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Scientific Mobility And Development: Toward A Socioeconomic Conceptual Framework[1]

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1 Introduction

The understanding of skilled migration and mobility as competitive is partly a reflection of early economic analyses of movements of skilled human capital as a zero-sum game (Bhagwati 1979; Bhagwati & Hamada, 1976). Developing counties were considered to have their human capital resources depleted by the flows of talented and skilled individuals to the developed world, particularly the United States (US House of

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Representatives, 1977). This led global institutions to focus on net 'brain gains' and 'brain drains' in relation to questions of development and fairness (Dickson, 2003; Docquier & Rapoport, 2005; InterAcademy Council, 2004; OECD, 2002; Ozden & Shiff, 2005; De la Vega, 2005). At the national level, specific policies to try and attract and retain scientific researchers have emerged (Laudel 2005; Zweig 2006), entrenching the view that scientific mobility, is at least to some extent, a product of competition between nations (Johnson & Regets, 1998).

The zero-sum understanding of human capital mobility has nevertheless been challenged by research in a diverse range of fields including innovation studies (Coe & Bunnell 2003), labour studies (Williams 2007), national innovation systems analysis (Hart 2007) and migration studies (Ackers 2005). Current research into scientific mobility also reflects the expanded geographic circulation of talented researchers, particularly toward Asia (Goldbrunner et al., 2006; Zweig 2006). The contemporary mobility of scientists has come to be understood as both a driver and a consequence of processes of organising knowledge production and distribution argued to be both increasingly globalised (Mahroum 2000) and diversified (Gibbons et al., 1994; Kleinman & Vallas, 2001). Network approaches to the distribution of researchers and knowledge have emerged, particularly to highlight linkages between scientists based in developed countries and their compatriots in developing ones. This approach argues that these inter-connections tend to form "diaspora knowledge networks", which can contribute to solving some of the human resource and economic growth issues confronting both poorer and richer countries (Barré et al., 2003; Meyer, 2001; Meyer & Wattiaux, 2006; Mahroum & De Guchteneire, 2006).

Although it is not explicitly discussed in the literature, understandings of mobility as a brain-drain/gain phenomenon are grounded in neoclassical conceptions of human capital. No comprehensive and systematic theory of scientific mobility has emerged to challenge the zero-sum approach to human capital. This paper is an attempt to progress in this direction. We argue that zero-sum approaches to scientific mobility implicitly rely on neoclassical economic assumptions concerning the properties of human capital. From our perspective, a first theoretical step to make to reflect on alternative ways to conceptualise scientific mobility is a systematic reflection on these properties. Indeed, thinking about the economics of science and scientific human capital has been dominated by the neoclassical economic approach. These models have traditionally argued that scientific codified knowledge has the economic properties of a public good. It is non-rival, non-appropriable and therefore cannot be efficiently allocated by markets. Conversely, human capital is assumed by the theory to have the properties of a private good, like any other rival and excludable good, which raises no particular challenges for market neoclassical theory.

Social theory has challenged these assumptions. Callon (1994, 2002) has argued that scientific knowledge is not inherently non-rival and non-appropriable and that its economic properties are extrinsically determined by the characteristics of the networks in which scientists deploy their activities. Bozeman et al. (2001) propose a conceptual framework according to which scientific and technical human capital is in part both context-dependent and socially configured through network ties. In this paper we review the traditional approaches of new growth economics and the economics of science to the properties of and scientific human capital. We rely on Callon's and Bozeman's conceptual developments to propose an analytical framework for the analysis of scientific mobility in which scientific human capital is argued to be context-dependent and distributed. We propose a distributed approach to scientific human capital mobility as opposed to the allocative one that derives from neoclassical premises. Finally, we discuss the implications of the proposed framework to rethink scientists' mobility from a developing country perspective.

2 The 'neoclassical' economic properties of scientific knowledge and human capital

The economics of science derives from interest in explaining the process of scientific knowledge allocation, and how this process relates to economic growth. It builds on neoclassical welfare and growth economics and the study of market failure, which prevents markets from achieving optimality in resource allocation. According to Arrow (1962), the classical reasons for the possible failure of perfect competition are indivisibilities, inappropriability and uncertainty. Goods that are efficiently traded in markets are private goods: they can be privately produced and allocated; they are defined as rival and excludable (or appropriable). Pioneer works by Arrow (1962) and Nelson (1959) addressed the particularities of the market for the commodity (good) 'knowledge'. They argued that the market for knowledge fails to achieve an optimal allocation due to the special properties of this good: knowledge is a non-rival, non-appropriable (non-excludable), and indivisible good.

According to both Arrow and Nelson, the non-rivalry of the good 'knowledge' is due to the fact that the use of certain knowledge by a certain agent does not deprive any other agent from using this knowledge simultaneously:

> "The use of existing knowledge by one firm in no way reduces the ability of another to use that same knowledge" (Nelson, 1959).

Romer elaborated on Nelson and Arrow in arguing that "rivalry is a purely technological attribute" (1990a) of economic goods for which reproduction has a considerable opportunity cost. On the contrary, the reproduction of a non-rival good is insignificant compared to the cost of producing the first unit. For example, reproducing software will only imply the cost of the tangible support to encrypt the knowledge (disc, floppy disc) just as reproducing a mathematical theorem might only imply the cost of a photocopy.

Appropriability or excludability refer to the possibility of the owner of a good preventing (excluding) others from using it. Excludability is a function of both technology and the legal system. A good such as the code for a computer program can be made excludable (or at least partially excludable) by means of a legal system that prohibits copying or by means of encryption and copy protection schemes (Romer, 1990a). However, once a good such as the code for the human genome is made publicly available, excluding agents from the use of this information is difficult, if not impossible.

> "The cost of transmitting a given body of information is very low […] no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information" (Arrow, 1962).

In summary, conventional goods are considered by economic theory to be both rival and excludable. They may be privately provided and allocated in competitive markets. In contrast, public goods are defined as being non-rival and non-excludable. They can neither be privately provided nor traded in markets. Scientific knowledge is assumed by growth economics and by the economics of science literature to possess the above characteristics of a public good2.

[2] The possibility of turning scientific knowledge into a partially excludable good, through institutional arrangements or encryption makes Callon (1994) refer to it as a 'quasi-public good'.

The so-called ‘new’ economics of science breaks from the neo-classical conception in not seeing ‘scientific knowledge’ as a homogenous good. Rather, the new economics of science draws a distinction between ‘codified’ and ‘tacit’ types of scientific knowledge, arguing that the processes of the production and diffusion of these types of knowledge are distinct and should be treated differently (Foray, 2004). The new economics of science defines ‘codified knowledge’ as “information: knowledge reduced and converted into messages that can be easily communicated among decision agents” (Dasgputa & David, 1994). Codified knowledge, understood as information, can therefore be considered relatively inexpensive to reproduce and circulate. It is codified knowledge, then, that is argued to have the properties (non-rival and non-excludable) of a public good (Dasgupta & David, 1994).

In contrast, ‘tacit knowledge’, as conceptualised by Polanyi (1966) is non-codifiable, relatively difficult and expensive to reproduce and cannot be expressed outside the action of the person who has it (Foray, 2004). Tacit knowledge is therefore embodied in individuals (or groups of individuals, routines, institutions). It is a form of “knowing by doing” (Amin & Roberts, 2008) that cannot be easily circulated. Rather, the transfer of tacit knowledge is a process that happens through practice, primarily co-learning in collocated activities.

The allocation of embodied knowledge (including its tacit component) is also assigned great relevance by economists in explaining endogenous economic growth (Lucas, 1988; Romer, 1993). However, it does not raise any particular challenges to neoclassical economic theory as it is analytically treated like the allocation of any other private good. In the new growth economics tradition, knowledge is incorporated into individuals through the variable ‘human capital’ (Nelson & Phelps, 1966; Lucas, 1988), as conceptualised by Schultz (1961, 1963) and Becker (1964). Following the human capital theory tradition, knowledge embodied in individuals is basically the result of individual decisions to invest in training and education; decisions which are made considering the costs of the training and the estimated return on this investment. In this theoretical context, agents are perfectly capable of estimating future returns and comparing them to interest rates.

Romer (1993: 72) understands human capital as a good which is “as close to a perfect good as one can get”. Romer’s conception of human capital explicitly includes ‘tacit knowledge’ such as the “ability to remember the commands of my word processor” (1993: 71) or the “ability to add” (1990a: 74). For Romer, human capital is rival because the person who possesses these abilities cannot be in more than one place at the same time. Additionally, the opportunity cost of reproducing such abilities is not negligible: “[t]raining the second person is as costly as training the first” (Romer, 1990a: 75). According to Romer, rivalry leads to the presumption that human capital is also excludable. He argues that a person who possesses a ‘piece of human capital’ can perfectly exclude others from benefitting from his or her abilities. Finally, whereas non-rival goods can be accumulated without limit on a per-capita basis, human capital cannot. Each individual can acquire a certain amount of skills. “When this person dies, the skills are lost” (Romer, 1990a: 75). As a result, human capital is considered by neoclassical economic theory and by the economics of science to have the properties of a pure private good. It can therefore be privately produced and traded in markets.

In summary, whereas scientific knowledge is considered a public good (non-rival & non-excludable) and therefore not allocatable through markets, human capital is considered rival and excludable (therefore perfectly allocatable). There is thus a tension in the literature between the allocation of scientific knowledge in general and of scientific human capital resources as knowledge bearing agents, due to the different properties of the knowledge that is circulated in different forms.

3 A neoclassical economic interpretation of scientific mobility

We may now ask ourselves about the implications of the above theoretical premises for the analysis of the distribution of human capital in economic and social systems. More specifically, we wish to focus on the subgroup of individuals who possess the skills needed to produce scientific knowledge and who are devoted to research activities. Whether we refer to human capital (new growth economics) or to tacit – embodied knowledge (new economics of science) does not affect our reasoning as in both frameworks the good is considered to be private (rival and excludable).

According to this proposition, each scientist (or each individual in a more general framework) possesses a certain amount of human capital that might change over time through experience and further education and that contributes to the creation of welfare (income, further knowledge) only where she/he is located. If human capital is private and easily tradable, it should be appropriable by the economic agent that 'buys' it, that is to say, by employers3.

The displacement of the person in which 'a piece of human capital' is embodied therefore implies a re-allocation of this human capital. Human capital may be (re)-allocated among organisations, countries, sectors, etc, following market and non-market forces. When scientists move, their human capital goes along with them. A net outflow of scientists from one organisation (or one country) to another implies a human capital loss and a net inflow implies a gain. Therefore, whether mobility is international, inter-sectoral or inter-organisational it can only imply a zero sum game (Bhagwati 1979;

[3] The consideration of human capital's 'ownership' raises conceptual problems which do not apply to the rest of typical private goods. Section 3 further addresses this issue.

Bhagwati & Hamada, 1976) as scientists cannot be physically located in several places at the same time, just as it is the case for any type of purely private good. From a neoclassical economics perspective, mobility of scientists (as mobility of any other piece of human capital) can only be addressed as a (re)-allocation phenomenon, which has knowledge cumulative and un-cumulative effects.

We may apply the terminology of the brain drain-gain literature (Dickson, 2003; Docquier & Rapoport, 2005; InterAcademy Council, 2004; OECD, 2002) to the above reasoning and say that scientists' mobility has knowledge drain and knowledge gain effects. The term brain drain was used for the first time in 1963 in a report by the Royal Society of London, in reference to the exodus of British scientists to the US (Brandi, 2006). In 1975, the US House of Representatives Committee on International Relations examined the question of scientific migration in the context of a study of science, technology and American diplomacy. Their Report described the brain drain as an issue with three-dimensions: 1) a manpower problem that affects growth patterns in both advanced and developing countries; 2) a development problem that "deprives the developing nations of much need human capital for achieving their major national goal, namely, modernization"; and 3) a science and technology problem related to the "management of resources and the building of infrastructure for modern industrial societies" (US HoR: 1977: 1048).

Since then, the concern for the negative consequences of scientists' emigration has been accentuated, especially in countries that register high outflow levels (De la Vega, 2005; Morano Foadi, 2006). The interest in understanding the features and consequences of these migratory flows for the countries of origin and destination has given rise to an abundance of literature4. Some of these studies have focused particularly on the relationship between the migration of professionals and technological change in the US (North, 1995; Ash & Söllner, 2002; Saxenian, 2002) and other countries (Saxenian, 2002, 2006; Saxenian & Hsu, 2001).

Public policies aimed at obtaining net positive inflows of researchers are consistent with the neoclassical theoretical view of the world. The Mobility Strategy for the European Research Area (CEC, 2001) is in part an example of this type of policy as it counts among its objectives the retention of researchers in Europe, the attraction of third-country researchers to the European Union and the encouragement of return of European researchers based outside the EU. We will refer to this set of objectives as 'retain-attract-return' policies.

This interpretation of the mobility phenomenon at the international scale, together with policies targeted at 'retaining and attracting' scientists lead to a 'global competition for talent' (Kapur & McHale, 2005) in which necessarily winners and losers appear. Labour markets are assumed to operate on an international scale and scientists respond to market signals by searching for the best job opportunities.

We argue that the brain-drain gain approach to scientific mobility and the policies that derive from this approach strongly rely on the neoclassical economic framework assumptions; that is to say on a theoretical construction in which knowledge embodied in individuals is treated as an intrinsically rival, appropriable and excludable good. A reconsideration and transformation of these assumptions has potentially important implications for the interpretation of the scientific mobility phenomenon. We will rely on social theory to argue that the economic properties of scientific human capital are not

[4] For a review of the literature on the international migration of qualified human resources see Gaillard and Gaillard (1998a). Brandi (2006b) studies the historical evolution of the international migration of qualified human resources from the Middle Ages to the beginning of the 21st century.

necessarily those assumed by the economic neoclassical framework. The following section takes a first step in that direction pointing out a major difference between human capital and typical private goods.

4 The economic properties of human capital: an unresolved discussion

According to Callon (2002: 284), the proponents of the new economics of science (Dasgputa & David, 1994) agree to consider embodied knowledge as a rival good: "A research director who recruits a scientist removes him or her from the market, for no other laboratory can employ him or her". However, in a previous paper (1994) he recognises certain differences between economists on this point and refers to the skills incorporated in human beings as non-rival goods: "Mobilizing the skills and techniques of an expert does not prevent another expert from mobilizing the same skills at the same time" (1994: 401).

The two statements are not necessarily inconsistent for the perspective used to address rivalry is different in each case. The later (2002) approach considers rivalry from the laboratory or organisation perspective: the skills of a scientist employed in a laboratory are inaccessible to another laboratory. In this case 'the good' is the skills embodied in a specific person. However, the earlier approach considers rivalry from the individual perspective: 'the good' is simply the skills. It is true that nothing necessarily prevents one person from developing exactly the same skills as another. Whilst it is very unlikely that a tennis player develops exactly the same skills as Rafael Nadal it is not impossible.

In contrast, for Romer (1993: 71) the human capital good is "the set of connections between neurons". Human capital incorporates skill sets, including generic skills, but Romer seems to imply that these skills are intrinsically a property of individual persons and are not identically reproduced. This is why, as discussed earlier, for Romer human capital is indisputably rival: "There is no way for anyone to take advantage of my ability to remember commands for my word processor without getting my permission […] because there is also no way for many people to make use of my ability at the same time it [human capital] is as rival good" (1993: 71, italics added). The individual is thus the 'owner' of human capital goods that are intrinsic to that person and perfectly excludable.

As these varying perspectives illustrate, dealing with the economic properties of human capital is anything but a simple task. Although eventually tradable in markets, embodied skills are very different to typical private exchangeable goods. The consideration of human capital's 'ownership' raises important conceptual problems that the economic literature has not addressed. When discussing excludability or appropriability a distinction needs to be made between the 'buyer's' perspective (the organisation that employs the person in which the human capital is embodied) and the 'owner's' perspective (the person in which the human capital is embodied). In the case of a typical private good the agent who purchases it in the market becomes the owner. In labour markets, employers acquire the right to benefit from their employees' embodied competences but they do not own the human capital they deploy.

Romer's approach is that of the owner's perspective. The perfect privateness of the good human capital derives from the fact that the owner has total control over the use of the individual's abilities: noone can use them without permission, noone can steal them. Human capital is therefore more perfectly private than other goods (i.e. a floppy disk) that can actually be stolen from the owner (1993: 72).

However, if we approach rivalry, appropriability and excludability from an employer's perspective the conclusions will be different. First, although it is undeniable that the same person cannot be physically located in two places simultaneously, this is not enough to derive definitive conclusions concerning the 'privateness' of her human capital, for an organisation is not necessarily capable of fully appropriating her embodied skills. The possibility of an organisation excluding others from accessing those skills will depend on a multiplicity of factors, which include institutional and organisational arrangements, and the person's (the owner's) will. The possibility of other organisations benefitting from those skills is therefore not a priori determined.

If organisations are not fully able to appropriate and control the human capital embodied in the scientists they hire, is it possible to state that human capital is a perfectly private (therefore rival-excludable) good? If we adopt the buyer's perspective, what are the factors that actually determine the degree of rivalry, appropriability and excludability of scientific human capital? We argue that these are important questions that need to be addressed in order to understand certain dynamics affecting the production and diffusion of scientific knowledge. In particular, reconsideration of the economic properties of human capital alters the conceptual background and hence the interpretative framework for understanding scientific mobility.

As discussed in section 2, in a context in which scientific human capital is considered fully rival and appropriable, mobility can only be addressed as an allocative phenomenon implying zero-sum knowledge drain and gain effects. Non-rivalr and non-appropriable scientific human capital may however lead to other effects, which are not typically addressed by the theory, but which may be of major relevance for economic development. The following section considers two 'distributed' models, one of scientific research (Callon) and one of scientific and technical human capital (Bozeman et al.), to further develop these arguments.

5 Is human capital private good?

Callon (1994) states that, according to economic theory, human capital has certain '*intrinsic'* properties that turn it into a private good. Callon makes a general argument that scientific knowledge (meaning codified scientific knowledge) is not necessarily non-rival and non-appropriable, as assumed by economic theory. He states that the properties of 'codified knowledge' are not inherent to 'the good' (the codified knowledge) but are extrinsically configured. He argues that this has major consequences for the conceptualisation of the dynamics of scientific research and the replication of knowledge. In this section we apply Callon's (1994, 2002) argument concerning the economic properties of codified scientific knowledge to scientific human capital to show that the economic properties of human capital are configured by their network. Secondly, we use Bozeman's et al. (2001) conceptual approach to scientific and technical human capital to highlight that the economic properties of human capital are also socially configured. In different ways, these two approaches prompt us to re-evaluate human capital's economic properties as context-dependent and distributed.

5.1 Rethinking human capital's properties from Callon's socioeconomics of scientific research

Callon (1994) addresses the question of to what extent science – meaning codified scientific knowledge – can be considered an inherently public good (non-rival and non-appropriable) as assumed by neoclassical economists. Callon argues from a position within sociological studies of science that understands the fabrication of scientific knowledge as a messy and irreducibly social process (Barnes, 1982). He argues that in order to use a codified statement produced by an agent, other agents must undertake a series of investments[5] without which the knowledge has no use. This he refers to as '*the thesis of the intrinsic inutility of statements'* (Callon, 1994: 403). In other words, codified knowledge such as a scientific paper has no use in and of itself, it is useful only when it can be read and understood and deployed as part of processes of knowledge production and or dissemination.

Callon's starting point for what he terms 'a socio-economics of scientific research' is "the replication of knowledge" (2002: 287). In making the object of analysis the 'replication of knowledge', he argues that the diffusion of basic scientific knowledge cannot be subsumed under the exchange of codified statements as information "because it is not statements that are duplicated but laboratories: consequently basic science cannot be reduced to information" (2002: 288). In other words, whilst concepts can be circulated in the form of information, this is only part of the work of 'replication'.

The replication of knowledge depends on what Callon terms "the set [statement + instruments + embodied competences]" (Callon 2002: 289). Following the work of Collins (1974), Callon assumes that the elements of 'the set' cannot be mobilised independently of each other (1994: 403). Therefore the work of replicating knowledge is equally dependent upon the availability and transporting of the requisite material devices and on access to the competences required to set up, calibrate and use this equipment.

The degree of non-rivalry of a statement (which refers to the unlimited possibility for all agents to use it once it has been produced) thus depends on the amount of investment needed to develop the skills and acquire the instruments that make it useful in a certain context. "Non-rivalry is in no way an intrinsic property of the statements themselves: it

[5] Reproduction investments, investments in acquiring and maintaining complementary assets (i.e. instruments, embodied skills, know how), and investments in the mobilisation of the codified statement (Callon, 1994: 404-405)

would be better to call it an extrinsic property and to consider the variable degrees of (non) rivalry" (Callon, 1994: 406).

Callon acknowledges that 'the thesis of the intrinsic inutility of statements' can be equally applied to skills and instruments (1994: 403). Although he does not expressly extend the argument to the economic properties of human capital, he provides the theoretical bases to make this step. We may argue that the possibility of agents (organisations and individuals) using what Romer would call 'a piece of human capital' depends on the availability of the complementary assets required (instruments and statements). The artistic capabilities of a great pianist are of little use in an environment lacking pianos and sheetmusic, for example. In other words, the utility of human capital is context dependent. The amount of investment required to gain access to, and understand, codified scientific knowledge and appropriate instrumentation thus determines the degree of (non-)rivalry of human capital.

If the economic properties of human capital are extrinsically determined it is the nature of the context that ascribes the degree of rivalry and excludability. Callon explains this in terms of the *structure of networks* in which scientific knowledge is produced. The notion of 'network' refers to 'translation networks': "a compound reality in which inscriptions…technical devices and human actors…are brought together and interact with each other. The networks vary in length and complexity" (Callon, 1995: 52). He argues that the degree of rivalry and excludability of codified scientific knowledge "is closely correlated to the form and state of the networks concerned" (1994: 313).

In 'consolidated networks' "competences and instruments have been duplicated in multiple copies and widely distributed" (Callon, 2002: 290) All the required complementary assets are available at each 'equivalent' node in the network. In such consolidated configurations a relatively extensive 'space of circulation' is elaborated, knowledge flows comparatively easily and is relatively difficult to appropriate. Callon argues that in consolidated networks the economic properties of statements are closer to those of a theoretical public good. We can apply this argument also to scientific human capital: within a consolidated network in which scientists already share a codified knowledge base, a modus operandi, types of infrastructure and instrumentation, etc, there is an extended space of circulation for human capital which is therefore relatively non-rival (easy to circulate and reproduce).

On the other hand, in ‘emergent networks’ codified scientific knowledge more closely resembles a private good, according to Callon (2002). This knowledge is less easily reproducible and usable than is the case in ‘consolidated configurations’. When new research findings and networks emerge, the number of actors sharing the use of common sets of skills, codified knowledge and instruments is by definition limited. Emergent findings remain easily or inexpensively appropriable within the localised setting as it is “easy to take ownership of a good that nobody understands and that has no utilitity outside its place of production” and “contrary to the traditional view, leaks and overflows are costly to organize” (Callon, 2002: 290). It is therefore more rival and excludable (Callon 2002). Again, we may apply the same reasoning to human capital. Mobility of human capital with relatively scarce (emergent) embodied competences would “presuppose the existence of a circulation space that does not yet exist” (Callon, 2002: 290). If no space for the circulation of skills yet exists, it is comparatively easy for organisations to exclude others from the overflowing of their human capital and more costly for others to try and reproduce those skills.

The economic properties of scientific human capital are also defined as extrinsically configured and dependent on the contexts in which it is deployed. Using Callon’s words we may state that these properties depend on the structure of the networks involved: in emergent networks human capital resembles a relatively private good; in consolidated networks it tends to be less rival and excludable[6]. In the following section we look at Bozeman's conception of scientific and technical human capital (STHC), to point out how in this framework the properties of human capital are similarly context dependent, but also socially and relationally defined.

5.2 Social and contextualised human capital: the 'scientific and technological human capital' approach

Bozeman et al. (2001) build on social and economic theory to broaden the traditional neoclassical approach to human capital. According to Bozeman et al. (2001: 721) standard human capital theory regards the human being as

> "a knowledge delivery mechanism into which inputs are added in the form of education and training and outputs are received in units of productivity, higher earnings and expanding economic growth. It is the emphasis on the value of knowledge creation, recombination, transformation and application process that is missing. The process that takes place within the black box is inherently social…and is missing from the theory".[7]

Scientific and technical human capital (STHC) is defined as the sum of scientific, technical and social knowledge embodied in a particular individual. More specifically it is composed by internal and external resources. Internal resources are classified into three overlapping categories: cognitive skills (not determined by the context, i.e. memory, mathematical reasoning), substantive scientific and technical knowledge

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[6] In section 4 we named the perspective we are using to discuss these properties 'the buyer's approach'.
[7] It is interesting to note the different approach to human capital that Romer (1992) and Bozeman (2008) do. For Romer, the process that takes place within the 'black box' is purely neuronal whereas for Bozeman it is inherently social. Both approaches are undoubtedly compatible as neuronal connections can be determined or conditioned by social interactions. However, putting the stress on the social process that leads to human capital formation and the conditions for its use leads us to reconsider its economic attributes which for Romer are clearly those of a purely private good.

(basically obtained through formal scientific education and training) and context skills (gained by doing, usually tacit knowledge acquired through design and implementation of specific research plans) (Bozeman et al., 2001: 726). External resources are the social capital that scientists bring to their work. They are embedded in network ties. Since the production of scientific knowledge is by definition collective and social, many of the skills are more social or political than cognitive (Bozeman et al., 2001: 727-728).

The human and social capital components of STHC are both important for our argument. The STHC framework classifies so-called ‘internal resources’ (human capital) into three overlapping categories: cognitive skills, substantive scientific and technical knowledge and context skills. According to Bozeman et al.,

> context skills are usually tacit and are obtained through experience in specific research settings. They cannot be directly brought to new scientific and technical problems, but they provide the basis for problem solving heuristics and comprise an action repertoire, which is transferable to other contexts (2001: 727).

The distinction between specific localised context skills and the generic action repertoire of science is central to understanding the economic properties of human capital. Whilst the two types of context skills are inculcated simultaneously in practice, we would argue that localised context skills are particularly rival and appropriable for they are difficult (and costly) to reproduce and transfer to different contexts. Conversely, generic skills and problem solving aptitudes are part of the “background knowledge” (Zellner, 2003) of science that is routinely and systematically reproduced and disseminated. These skills comprise an aspect of the professional *habitus* of scientists (Bourdieu, 1975) and are relatively non-rival and are not appropriable.

This argument seems consistent with the approach taken by Callon (2002). If we consider ‘context skills’ in relation to Callon’s description of emergent and consolidated networks, it seems reasonable to assume that in a ‘consolidated configuration’, where scientists share a common knowledge base and action repertoire (including the use of a set of instruments and statements), a relatively extensive space of circulation exists. From the ‘buyers perspective’ the properties of human capital being circulated are relatively non-rival and non-appropriable. Alternatively, localised context skills seem comparable to emergent embodied capabilities for which there is a restricted circulation space. Human capital in such emergent configurations or localised contexts is a relatively rival and appropriable good.

However, STHC also includes the additional component of “social capital”, here conceptualised “as the cooperative glue that binds collaborators together in knowledge exchange”, (Bozeman et al., 2001: 723). Social capital includes the resources that connect scientists with their colleagues, funding agencies, other laboratories, firms, etc. Unlike human capital as traditionally conceptualised by economic theory, which resides in the ‘connection between neurons’ within the brain of its owner and is therefore explicitly individualized, Bozeman et al. argue that ‘social human capital’ “inheres in relations between people and therefore cannot itself be owned” (Bozeman et al., 2001: 723).

In other words and following Bozeman’s statements we could say that ‘social capital’ is embedded in external relationships and therefore inherently inappropriable. Furthermore, Bozeman et al. (2001: 723) argue that “the interplay between social and human capital is so fundamental, intimate and dynamic that neither concept is fully meaningful by itself, making it nearly impossible in the end to pinpoint where one leaves off and the other one picks up”. There is thus an inherently inappropriable component of STHC which is not easily distinguishable from the other components.

The social dimension of STHC is thus by definition inappropriable (non-excludable) and embedded in network ties. It is logical to derive from this that the degree of inappropriability of the STHC associated to a certain scientist will depend to some extent on the characteristics and configuration of these social networks. There is thus an important difference between Callon's and Bozeman's conceptualisation of 'networks'. However, these differences do not have major implications in terms of our argument, as both analytical frameworks permit us to derive the conclusion that the degree of appropriability of scientific human capital is externally (extrinsically/socially) and not internally (intrinsically/individually) determined.

One of the major contributions of the STHC framework is the categorisation of embodied scientific skills into different types, which are closely and dynamically linked to each other. Moreover, the theory states that the composition of an individual's STHC is constantly reconfigured over time (Bozeman et al. 2001: 727). We may thus derive some conclusions concerning the economic properties of STHC. On the one hand, these properties will depend on the individual's composition of STHC at a certain analytical instant: for example the more important the social skills and relationships, the less appropriable her STHC will be. On the other hand, we may argue that the more important localised context skills are during a particular period, the more rival and excludable the STHC will be. The balance of these components is dynamic and transforms over time in the course of a scientific career. The economic properties of STHC are therefore not constant over time.

We rely thus on Callon's and Bozeman's conceptual developments to propose an analytical framework for the analysis of scientific mobility in which scientific human capital is not considered as an a-priori perfect private good (as implicitly assumed in the literature on brain-drain). On the contrary, we argue that the economic properties of human capital change over time depending on its skills-type composition and that these properties are extrinsically determined by the characteristics of the networks in which scientists deploy their activities. The economic properties of human capital are thus argued to be context dependent and distributed. These premises have important implications for the assessment of scientific mobility, which we develop in the following section.

6 Reconceptualising human capital mobility: from an allocative to a distributed human capital model

We have argued that scientific human capital should not be conceptualized as simply a private good, as defined by economic theory. Scientific human capital allocation should therefore not be considered a theoretically equivalent problem to the allocation of apples in markets. Relying on social theory we come to the conclusion that the economic properties of scientific human capital are shaped (and re-shaped) by the contexts and networks in which it is deployed. These properties thus transform as contexts and networks change. The neoclassical economic framework does not permit us to deal analytically with this substantial complexity because it is designed to explain allocation of economic goods that are assumed to have *a priori* invariable properties. In order to deal theoretically with variable and evolving economic properties we need to move from the allocative economic neoclassical model to a broader conceptual approach that allows us to integrate the temporally, spatially and socially ‘distributed’ nature of scientific human capital.

The re-conceptualization of the economic properties of scientific human capital has major implications for how we understand and evaluate its production, use and diffusion in science systems. As discussed in section 2, in the standard neoclassical approach human capital can be allocated in markets like any other private good and is equally usable in every context. From this perspective, the mobility of scientists can only be understood as a re-allocation process through which human capital units are transferred among organizations leading to 'brain-drain' and 'brain-gain' effects. We argue however that a 'distributed' approach means that: 1) the mobility of scientists is conceived as a process integral to the production and circulation of all scientific knowledge; 2) human capital mobility (re-)configures scientific networks; and 3) the context dependent and varying economic properties of scientific human capital influence both the role and the effects of mobility, which in turn may modify these properties. The following paragraphs outline the theoretical bases of these arguments.

Section 5.1 established that human capital is fundamental to the replication of scientific knowledge as a key component of "the set" that is replicated: [statement + instruments + embodied competences]" (Callon 2002: 289). However, the mobility of scientists is a non-substitutable element of the replication process, especially in the case of emerging scientific knowledge. In the case of new or 'emergent' research findings, Callon argues that

> "there is only one copy of this package and the first replication implies its total duplication in a way that is entirely comparable to the (re)production of a normal good such as an automobile or a lemon squeezer. On the basis of its physical characteristics, it is thus appropriable at a small cost" (2002: 289).

The replication of the emergent research thus involves duplication of 'the set', which given the localised conditions of its (re)production is, at this point, actually an easily appropriable and hence rival good. If the same human capital, manipulate the same instruments using the same codified instruction then the findings can be most easily duplicated. 'The set' is intact and the operations can be simply repeated. However, this we might call 'repetition' and see that there is virtually no addition cost involved in duplication.

The difference between 'repetition' and the 'replication of knowledge' is that replication involves movement, the transporting of elements from "one setting to another" (Pickering 2005). If we consider the components of 'the set' (and we are talking specifically about new or emergent findings here), the codified knowledge (statement) that is developed can be easily reproduced and circulated to a different space and into the hands of different human capital (for example through priority claim journal articles). The material devices (instruments) can also be industrially manufactured and reproduced in time and, even if customised to some extent or fabricated on site, can in all likelihood be duplicated precisely by competent engineers and installed in different locations (this, of course, also depends on the physical size and financial investments required).

However, in emerging configurations embodied competences are not substitutable by either other components of 'the set' or by a simple replacement human capital. According to Callon therefore, the "more original the findings or, in other words, the scarcer the embodied competences that accompany them, the higher the costs of their reproduction because it cannot simply be amputated from all the other elements that form a whole" (2002: 289). As discussed above, embodied competences are context dependent, specifically when dealing with new discoveries and original findings. In addition, embodied knowledge, including its non-codifiable tacit dimension, has to be *transferred* between individuals or teams, acquired in the realm of demonstration and practice from those who are competent.

Callon argues that the transporting of embodied competences would "presuppose the existence of a circulation space that does not yet exist. It is easy to take ownership of a good that nobody understands and that has no utility outside its place of production" (Callon 2002: 290). In emergent configurations the mobility of human capital is thus essential to the replication of scientific knowledge. A space of circulation cannot be established without human capital mobility, whether through the movement of the holder of scarce embodied competences to establish new 'equivalent' nodes, or via the circulation through the localised context where these embodied competences originated and can be transferred. Scientific human capital is under these circumstances highly rival and appropriable but remains transferrable to another context only when accompanied by the necessary investments to replicate "the set". If these investments are not undertaken, mobility may even lead to a 'negative-sum game' in which neither the sending institution nor the receiving one can benefit from the displaced human capital. However, once replication has become multiple and a well-defined space of circulation established, embodied competences can be easily 'inserted' and human capital is relatively interchangable. Scientific human capital is less rival in this context (less costly to reproduce) but also less appropriable. Spillovers are common. Under these circumstances, mobility may eventually lead to 'positive-sum games' in which several organisations succeed in benefiting from the same human capital. However, this stage cannot be reached without the prior extension of the circulation space. Scientific human capital mobility is hence not an epiphenomenon, it is a fundamental process underlying the production and diffusion of scientific knowledge.

A second point following from the fundamental significance of human capital mobility for scientific knowledge generation is that the movement of scientists re-configures networks. Human capital and complementary assets (statements, instruments) are assembled in localised research sites. The mobility of human capital shapes, and is shaped by, investment in complementary assets and their utilisation. When scientists move networks alter and arrangements of human capital and complementary assets are transformed. Scientific mobility may lengthen or link networks to extend consolidated configurations (capacity building) or contribute to the establishment of emergent nodes. Scientific human capital mobility can also have a 'domino effect', leading to chains of movement through spaces of circulation. Human capital mobility is thus a fundamental and dynamic process shaping the evolution of scientific networks over time.

The third related point is that the mobility of scientists has consequences for the economic properties of human capital. As we described in detail, above, the economic properties of scientific human capital are context dependent and extrinsically determined. One consequence of the movement of scientists is the potential transformation in the degree of rivalry and excludability of their human capital. The mobility of human capital is therefore not a question of the simple allocation of a rival good. Rather, scientific mobility may alter the degree of rivalry of human capital as networks are re-configured and different co-efficients of relatively specific or generic context skills are deployed in scientific work. In addition, scientists' networks of social capital that are integral to the collective nature of their work may be differently utilised and leveraged subsequent to changes in organisational or geographic locations. A scientist's embodied skills and tacit knowledge may become relatively more or less rival when transferred from one setting to another.

7 Discussion: scientific mobility and development

A distributed approach to scientific human capital mobility has important implications for how we conceive the role of mobility in capacity building processes. For example, the emigration of a scientist from a developing science system to a highly developed one (traditionally considered as a knowledge/brain drain) could stabilise or further strengthen the participation of her country of origin in internationally consolidated configurations, thus contributing to multidirectional knowledge transfer and to the reinforcement of her home country science system (capacity building). By the same token, the repatriation of a researcher involved in experimental emerging research abroad, if not well managed, could turn into a lose-lose situation in which neither the laboratory of origin, nor the home country, could capture the value embodied in scientific human capital once separated from the context in which the relatively new knowledge is emerging and developing. Policies designed to attract researchers to return are thus argued to need to consider whether the scientific human capital is deployed in relatively emergent or consolidated networks. From this perspective the role of public policies would no longer be to build 'markets' able to attract and retain scientists but to observe and support the process of network (re)configuration.

The socioeconomics approach to scientific mobility we propose argues that mobility, like knowledge production, is not context free. Every scientist 'owns' particular co-efficients of specific and generic context skills that enable them to create and innovate in seeking new knowledge, but which are also part of their scientific *habitus* that allows them to adapt to localised scientific settings as part of their professional capability. Specific and generic skills cannot necessarily be treated as equivalent in relation to the economic properties of scientific human capital.

From the buyer's perspective, for example that of a company or a developing country, a socioeconomics of scientific mobility thus requires three levels of analysis. Firstly, an understanding needs to be developed of the extent to which mobility reconfigures networks in which the buyer has an interest. Secondly, to what extent do these reconfigurations, and the emergent compatibilities between context skills and research settings, transform the economic properties of scientific human capital in which the buyer makes investments. Finally, such an approach should then consider the institutional and policy arrangements that 'frame' this process and their historical evolution. Public policy that invests in scientific human capital as part of a well-informed strategy to build and reinforce spaces of circulation that meet particular economic and development goals (innovation, commercialization, capacity-building) has the potential to better advance the interests of developing countries than trying to compete for human capital resources viewed as homogenous goods allocated as part of a zero-sum game.

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