variations of the model parameters might affect the tightness that, in turn, determines new levels of the stock of technological progress in the long run. The equilibrium conditions (34) and (35) suggest that the parameters of interest are search intensity, project advertising, the relative bargaining power and the fee rate, which we will discuss in turns.

4.1.1 Search intensity and project advertising

As previously stated, the optimal values of a and b strictly depend on the form of the cost functions, and are independent of market variables. Specifically, the KTOs use researchers in search s to match the firm projects to maximize the KTO utility and, symmetrically, firms use their vacancy rate v to attract KTO's researchers according to their profit needs. The former do not vary their search intensity, the latter do not vary their advertising for each new vacant TTP, and the optimal levels of a and b are defined by the Solow conditions (11) and (20), respectively.

However, if the cost functions $C(a)$ and $B(b)$ change over time, then a^* and b^* also change, and these changes affect the optimal values of x and A in steady state. The cost functions can be influenced either by incentives and subsidies or productivity changes. The latter affect search intensity and project advertising, independently of the effects that the tightness of the TT market may directly or indirectly have on them.

Let us assume that a permanent change in the shape of the cost function $C(a)$ increases the optimal search intensity a^*. This change directly affects equations (34) and (35). In Figure (2) this change is described by an *upward* shift of the $x(A)$ curve and a *downward* shift of the $A(x)$ curve. Therefore, starting from the equilibrium E, the system moves to the new equilibrium E'.

The new equilibrium is characterized by a higher value of the tightness x and by an ambiguous impact on the stock of technology A. Figure (2) shows the case in which the new equilibrium value of A is unchanged. However, trading externalities in the TT market cause the equilibrium value of A to be ambigous. The externality arises because, initially, the new higher level of a^* increases both the probability $q(x, a, b)$ that a firm matches a suitable KTO's researcher for its vacant project, and the probability $m(x, a, b)$

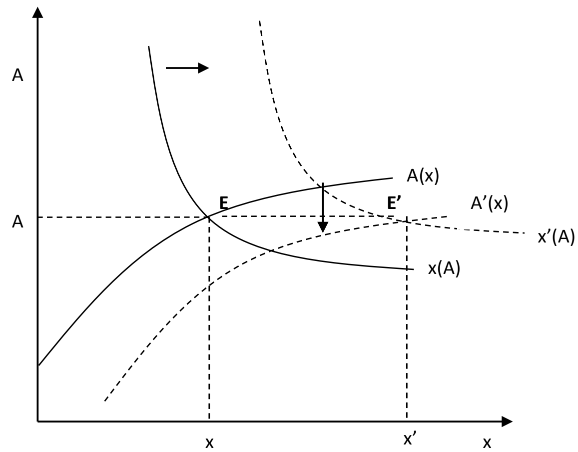

Figure 2: Long-run effects of higher search intensity a

that a researcher will match a suitable TTP, whatever the fee rate. But, from equation (34) we obtain that for a given value of A, the tightness x increases as a direct effect of the higher cost $C(a)$. The higher x, in turn, negatively affects the probability $q(x, a, b)$. Thus, there is an offsetting effect at work because of the *substitutability* between search intensity and project creation: when search intensity rises, firms create more vacant projects relative to researchers in search but, eventually, the increase in the tightness x reduces firm probability $q(x, a, b)$ to find a match. Consequently, firms will respond by offering less TTPs because of the lower probability to fill the vacant projects. In other words, the higher market tightness might reduce (increase) the technology stock in equilibrium, if the negative effect of the increase in the tightness prevails (is lower than) over the positive effect of the increase of the search intensity a. Hence, this negative trading externality might eventually offset the incentive of firms to offer innovative projects to attract KTO's researchers in steady state, with a negative cumulative impact on the technological progress.

We note that changes in advertising investment also affects the $x(A)$ and $A(x)$ curves. Let us assume an increase in b. Figure (3) shows that also in this case the final effect on A and x may be ambiguous. Indeed, while the curve $x(A)$ undoubtedly shifts *downward*, the shift of the $A(x)$ curve is

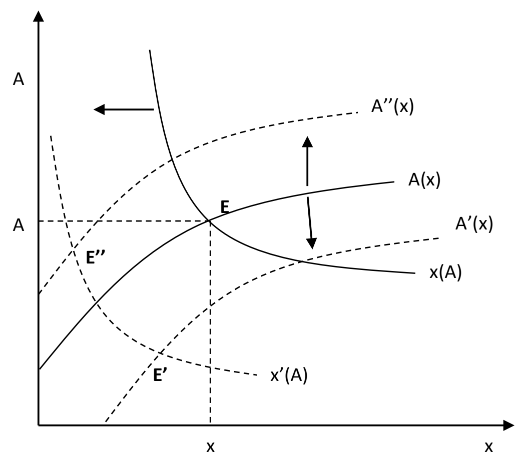

Figure 3: Long-run effects of higher projects advertising b

undetermined because b affects both the numerator and denominator of the ratio $\frac{1+B(b)}{q(x,a,b)}$. Therefore, the overall effect of an increase in b is undetermined. In general trading externalities make impossible to calculate the long-run impact of a change in b on the tightness x and the technology stock A. The result depends on the relative changes (and shifts) of (30), (35) and $v = xs$ that determine the equilibrium value of n and s after the change of b, and consequently the steady state equilibrium in the space (A, x). Therefore, either the existence of *complementary* or *substitutability* between x and A strictly depend on the parameter values, and the new equilibrium can be represented either by point $E^{'}$ or $E^{''}$ in Figure (3).

Whether or not a particular allocation is possible is an empirical matter, and in this study we do not venture into a quantitative analysis. However, we underline that in both cases the ambiguity of parameter changes on technological progress A is caused by the presence of search externalities. As in Pissarides (2000) and in Calcagnini et al. (2015), we refer to these externalities as congestion externalities: when search intensity and project advertising rises, the probability for researchers and firms also changes, and this eventuality affects the technology evolution in the long run.

4.1.2 Relative bargaining power

The bargaining power β is another shift variable that affects the relationship between the tightness x and the technological progress A in the long run. In our model, changes in β mirror changes in the bargaining strength due to policy decisions.

These changes have an unambiguous effect on all endogenous variables. If β increases, the distribution of the surplus generated by the TTPs changes in favor of the KTOs. [3] If this is the case, the relative share $\frac{1-\beta}{\beta}$ can be considered as a further shift variable in the relationship between tightness and technological progress, and from (34) we obtain that the tightness x is lower for given value of A, while equation (35) does not change. Figure (4) shows the final effects of these changes: following an increase in β, the new steady state shifts on the left along the $A(x)$, reducing both A and x, and the equilibrium moves from E to E'.

Thus, an increase in the bargaining strength of KTOs results in a destruction of collaborations, together with an increase in the number of researchers in search of new projects, and a decrease in vacant projects offered by firms. This is a general result: β determines the division of the surplus and firm incentives to feed technological progress. Thus, the increase of the KTO profit share imposes a joint loss to firms and KTOs: with a smaller x they share a decreasing surplus.

4.1.3 The fee rate

When β increases, the firm could maintain its profit share by paying low wages. But, in our model, the fee rate f only affects equation (35) and the relationship between A and f is positive: a higher fee rate tends to raise the technology stock in the long run. A way to rationalize this behavior is that firms try to recover the lost profits by raising the productivity of the new TTPs. A higher fee rate is associated to a higher technological content of projects that, in turn, increases profits. This finding is consistent with some empirical contributions to the field that found that more efficient technology transfer activities are positively related to the percentage of royalties (Siegel, et al., 2003; Phan and Siegel, 2006) or rewards to faculty members involved in such activities (Friedman and Silberman, 2003; Lach and Schankerman,

[3]In Italy β is approximatively equal to 10% , i.e.: the 10% of the surplus generated by a TT project is gained by the university.

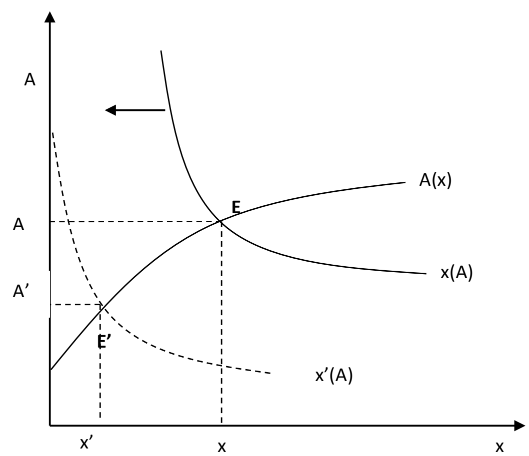

Figure 4: Long-run effects of higher KTO bargaining power β

2004). However, we note that the overall effect of an increase in f is to raise A and reduce x. Intuitively, this means that a smaller number of vacant projects is offered relative to the researchers in search. Tightness unambiguously falls, but the higher productivity of the TTPs in place cover the higher costs of researchers and firms' profit. The equilibrium moves from E to E' in Figure (5).

What has the microfoundation of the TT issue added to the traditional empirical analysis of this trade? First, a lesson learned is that many of the partial effects of parameter changes are more complex of what expected once fee rates and the surplus are endogenized and the model solved for an equilibrium. Second, some effects amplify the problem of nonuniqueness and ambiguity. Search intensity and project advertising can generate unexpected effects on the TT trade and technological progress. Finally, with increasing fee rates, the effects of changes on the equilibrium value of the technology can offset the transitory reduction of the profit share. This may be a crucial conclusion to develop new policies aimed at sustaining productivity and economic growth.[4]

[4]See Kochecova et al. (2015) for a systematic review of academic studies on public policy measures in support of technology transfer.

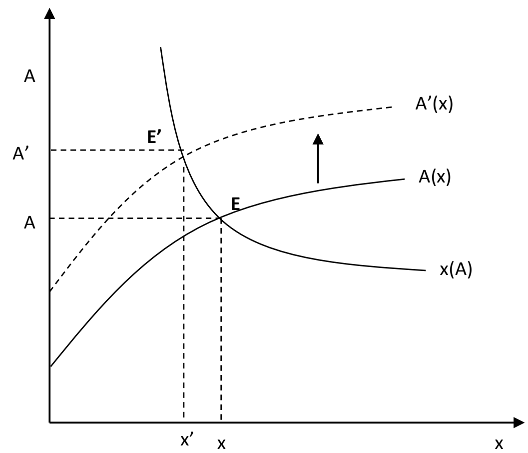

Figure 5: Long-run effects of higher fee rate f

5 Conclusions

In this paper we provided a microfoundation of the matching process that characterizes the functioning of the TT market. We demonstrated that if firms and researchers within KTOs search for each other, the equilibrium level of the TT market may be either too high or too low. This inefficiency is due to search externalities that depend on tightness, that is the ratio between vacant projects and researchers in search, but also on the level of search intensity, project advertising and the relative bargaining power between firms and KTOs.

As an additional, but crucial, result we find that technological progress and tightness are strictly related in equilibrium. From our analysis emerges an ambiguous impact of changes in search intensity and project advertising on technological progress because of the complementarity and substitutability between tightness and technology: when researchers in search increase their search intensity, firms respond by lowering their effort to find a matching. This behavior generates a negative externality that depresses the overall state of technological advancement in steady state. Similar unpredictable outcomes are caused by changes in project advertising (researchers find projects more easily), while changes in the relative bargaining power (the profitability of the project is altered) and fee rate (KTOs would earn less than the reservation fee rate) both result in collaboration destructions. However, their impact on technological progress is not unique.

We showed these results within a competitive model of firms and KTOs, where search intensity and project advertising induce more or less project search and matching in the TT market. We are able to understand what happens in equilibrium, but we decided to not discuss the transitional paths and the adjustment processes by choice. However, the disequilibrium phases hide important elements that provide additional informations on the functioning of the TT market and the role of policies aimed at affecting its efficiency (and skill) in the short and long run. This is however straightforward. In our future research agenda, we aim at analyzing the transitions from one equilibrium to another.

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