Innovation, Higher Education
and Research for Development

Programme on Innovation, Higher Education and Research for Development (IHERD)

Background document

Public Financing of Research

Taxonomy of public research-funding apparatuses

Draft Report

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Contents

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Preamble

The present study aims to propose a methodology for identifying typological similarities among *public research-funding apparatuses*, with universal applicability to OECD, other developed, as well as emerging and developing economies, primarily for *policy-learning* and potentially also for policy-making purposes.[1] The term 'public research-funding apparatus' refers to the structured set of instruments by which public research funding (as defined in paragraph 1.3.2 below) is performed. It is not a system in itself, but a vital component or *sub-system* of a *national innovation system*.

The proposed methodology is based on a structured set of multidimensional criteria, each one of which examines a different aspect of public research-funding apparatuses, and can be assessed by means of a proposed set of predominantly qualitative but also quantitative indicators. Existing criteria and indicators of this type have been used until now primarily for identifying 'best practices' in developed countries and for benchmarking established innovation systems of advanced economies, mostly on the basis of their R&D output, and have never been systematically put together and studied for policy-analysis and policy-learning purposes.

The present study focuses on the modalities, instruments, governance structures, objectives, evaluation mechanisms, and other aspects of public research funding, rather than on the attainment of its objectives, the successfulness of its implementation or its actual impact on the national innovation system or the economy at large; in other words, it focuses on the structure and function of public research-funding apparatuses, rather than on their output and performance. The intended universal applicability of the proposed methodology entails that the criteria, on which this methodology is based, will also reflect the particularities of innovation systems in developing countries and take into consideration technology- and innovation-related development issues.

Assessing the *effectiveness* or the *efficiency* of public research funding,[2] or indeed any aspect of its socio-economic impact, or evaluating the overall quality of the national innovation systems into which public research funding is directed, is out of the scope of this study. Nevertheless, some indicators typically related to the 'output side' of public research funding, or to the structure and properties of the national innovation systems per se, of which the public research-funding apparatuses under study form part, are inevitably employed in this taxonomic exercise. As a matter of fact, the identification of generic characteristics of national innovation systems and their association to public research-funding apparatuses is deemed to be an indispensable part of this exercise. This is because a 'holistic' understanding of the innovation systems in which public research funding takes place is necessary in order for the structural differences and specificities of developed and developing countries to be properly understood and accounted for.

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[1] *Policy-learning* refers to the structured and conscious change in the way of collectively thinking about a specific set of policy issues, including the way of framing the policy issues, and which may result in 'public sector innovations' (KEMP & WEEHUIZEN, 2005), and, by extension, in innovations in policy-making.

[2] *Effectiveness* of public research funding refers to its capacity to produce results either in terms of technological knowledge output or in terms of macroeconomic improvements, e.g. productivity gains which translate into macroeconomic growth, job creation, etc. *Efficiency* of public research funding refers to the extent to which results are maximised with the minimum use of resources for their achievement.

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The product of this study is intended to be used as a principal or complementary tool for cross-country comparisons for policy-learning purposes, and as a reference text for informed policy intervention in the field of research and innovation with a developmental perspective. Target end users of the study, therefore, include STI policy-makers in developing and developed countries, as well as development agencies interested in funding research capacity building in developing countries.

The study is complemented by 13 country-specific case studies on public research-funding apparatuses of both OECD and developing economies. The methodology proposed here is applied to this sample subject to data availability, and to the extent that this is permitted by its limited size.

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1. Theoretical context

1.1 Innovation systems and the systemic paradigm

1.1.1 The systemic paradigm

The general theoretical framework of this study is consistent with the *systemic* construal of the *innovation process* (i.e. the process of technological knowledge production, diffusion and appropriation). The systemic turn in technology and innovation studies emerged in the 1980s on Schumpeterian, institutionalist and evolutionary underpinnings. The emerging paradigm displaced the strongly reductionist, 'mechanistic' construal of innovation as a linear, deterministic input-output process, which resonated the notorious 'linear model of innovation' and was consistent with the dominant neoclassical paradigm of economic theory, by shifting the focus on the structural, procedural and relational characteristics of the innovation process.

The systemic paradigm in innovation studies is based on the recognition that technological knowledge is generated and diffused in complex systems of adaptive (or reflective) heterogeneous economic agents, usually with bounded rationality and limited information on their economic environment.[3] These systems are typically open, at a far-from-equilibrium state, and exhibit nonlinear dynamics, self-organisation, endogenous novelty, and path dependence.[4] They have network structures with nontrivial topologies shaped by the interactions of economic agents, which are regulated through formal institutions and informal social norms, conventions and habits. The populations of economic agents, institutions/norms and technologies co-evolve by undergoing three fundamental evolutionary processes, namely selection, variation and retention. The co-adaptive interactions of individual economic agents generate symbiotic relationships, which can be antagonistic (competitive), synergetic (mutualist) or exploitative.[5]

1.1.2 Innovation systems and public research-funding sub-systems

The systemic paradigm in innovation studies inspired the theories of *national innovation systems* – a concept widely used in the present study.[6] The term *innovation system* is defined by FREEMAN (1987) as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies". Clearly this definition emphasises the *institutional dimension* of the innovation process, whereas LUNDVALL (1992) emphasises the *relational dimension* of national innovation systems by defining them as "the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge [...] and are either located within or rooted inside the borders of a nation state".[7]

A fundamental determinant of an innovation system's fitness is its *absorptive capacities*, i.e. its ability to 'appropriate' technological knowledge. In the context of the innovation process, 'to appropriate' means to tap either domestically produced technological

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[3] SIMON (1955; 1956).

[4] CHORAFAKIS & LAGET (2009).

[5] Ibid.

[6] The term (*national*) *innovation system* is attributed to FREEMAN (1987), and LUNDVALL (1992). The extensive bibliography on this topic includes NELSON (1993); OECD (1997); EDQUIST (1997); EDQUIST & HOMMEN (1999).

[7] Cited in OECD (1997).

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knowledge (generated using own cognitive resources, including domestic R&D investment), or spillovers of technological knowledge produced elsewhere, and to transform them into tangible economic results – in microeconomic terms increased productivity and in macroeconomic terms growth and jobs. The inadequate absorptive capacities of a national innovation system reduce the efficiency and the effectiveness of public investment in R&D, and may cause the whole public research-funding apparatus to fail to meet the objectives for which it was designed. However, the absorptive capacities of an innovation system are not an immutable feature of the system, but can be methodically built and enhanced. The quantity and quality of human and social capital involved in the innovation process, as well as the strength, coherence and diversity of the industrial basis are fundamental determinants of the absorptive capacities of an innovation system. This gives an indication how absorptive capacities can be enhanced.

National innovation systems exhibit diverse levels of development or 'advancedness' which do not necessarily coincide with the 'stage of development' of the economies in which they are embedded, although a certain degree of correlation does exist, as explained below. A crude classification of the national innovation systems according to their distance from the *world technology frontier* (see paragraph 3.2, criterion A.3) proposed in this study is into *frontrunners*, *established*, *emerging* and *embryonic*. Developed economies usually (but not always) are equipped with 'established' or 'frontrunner' innovation systems and developing economies with 'emerging' or 'embryonic' ones. It is not unusual, however, for a 'developmental' state in a developing country to succeed in building significant absorptive capacities,[8] and hence a near-established innovation system, by deploying a comprehensive techno-industrial strategy specifically aimed at the enhancement of the absorptive capacities of its national innovation system. This is not uncommon in rapidly industrialising economies, and for the second half of the twentieth century it has been the norm rather than the exception in East Asia, including Japan, and more recently China. The development status of an innovation system cannot be assessed on the basis of simple unidimensional criteria – for instance, it cannot be sufficiently measured by R&D intensity alone (see paragraph 3.2, criterion A.2 for a definition) – but by a combination of quantitative and qualitative, and often multidimensional knowledge-economy indicators.

As already noted, the status of a national innovation system determine the fitness of the public research-funding apparatus, and for this reason it is relevant to the taxonomy developed in this study. In a fragmented, dysfunctional innovation system, any of the sub-systems of which does not work properly, or in an innovation system with inadequate absorptive capacities, public R&D investment is doomed to fail to be efficient and effective, and ambitious quantitative targets for R&D intensity may prove futile, or even resource-wasting and potentially distortionary for the economy.

In the particular case of embryonic innovation systems in developing (especially in low-income) economies, any direct comparisons with established innovation systems in advanced industrial countries drawn on the basis of the same quantitative indicators will be largely problematic and misleading, given the pervasive market failures, the distortions in relative factor prices, the institutional dysfunctions, and the government failures common in low-income economies. The criteria to be applied in such cases should, therefore, be accordingly adapted to the contextual specificities of the group. This group is highly diverse, and actually much more heterogeneous than the group of

[8] The term *developmental state*, introduced by JOHNSON (1982), refers to states which lead the industrialisation drive in latecomer economies, taking on developmental functions, as opposed to states with a predominantly regulatory orientation. Japan is an archetype for the former and the US for the latter type.

developed economies, especially with regard to their capacities and performance in research, technological development and innovation.

1.1.3 Distributed knowledge and economies of complexity

As technologies become more elaborate, the complexity of the innovation process, and by extension, of innovation systems, increases, and so do factor indivisibilities in technological knowledge production. This raises the entry barrier for firms at the micro-level, as well as for developing economies which aspire to technological development at the macro-level. In developed economies a response to increased factor indivisibilities in technological knowledge production is the widespread adoption of the *open innovation* paradigm, which entails that firms, including transnational corporations (TNCs), increasingly rely on *distributed knowledge* accessed through supra-national knowledge networks, externalise R&D functions, and perform collaborative R&D, while the innovation life cycle gets significantly shorter. Firms engage in cooperation in order to exploit technological spillovers, to avoid technological lock-ins, to pool the risk of investment in uncharted territories of the technological landscape, to share the high costs of research, but also to take advantage of the increased efficiency of networks in generating and diffusing new technological knowledge compared to internalised, vertically integrated organisational structures.

The complexity of innovation systems may increase in two distinct ways:

(i) the number and diversity of economic agents involved in the innovation process, i.e. the number of nodes of the network-like innovation system, may increase, in which case the division of labour in technological knowledge production is extended;

(ii) the volume and strength of links among the economic agents involved in the innovation process may increase, in which case the division of labour is intensified and deepened.

The increased 'collective efficiency' of the innovation system in the first case is attributed to Marshallian *external economies of scale* in technological knowledge production, while in the second case to *economies of complexity*.[9]

The Marshallian concept of 'external economies of scale', i.e. scale economies external to (competitive, non-monopolistic) firms but internal to the entire industry, is a hybrid between externalities and traditional ('internal') economies of scale ingeniously devised by Marshall to reconcile Cournotian increasing returns with the competitive equilibrium framework. External economies of this kind are supposed to arise from the development of an industry as a whole, unlike internal economies which, according to Marshall, arise, among other reasons, from the intensification of the division of labour within a firm. Agglomeration economies is a territorially specific form of external economies of scale.

Economies of complexity, on the other hand, ensue from the intensification and deepening of the (external) division of labour, i.e. the increase of the number and strength of ties among interconnected units, ceteris paribus, and the subsequent increased specialisation within this external division of labour. Economies of complexity lie at the heart of the innovation process, and are the principal source of increased efficiency of the open innovation model. Beyond a certain threshold of systemic complexity, *diseconomies of complexity* may settle in.

[9] CHORAFAKIS & LAGET (2009); CHORAFAKIS (2013).

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1.2 Types of technological knowledge and research

Understanding the nature and purpose of technological knowledge and of research is essential for delimiting the scope of government intervention in the innovation process and for designing meaningful and effective public research-funding instruments. This is not always the case in RTDI policy-making, especially in countries with underdeveloped national innovation systems and public research-funding apparatuses, where the objectives of intervention are obscure, and funding is dissipated in activities which in the end do not generate the desired economic effects and, therefore, do not necessarily promote public interest.

1.2.1 Types of technological knowledge

The term *technological knowledge* denotes in this study 'knowledge with actual or potential economic effects'. In this very broad definition the qualifier 'technological' does not necessarily signify 'technical' or 'applied', but refers to economically relevant knowledge (including 'scientific' or 'theoretical' knowledge), which is ultimately capable to affect the means or the process of production, in the direction of increasing the productivity of the classical production factors (capital and labour). By this definition technological knowledge itself is essentially an intangible factor input in the production process.

Four types of technological knowledge can be distinguished on the basis of its degree of *embodiment* in economic agents or artefacts, its *codifiability*, its *contextuality*, i.e. the extent to which its valorisation is context-dependent, and its *appropriability*, i.e. the extent to which its economic value can be privately appropriated:[10]

Universal (also 'scientific', 'generic', 'theoretical', 'basic' or 'fundamental') knowledge is disembodied, formal, codifiable, and minimally contextual. It bears the characteristics of a public good (i.e. non-rivalry and non-excludability), which makes it not directly appropriable on a private basis, and has strong positive spillover effects on overall economic activity. This type of technological knowledge is the foundation on which other types are built. Its limited appropriability, however, reduces the incentives for its private production, and, as a consequence, it is generally under-produced by the market. For this reason public investment is required to ensure its sufficient provision to the benefit of society at large. This type of technological knowledge is typically contained in scientific publications, and hence can measured by bibliometric indicators.

Instrumental (also 'technical', 'specific', 'applied') knowledge is another disembodied and codifiable form of technological knowledge, but more contextual than the previous type, as it is produced and used in more specific techno-economic contexts. This type of technological knowledge can be rival and excludable prior to the allocation of intellectual property rights (IPR), becomes publicly accessible after the allocation of IPR, even though its direct utilisation is restricted, and ceases to be excludable with the expiry of IPR in the longer run. It can be considered, therefore, as a 'quasi-private' good. It is not unusual for this type of knowledge to be produced by public institutions, in which case it can be considered as a quasi-public good.[11] Technological knowledge contained in patents usually belongs to this type, in which case it can be measured by patentometric indicators.

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[10] CHORAFAKIS (2013).

[11] The term *quasi-private* denotes a good that in principle is rival and excludable, but with spillovers that in the longer run erode its excludability, and consequently, its private nature. In existing literature the term 'quasi-private' is sometimes used differently, to denote private goods provided by the government. *Quasi-public* are publicly provided and socially beneficial goods, which however are neither fully non-rival nor non-excludable.

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Organisational knowledge is embodied in organisational structures, both internal or 'integrated' (e.g. corporate structures) and external or 'quasi-integrated' (organisation networks).[12] This type of technological knowledge is limitedly codifiable, and highly contextual. It is collectively produced within or between organisations, and owned, protected and exploited by them as a private asset. In the short run it confers technology rent to its proprietors, but in the longer run it may diffuse to competitors through labour mobility, imitation, reverse-engineering, etc.

Individual knowledge is embodied in economic agents in the form of technical skills and know-how (as opposed to 'know-what'), and can be developed through learning-by-doing, vocational training or even formal education. This type of technological knowledge is both rival and excludable, and as a result, is a private good. It is non-codifiable, 'tacit',[13] and highly contextual.

1.2.2 Types of research

The fundamental dichotomy between basic and applied science observed in Bush's highly influential 1945 report "*Science – The Final Frontier*",[14] was taken further by STOKES (1997) with the distinction between three types of research in a two-axis classification scheme. Each type of research corresponds to a quadrant defined by the two axes and named after Bohr, Pasteur, and Edison. The horizontal axis tells whether research has 'considerations of use', and the vertical axis whether it aims at 'fundamental understanding' of observed reality. Bohr's quadrant corresponds to *pure basic research*, which is supposed to have no considerations of use, but seeks fundamental understanding; Pasteur's quadrant corresponds to *use-inspired basic research*, which does both; and Edison's quadrant corresponds to *pure applied research*, which has only considerations of use.

Stokes's classification scheme is compatible to that of a standard reference document in innovation studies – the Frascati manual (OECD, 2002). The manual distinguishes three types of R&D activities, *basic research*, *applied research* and *experimental development*. Basic research is defined as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view"; applied research as "original investigation undertaken in order to acquire new knowledge directed primarily towards a specific practical aim or objective"; and experimental development as "systematic work drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed".[15]

Pure basic research in Bohr's quadrant generally aims to produce universal technological knowledge. Use-inspired basic research in Pasteur's quadrant, and pure applied research in Edison's quadrant result in the production of instrumental or organisational technological knowledge.

[12] KOGUT & ZANDER (1992).

[13] The term *tacit knowledge* is introduced in POLANYI (1967).

[14] BUSH (1945).

[15] OECD (2002).

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1.3 Public research funding

1.3.1 Rationales for the public provision of research funding

There are two contrasting rationales for government intervention in the innovation process. The first, which will be termed 'Paretian', is consistent with the neoclassical-rooted school of thought of welfare economics. The second, which is becoming increasingly dominant in innovation studies and in RTDI-policy discourse, has Schumpeterian origins.

In the neoclassical-welfare economics context government intervention is justified in case of 'market failures', i.e. aberrations from the competitive market norm leading to Pareto-suboptimal allocations of resources. Government intervention aims to restore the *static efficiency* of the market. Market failures include externalities and spillovers, the under-provision of public goods, missing markets and incomplete contracts, and uncertainty deterring economic agents from engaging in market transactions.

In the specific context of the innovation process, three typical sources of market failure are identified: *indivisibilities* linked to increasing returns, *inappropriability* related to externalities, and *uncertainty* inherent in R&D investment.[16]

(*Factor*) *indivisibilities* result in a high minimum-efficient scale for producing new technological knowledge, and, relatedly, in high setup costs. As the production of new technological knowledge is becoming more complex and demanding, indivisibilities tend to increase, and so do the barriers to entry for new firms and the costs of innovation-based competition for incumbent firms. For this reason firms increasingly resort to the adoption of the open innovation paradigm. Government intervention in this context may take several different forms, including the use of public research funding to foment R&D collaboration on the basis of the open innovation model, to construct large research infrastructures, to facilitate access to venture capital, to provide direct or indirect industrial subsidies, to co-fund public-private partnerships in innovative activities, etc. (see also paragraph 3.2, criterion B.8).

Inappropriability is a serious issue in the case of the non-rival and non-excludable universal type of technological knowledge. Due to its public good characteristics this type of technological knowledge exhibits strong spillovers, and tends to be generally under-produced by the market. Government intervention through public research funding in this context aims to ensure the sufficient provision of this type of knowledge for the benefit of the innovation system at large. In the case of rival technological knowledge of the instrumental or organisational type, the problem of inappropriability is partially tackled through the establishment and protection of IPR, but also again through public research funding directed into the production of the inappropriable segment of technological knowledge.

Uncertainty is an inherent feature of the innovation process. Innovation-related uncertainty does not result from incomplete information alone, but (mainly) from the non-deterministic, discontinuous, open-ended nature of the innovation process, which is marked by complexity, emergence, and endogenous novelty, and from the related nonlinear complex dynamics of self-organised innovation systems. Government intervention through public research funding in this context will aim to assume part of the risk of private R&D investment by providing loans and guarantees for innovative activities, to facilitate access to venture capital, to encourage risk pooling through collaborative R&D (including public-private partnerships), and to subsidise innovative activities.

[16] ARROW (1962).

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The Paretian 'market-failure' rationale for government intervention in the innovation process is highly influential, and despite its neoclassical origins it is often evoked in RTDI-policy discourse even in cases where the 'systemic' paradigm has been wholeheartedly espoused.

In the Schumpeterian context market power, increasing returns, information asymmetries, and other deviations from the competitive market norm are not seen as 'market failures' but rather as potential driving forces of innovation-based competition. From a broadly-defined 'neo-Schumpeterian' perspective policy intervention should aim to support and accelerate the pace of technological progress rather than to restore competitive market conditions, and is justified as a means to offset technological lock-ins, to induce technological trajectory shifts,[17] and to increase the absorptive capacities and improve the *dynamic efficiency* of innovation systems.[18]

Dynamic efficiency is an intertemporal property of an innovation system, which characterises the state of the system as a whole instead of the state of its micro-elements, the individual economic agents. Attaining dynamic efficiency is an open-ended process, which involves the 'adaptive walk' of the system in the technological 'fitness landscape'. During this evolutionary process a multitude of *local* optima are compared and some of them become the system's attractors, whenever the system's trajectory (temporarily) settles in them.

Policy intervention in this context may aim to shift the economy from a developmentally 'inferior' attractor basin where the economy has spontaneously settled – what in development theory is called a 'low-level equilibrium'[19] – to a superior one. This may require the inducement or acceleration of *technological convergence* to the world technology frontier (see paragraph 3.2, criterion A.3) by shifting technological trajectories and by expanding the absorptive capacities of the national innovation system. In this case policy intervention will be more complex than in the case of merely tackling market failures, as it requires the mobilisation of a multitude of socio-economic resources on the basis of a strategic techno-industrial plan. In that case, RTDI policy is more effectively combined with other policies (the most instrumental of which is industrial policy).

Government intervention aiming to ensure the dynamic rather than to restore the static efficiency of an innovation system is particularly relevant for developing economies with embryonic or fragmented national innovation systems, which aspire to improve their position in the global knowledge economy. Active government intervention in an innovation system, in a way that breaks old path dependences, and which is intended to cause technological 'leapfrogging' by changing the nature of comparative advantage of an economy, are typically associated with the 'developmental state' paradigm.[20] By contrast the perception of the role of the state merely as a regulator and guarantor of the institutional framework and the enforcement of IPR, is consistent with the neoclassical-welfare economics approach.

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[17] Smith (2000).

[18] Chorafakis & Pontikakis (2011).

[19] Nelson, 1956; Bardhan, 1993.

[20] The term *developmental state*, introduced by Johnson (1982), refers to states which lead the industrialisation drive in latecomer economies, taking on developmental functions, as opposed to states with a predominantly regulatory orientation. Japan is an archetype for the former and the US for the latter type.

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1.3.2 Definition, characteristics and instruments of public research funding

Public research funding is the main means for exercising research, technological development and innovation (RTDI) policies, and therefore it is the principal set of instruments for government intervention in the innovation process, with significant leveraging capacities, both in developed economies with established national innovation systems and in developing economies. An alternative set of instruments for exercising RTDI policies is the set of regulatory measures which constitute the institutional and legal framework in which the innovation process takes place, ranging from the IPR regime to tax incentives for innovation. These are out of the scope of this study.

Public research funding is a major component of R&D investment. It involves direct transfers from government (national/federal, regional/state, and local) in the form of contracts, grants or donations (excluding repayable loans to enterprises for conducting R&D) for the coverage of current costs (mainly R&D personnel labour costs and non-capital expenditures on materials, supplies, etc.), and capital expenditures (investment in fixed assets) for performing R&D.

The most common instruments of public research funding are grants (in the generic sense of the term) directed to research projects, programmes or performers. *Project-funding grants* have a fixed (short to medium term) duration, involve explicitly defined (groups of) beneficiaries, and are usually allocated competitively through a process of project evaluation (see paragraph 3.2) on the basis of the project's proclaimed research objectives contained in the project proposal. *Programme-funding grants* are usually longer-term funding schemes provided for thematically interrelated project portfolios. *Performer-funding grants* are funding lines extended to research-performing individuals, groups or organisations, which leave to the beneficiaries a certain degree of discretion regarding their use, and are not necessarily intended for a specific project or in the context of a specific programme.

Public research funding is more specifically referred to as 'government-financed gross expenditure in R&D' (government-financed GERD) or 'Government Budget Appropriations or Outlays for R&D' (GBAORD). These two definitions of public research funding are not entirely equivalent in that government-financed GERD is estimated on the basis of reports by R&D performers, and involves R&D performed exclusively on national territory and funded by all levels of government, whereas GBAORD is estimated on the basis of reports by R&D funders, involves R&D funded mainly by central/federal government, and includes government funding to foreign R&D performers. Government-financed GERD has two main components, namely direct government funds and public general university funds (GUF). The latter are funds destined for education and research occupying an important share of public research funding, which are financed directly from government budget (typically by Ministries of Education).[21]

Public research funding represented on average a 0.75% of the GDP of OECD economies in 2009, with the highest share of government-financed R&D funding in the GDP exhibited by the US, Finland, Iceland, Portugal, South Korea, Denmark and Sweden. The ratio of public research funding to total GERD, however, tends to be higher in less-industrialised economies, where private funding of R&D is in short supply. In advanced industrial economies with abundant provision of private funding to R&D, public funding is commonly used as an instrument for supporting the provision of certain types of technological knowledge, which are deemed to be 'socially' beneficial but would otherwise not be provided by competitive markets due to their particular characteristics.

[21] OECD (2002).

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2. Methodology

1.4 Taxonomic classes

The methodology for the typological identification of public research-funding apparatuses proposed here is based on a number of criteria, which can be assessed by predominantly qualitative, but also quantitative indicators. These criteria cover various structural, functional, instrumental and organisational aspects of public research-funding apparatuses considered as sub-systems of national innovation systems. Some of these criteria are multidimensional in the sense that they examine complex aspects of public research-funding apparatuses or of innovation systems, whose assessment involves the use of more than one qualitative or quantitative indicators.

The criteria are grouped in four classes: The first class consists in criteria characterising the national innovation systems to which the public research-funding apparatuses under study belong. The second class subsumes criteria which refer to the rationale, objectives, and priorities of public research funding, and, more specifically, to the extent to which the design of public research funding apparatuses is determined by and responsive to (national) economic, societal and developmental challenges, especially in the case of developing countries. The third class of criteria examines the governance structure of public research funding, including the public research-funding allocation modalities and the distribution of competences among policy-makers involved in the design and implementation of RTDI policy. The fourth class of criteria refers to the scope of the evaluation functions attached to public research-funding apparatuses (or the lack thereof), and their role in determining the allocation of public research funding.

The 'types' of public research-funding apparatuses identified in this study are defined by multiple criteria, but not all criteria listed below are used in this taxonomical exercise to distinguish types – some of them are merely used to define variations or sub-types within a type. Moreover, criteria from one class may be closely related to or entail criteria from other classes, which narrows down the number of their potential combinations for taxonomical purposes.

1.5 Criteria and indicators

1.5.1 Limitations of quantitative indicators in developing countries

This study proposes the use of both qualitative (categorical) and quantitative (numerical) indicators for the assessment of the taxonomical criteria, although its analytical orientation is predominantly qualitative. Most commonly used quantitative indicators have been typically devised for established innovation systems of capital-rich – not only in terms of physical and financial capital but also in terms of human and social capital – advanced industrial economies. For this reason, when assessing various aspects of innovation systems, including public research-funding apparatuses, in developing economies, these indicators should be used with caution, bearing in mind the various limitations they are subject to, and always submitting them to empirical reality checks.

These limitations include the following:

- Datasets are often incomplete or even unreliable, due to the lack of transparency and methodological consistency in data collection, which in turn may be caused by institutional instability or inadequate data collection infrastructures, among other factors.

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- International donors and funding agencies, as well as NGOs and other foreign organisations often play a decisive role in the management of public research funding in developing (especially low-income) countries which rely on foreign aid. This influence is not always directly reflected in observable empirical data.
- Public research funding in developing (especially low-income) countries is often controlled by a limited number of organisations, and ends up in individual transfers to researchers or research groups rather than to institutions, and thus remains undeclared and unaccounted for in official statistics.[22]
- Salaried researchers may not have separate research budgets, while unpaid research is not uncommon, especially in the case of university researchers.
- Double counting of researchers.
- Some developing countries may exhibit an even lower propensity to patent and publish than expected on the basis of their research capacities, due to insufficient access to electronic resources and telecommunication means (such as common internet use, electronic journals, etc.), the lack of supportive institutional structures, which results to disproportionate transaction costs, for instance for patenting, etc., or even due to a culturally induced loose attitude towards IPR.
- In developing and emerging economies the most common type of innovation activities are those leading to minor, incremental changes or adaptations, which in principle are not formally accounted for as R&D activities.[23]

1.5.2 Taxonomical criteria and corresponding types and indicators

A Innovation System Context

Placing public research-funding apparatuses in the specific context of the innovation systems to which they belong, but also in their broader socio-economic context, is indispensable in order for this taxonomical exercise to be empirically relevant and for the proposed typology to be practically useful for policy-making purposes. The structural characteristics of the national innovation systems, but also of the economic structure in which these innovation systems are embedded, largely determine the effectiveness and the efficiency of public research funding, and the optimal design and use of its instruments. It would therefore be unwise to separate the typological identification of a public research-funding sub-system from the broader context of the national innovation system to which it belongs, as these two are mutually determined.

This class of criteria examines the following aspects of a national innovation system, which are relevant to the typological identification of public research-funding apparatuses: The degree of the involvement of the state in the innovation process; R&D intensity, i.e. the relative volume of public and private resources dedicated to R&D activities in the economy; the distance of the national innovation system from the *world technology frontier*, and the rate at which its position with respect to this frontier changes, i.e. its rate of *technological convergence* or *divergence*; the role of the national innovation system in the global division of labour in the production of technological knowledge, and in particular its structural position in global knowledge networks; and finally, the type of its internal division of labour as determined by the degree of its thematic or sectoral diversity.

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[22] GAILLARD (2008) cited in OECD (2012: 4).

[23] OECD (2005: 499).

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A.1 State involvement in the innovation process

The state plays a crucial role in shaping and determining the function and orientation of a national innovation system, especially during the first stages of ‘cognitive capital’ accumulation in rapidly industrialising economies with dynamically emerging innovation systems. Even in OECD economies the state often may take the lead in R&D investment when there is a lack of market incentives for private firms to invest in R&D at a level which is considered socially optimal or politically desirable, typically in the case when the industrial basis is weak, when the costs of entry for private firms are high due to large indivisibilities in technological knowledge production in relation to the firms’ capacities, or for certain types of technological knowledge with public good characteristics (e.g. the ‘universal’ type) which make them difficult to appropriate. In this context two types of national innovation systems can be distinguished by this criterion:

- *state-led* national innovation systems, in which the state acts as the ‘prime mover’ of the innovation process by being the principal investor in RTDI activities in the economy;
- *market-driven* national innovation systems, in which private firms drive the innovation process and collectively have the largest share of investment in RTDI activities in the economy.

This dichotomous criterion is rather rudimentary, but useful for a basic identification of national innovation systems types, which will subsequently be used in the typological identification of public research-funding apparatuses. The nature of state involvement in technological knowledge production is examined and assessed in detail by the more refined criteria of class B. This criterion here is particularly associated to B.1 (intervention rationale) and B.6 (appropriability of publicly funded research results).

State involvement in the innovation process cannot be adequately assessed on the basis of quantitative indicators alone: a comprehensive approach requires a more contextual analysis of the role of the state in the economy, which should be able to identify the extent the state employs industrial policy instruments and adopts technological development strategies, and, in the case of developing countries, to tell whether the state is essentially ‘developmental’.[24]

A simple quantitative indicator commonly associated with this criterion is the ratio of government- to industry-financed GERD. As a rule of thumb, in advanced industrial economies this ratio tends to be low (close to 1:2), whereas in less-industrialised countries (including OECD economies with relatively weak industrial bases), which however do invest in human capital and set more ambitious targets of R&D intensity (see criterion A.2: Research intensity), the ratio is usually inversed (close to 2:1). In Europe this ratio is generally higher than in the US, and this also reflects different perceptions with regard to the desirable amount of policy intervention in the market and in the innovation process, and also the perceived necessity to bridge the seeming technology gap between Europe and the US.

A relatively high government- to industry-financed GERD ratio, however, does not necessarily entail that the innovation system is state-led, and likewise a low ratio does not necessarily indicate a market-driven innovation system: State intervention in RTDI may materialise through other, non-financial instruments, such as ad hoc regulation or strategically devised policy mixes with a strong influence on the innovation process involving policies other than RTDI. The high government- to industry-financed GERD ratio is, therefore, a necessary but not sufficient condition for an innovation system to be identified as state-led. In general, there is no generalisable optimality rule for public

[24] See footnote no. 8 for a definition.

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R&D investment compared to private, as this merely reflects the specificities of the underlying innovation system and the aspiration level of policy-makers.

A.2 Research intensity

R&D intensity is the most common criterion for assessing national innovation systems, and by extension public research-funding apparatuses. R&D intensity is typically measured by quantitative indicators, most commonly by the ratio of gross expenditure in R&D (GERD) to gross domestic product (GDP). Government-financed GERD:GDP or GBAORD:GDP ratios alone are not suitable indicators for assessing R&D intensity, as the latter depends on other structural characteristics of the national innovation system beyond public research funding.

The GERD:GDP ratio is universally used in the formulation of quantitative targets for research policy, and, by extension, for public research funding, but its use for this purpose has several caveats: It is an indicator more meaningful for advanced industrial/OECD economies, and, limitedly, for upper-middle income emerging economies. In low- or lower-middle income economies potential distortions in relative factor prices, including wages, the relative scarcity of human capital, and large disparities between domestic and international factor prices make this indicator inappropriate for cross-country comparisons and not entirely reliable in the case of less-developed countries. It should, therefore, be used with caution when setting quantitative targets for research policy in this type of economies.

Another caveat of this indicator is that it cannot truly reveal R&D intensity without also examining the composition of research funding in terms of its public or private origins. For this reason it should be examined jointly with the government- to industry-financed GERD ratio. The combination of the two indicators permits the identification of four types of national innovation systems as follows:

- *market-driven with high R&D intensity*, where the GERD:GDP ratio is higher than the OECD average, and the government-financed to total GERD ratio is close to or below the OECD average; these are usually advanced industrial economies with established innovation systems;
- *state-led with high R&D intensity*, where the GERD:GDP ratio is higher than or close to the OECD-average, but GERD is largely government-financed; these are usually developed economies with relatively weak industrial bases but integrated (or aspiring to integrate) in the global knowledge economy;
- *state-dominated with low R&D intensity*, where the GERD:GDP ratio is lower than the OECD average, and R&D investment is dominated by public funding, which is typically directed to higher education institutions; these can be emerging innovation systems of developed or developing economies;
- *low state intervention with low R&D intensity*, where the GERD:GDP ratio is lower than the OECD average, and the state under-invests in the innovation system.

A.3 Distance to the world technology frontier

The *world technology frontier* is demarcated by the position in technological space of the global technological leader in any given industry, i.e. the highest attainable level of technology in that industry. An obvious caveat in assessing a national innovation system as a whole on the basis of this criterion is that probably no single economy can be a technological frontrunner in all industries at the same time. Conventionally, however, the world technology frontier is taken to be represented by the total factor productivity (TFP) of the US economy. The distance of any other innovation system from the world technology frontier demarcates the *technology gap* of the economy in which this

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innovation system is embedded, and is considered to measure the general 'advancedness' (or backwardness) of a national innovation system.

The principal source of (knowledge-based) productivity growth in an economy whose innovation system is far from the world technology frontier is the adoption of existing technologies produced by the frontrunners. As the innovation system converges to the world technology frontier, productivity growth is increasingly sustained by innovation rather than by adoption and emulation.[25] For this reason, the distance of a national innovation system from the world technology frontier can be a useful criterion for determining the policy targets of public research funding. A related criterion is the rate of convergence (or divergence) of a national innovation system to the world technology frontier, which largely determines whether an economy is emergent and rapidly industrialising or technologically stagnant. On the basis of these two criteria combined we distinguish three types of national innovation systems:

- *frontrunner* national innovation systems, which demarcate the world technology frontier in a large number of industries;
- *established* national innovation systems, which on average are not far from the world technology frontier, and at or close to the frontier in a number of dominant industries;
- *emerging* national innovation systems, which are positioned below the world technology frontier, but are rapidly converging to it;
- *embryonic* national innovation systems, which are still underdeveloped, far below the world technology frontier, and stagnant or divergent.

The indicator most commonly used for assessing the distance from the world technology frontier is the logarithm of the ratio of TFP of the economy in question to the US economy. The caveat of this indicator is that it is based on the conventional neoclassical perception of technological progress as a 'Solow residual'. In real terms, however, this residual, does not capture productivity gains exclusively due to technological progress, but also due to other concomitant factors. Alternative quantitative indicators for measuring the distance of an innovation system from the world technology frontier are mostly 'knowledge output' indicators, such as patent and scientific publication counts per million population, new-to-market product innovations, high-technology exports as percentage of GDP or of total manufactured exports, etc. A caveat of these alternative indicators is that they capture mainly technological advancement due to pure innovation, and in particular 'codifiable' technological knowledge production, but not due to technology adoption and emulation, which is more common in developing countries.

A.4 Position in the global division of labour

The position of a national innovation system in the global knowledge economy is an essential determinant of its typological classification. This criterion is structural and requires an analysis of the global knowledge networks in which national innovation systems are embedded with the use of relational, i.e. network-analytical, indicators. These global knowledge networks are generated by real interactions of economic agents involved in the innovation process, as in the case of research collaborations, or are derived from conceptual associations among agents and their research output, as in the case of academic and patent citations. Knowledge networks generated by real socio-economic interactions can be the open-ended result of spontaneous tie formation, or the predetermined result of affiliations within a specific institutional setting. Knowledge networks may convey universal knowledge, as in the case of academic co-publication and citation networks, instrumental knowledge, as in the case of patent co-invention

[25] See VAN ELKAN (1996); ACEMOGLU *et al*. (2006).

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and citation networks, or even organisational knowledge, as in the case of corporate networks of joint ventures and strategic alliances.[26]

At the micro-level of economic agents involved in the innovation process – including private firms, public organisations, and higher education institutions – network ties and network positioning have proven to be crucial factors for the diffusion and appropriation of technological knowledge.[27] This type of networks have been extensively analysed from a topological and econometric perspective. Academic co-publication and citation networks are among the first and most extensively explored forms of knowledge networks.[28] Patent co-inventor and citation networks have also been extensively investigated yielding interesting insights on the innovation process.[29] With regard to inter-firm R&D collaboration the most common form occurs on an ad hoc or strategic basis, which can be equity-based, e.g. joint ventures, cross-equity holdings; contract-based, e.g. joint R&D agreements, customer-supplier relations, and technology acquisition including cross-licensing, technology exchange agreements, licensing, etc.; and spot-market-based.[30] Another important type of inter-organisational collaboration is between universities or public research institutes and the private sector. All these forms of collaboration generate networks of organisational knowledge.

From a macro perspective, the aggregations of the abovementioned micro-level knowledge network ties at the level of the national (or regional) innovation systems can be represented as inter-national (or inter-regional) knowledge networks, in which entire innovation systems can be analytically treated as nodes. The calculation of the socio-metric indicators, and in particular of various centrality, connectedness, cliquishness, and peripherality indicators (e.g. eigenvector, betweenness, closeness, and integrated centrality, brokerage, clustering, and coreness), of these networks reveal the relative positions and structural influence of the national (or regional) innovation systems under study in the global knowledge economy, also with regard to its core-periphery divide. On that basis the innovation system can be one of the following:

- a *hub*, i.e. a highly-connected node which occupies a central position in the core of the global knowledge economy;
- a *broker*, i.e. a node which acts as a bridge connecting otherwise disjoint segments of global knowledge networks; this type of node typically exhibits high betweenness centrality, as a large proportion of technological knowledge flows through it;
- a *partaker*, i.e. a node with average centrality indicators, locally embedded in the global knowledge network, but without any significant structural role in it;
- an *island* or, more likely, a *leaf*, i.e. an isolated or pendant node in the global knowledge network with very limited or no connections to the network. In the case of a pendant node (a 'leaf'), its (principal) ties are usually with a central node of the 'core'; in the case of developing countries this may typically follow historical patterns of colonial or other types of dependence.

A.5 Internal division of labour

The division of labour in the generation and appropriation of technological knowledge among the heterogeneous agents which constitute a national innovation system

[26] See paragraph 2.2.1 for definitions of *universal*, *instrumental* and *organisational* technological knowledge.

[27] VALENTE (1995) presents a number of models supporting this hypothesis, including threshold and critical mass models of diffusion and adoption.

[28] See NEWMAN (2001); BARABÁSI *et al.* (2002); WAGNER & LEYDESDORFF (2005).

[29] See BALCONI *et al.* (2004); BRESCHI & LISSONI (2005).

[30] See MOWERY *et al.* (1996); HAGEDOORN (2003).

determines the structure and, to a large extent, the functioning of this system; as such, it is probably the most crucial taxonomical criterion for innovation systems.

The internal division of labour in an innovation system is a composite criterion with a multitude of dimensions, including the degree of specialisation of the agents involved in the innovation process, which in turn is related to the sectoral and thematic diversity of performed R&D, and the relative size and resources of the performers; and the way they are integrated in the innovation system, which determines the articulation and cohesion of the innovation system as a whole. On this basis the following types of internal divisions of labour in innovation systems can be distinguished:

- *extensive and cohesive* division of labour, with horizontally or vertically quasi-integrated, sectorally diverse, but specialised and coherently articulated R&D performers, which resembles a *polyculture*;
- *intensive and cohesive* division of labour, with vertically quasi-integrated, coherently articulated R&D performers specialised in a limited number of industrial sectors or thematic areas, which resembles a *mono-* or *oligoculture*;
- *extensive and slack* division of labour, with dispersed resources, and large diversity of R&D performers, who are loosely integrated in the division of labour, and lack systematic specialisation;
- *limited* division of labour, with scarce resources, and a limited diversity of R&D performers, who lack systemic integration.

The assessment of this multidimensional criterion is mainly contextual and qualitative, but it can also be partially based on quantitative indicators, notably concentration and diversity indices applied on industrial output or patent data.

B Objectives and Priorities

This entire class of criteria is the most essential in determining the typology of public research-funding apparatuses as it examines the objectives and priorities of public research-funding instruments, and in particular the following fundamental issues: the rationale for government intervention in the innovation system; the extent to which public research funding is prioritised and deliberately concentrated in a select number of sectors, industries and thematic areas, and whether this concentration has a strategic orientation, i.e. whether it is part of a techno-industrial strategy; the type of supported R&D according to the appropriability of its expected results, i.e. the extent to which public research funding is directed to the support of technological knowledge of a specific type (perceived as public or as private good); the general objective promoted by public research funding (among connectivity, concentration and cohesion); and the specific type of investment activity targeted by public research funding.

Some of the criteria in this class are assessed contextually and qualitatively through experts' opinions, which involves a certain degree of subjectivity, but in many cases this assessment can be complemented by quantitative criteria as explained in detail below.

B.1 Intervention rationale

In paragraph 1.3.1 we examined in detail the Paretian and the neo-Schumpeterian rationales for public provision of research funding, and, more generally, for government intervention in the innovation process: While the Paretian rationale justifies government intervention aiming to restore the static efficiency of the innovation system vis-à-vis 'market failures', the neo-Schumpeterian rationale sees government intervention as a means to improve the dynamic efficiency of the innovation system, to

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increase its absorptive capacities, to cause its technological trajectory to shift towards a 'superior attractor basin', and to eventually induce its convergence to the world technology frontier. Depending on the underlying intervention rationale, public research funding, therefore, may follow existing patterns of comparative advantage in the economy or be part of a strategy for shifting the nature of comparative advantage in the longer run.

On this basis we distinguish two generic types of government intervention rationale in the innovation process through public research funding:

- *counteractive* intervention rationale, aiming at the correction of 'market failures' and the restoration of the 'static efficiency' of the innovation system;
- *proactive* intervention rationale, aiming to change the evolutionary trajectory of the innovation system and to ensure its 'dynamic efficiency'.

In actual public research-funding apparatuses it is not impossible for the two intervention rationales to eclectically co-exist in the proclaimed RTDI policy objectives.

The indicators for assessing this criterion are contextual and qualitative.

B.2 Diversity

Public research funding may support R&D activities in a wide range of industrial sectors or thematic areas or be directed to specific thematic areas or industrial sectors. In the former case the thematic diversity of public research funding may be supported by sufficient amounts of cognitive and financial resources, or simply be the indication of dispersion of scarce resources. By this criterion we distinguish the following types of public research funding:

- *diversified* public research funding, which sufficiently supports activities in a wide range of industrial sectors or thematic areas;
- *concentrated* public research funding, directed to a limited number of industrial sectors or thematic areas on the basis of set national priorities;
- *dispersed* public research funding, i.e. public research funding thinly spread over a wide range of thematic areas, without a substantial impact in any.

This criterion is closely related to criterion A.5 (internal division of labour), but also to B.3 (directionality).

The assessment of this criterion can be based on quantitative indicators, although their availability in the case of developing economies may be limited. In the absence of reliable quantitative indicators the assessment of the diversity criterion can be contextual.

B.3 Directionality

This criterion examines the extent to which public research funding is directed to selected sectors or thematic areas or actors in a national innovation system on the basis of national priorities set in the context of technological and industrial policies. By this criterion public research funding can be said to be:

- *strategically directed*, when it is systematically geared to serve actual and future needs of the economy on the basis of a strategic techno-industrial plan;
- *oriented*, when it is responsive to the actual needs of the economy, and in particular aligned to those of the national industry, without necessarily aiming to change the nature of comparative advantage of the economy;
- *non-oriented*, when public research funding does not exhibit thematic or sectoral orientation, either because funding is dispersed over a large range of non-prioritised research activities (usually resulting in the production of universal-type

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technological knowledge), or because the national innovation system is 'embryonic', weak and not sufficiently integrated in the economy.

A high degree of directionality in public research funding, especially when it is of a strategic nature, is typically associated with the 'proactive' intervention rationale (criterion B.1 above).

The assessment of this criterion can be based on a contextual analysis of stated RTDI policy objectives (or the lack thereof) from relevant policy documents.

B.4 Contextuality

This criterion examines the degree to which the design and the objectives of public research funding stem from and are adapted to the specificities of the national innovation system and the national economy in which the latter is embedded. In developing (especially low-income) countries it is not uncommon for the institutional setting of their national innovation systems, and in particular of their public research-funding sub-systems, to be either 'de-contextualised' versions of perceived 'best practices' copied from developed countries, or 'conditionalities' exogenously imposed by foreign agencies, aid donors, and international financial institutions. These perceived 'best practices' have been extracted from their socio-economic context and emulated in an uncritical or distorted way, which does not serve the specific developmental needs of their economies and societies.

On the basis of this criterion the following three types of public research-funding institutional designs can be distinguished:

- *endogenously determined* institutional design, which is the outcome of either an endogenous evolutionary process or a critical and contextualised adaptation of foreign 'best practices';
- *emulated* institutional design, which stems from the direct transfer of perceived 'best practices' without adapting them to the specific socio-economic context of the innovation system;
- *externally dictated* institutional design, stemming from conditionalities attached to developmental aid.

The assessment of this criterion is purely qualitative and context-dependent.

B.5 Responsiveness to socio-economic challenges

This criterion examines the extent to which public research funding is responsive to specific challenges faced by the society and the economy.

The responsiveness of RTDI policy, in general, to socio-economic challenges is difficult to identify and measure for the reasons that RTDI policy is typically supply-side, and its welfare-enhancing effects are perceivable only in the longer run and indirectly. Addressing societal challenges through RTDI policy, and in particular through public research funding, is an extremely complex and often elusive undertaking, especially in developing countries: In the case of emerging economies, RTDI policies, which form part of broader strategies for techno-industrial development, are not necessarily designed to address societal challenges, such as poverty alleviation, social inclusion, environmental protection, health protection, security, etc., as their main goals are technological upgrading, accelerated industrialisation and macroeconomic growth. In the short run these policies may even have adverse effects on socio-economic inequalities, public health and the environment. Moreover, these policies are often not even geared towards fomenting existing economic structures, as their objective is precisely the structural transformation of the economy. In the case of less-developed low-income economies which lack a techno-industrial strategy, a mismatch between socio-economic challenges

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and public research funding objectives may ensue from the fact that the policy objectives are reproduced or foreign-imposed without having been adapted to the context of the economy and society in question.

A dichotomous application of this criterion leads to the distinction of two types of public research-funding apparatuses:

- a *responsive to socio-economic challenges* public research-funding apparatus is one which has explicitly identified and prioritised societal or economic challenges for the innovation system in which it belongs, and has been designed accordingly;
- an *unresponsive to socio-economic challenges* public research-funding apparatus is one which either has entirely failed to identify socio-economic challenges, or it exhibits a mismatch between its set priorities and its real challenges.

The assessment of this criterion is qualitative and context-dependent. A quantitative indicator available for countries covered by Eurostat, which may be relevant to the assessment of this criterion, is GBAORD by socioeconomic objectives (NABS).[31]

B.6 Appropriability of research results

This criterion examines the dominant type of research activities which public research funding promotes in terms of the appropriability of the research results, i.e. whether and to what extent the produced technological knowledge can be appropriated as a private good, or spill over and be beneficial to the society at large as a public good. On the basis of this criterion a public research-funding apparatus may primarily promote:

- *pre-competitive* research activities of the basic or the applied type leading to the generation of technological knowledge mainly of the universal type, i.e. of a public good nature. This type of public research funding addresses the problem of under-provision of universal technological knowledge by the market, when 'competitive' research is sufficiently funded by the industry; however, it can also be the result of the lack of directionality of public research funding, especially when the main bulk of public research funding is directed to higher education institutions.
- *quasi-competitive* research activities of the applied type leading to the generation of instrumental technological knowledge of a quasi-public or quasi-private good nature. This type of public research funding may be geared to the needs of the 'national' industry, and also may have the potential to increase the appropriability of universal technological knowledge produced in other segments of the national innovation system (e.g. in academia).
- *competitive* research activities of the *applied* or *experimental development* type leading to the generation of instrumental or organisational technological knowledge of a private good nature. This consists in the direct support to private R&D activities, in which case the outcome of publicly funded research is appropriated by private-sector R&D performers. This is an indirect form of industrial subsidy and a potentially powerful industrial policy instrument.

In any national innovation system all three above types usually co-exist; however, one of them is usually dominant in public research funding.

This criterion is mainly assessed by quantitative indicators, including the breakdown of the GERD by type of activity (basic research, applied research, and experimental development), and the share of direct government funding in BERD.

[31] Nomenclature for the analysis and comparison of scientific programmes and budgets.

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B.7 Distributional implications and efficiency gains

The allocation patterns of public research funding may have indirect implications for the distribution of cognitive resources, and lead to different types of efficiency gains in the innovation system. These distributional implications and the associated efficiency gains are not always unintentional (e.g. in the form of externalities), but are often induced by implicit or explicit RTDI policy objectives. In this context, public research funding may aim to promote:

- *connectivity* of research performers, the exchange of information and the circulation of technological knowledge; the potential efficiency gains from this type of public research funding allocation can be increasing returns in the form of *economies of complexity*, accruing from the intensification of the external division of labour in technological knowledge production;
- *concentration* of cognitive resources in a select group of research performers; the efficiency gains in this case are expected to be increasing returns in the form of *internal economies of scale*; the spatial concentration of cognitive resources may lead to agglomeration economies in the form of Marshallian *external economies of scale*, accruing from the extension of the localised division of labour in technological knowledge production;
- *cohesion* of the innovation system through equitable distribution (or redistribution) of cognitive resources aiming at *local capacity building*; in this case public research funding is used as an instrument for enhancing the local absorptive capacities of the innovation system, including the absorptive capacities of regional innovation systems (in which case public research funding becomes instrument of regional technological development), in order to bridge the 'technology gap'; the expected (dynamic) efficiency gains accrue from the increased *cohesion* of the national innovation system.

In a complex innovation system all three types of distributional propensities and the associated efficiency gains may co-exist, no matter how incongruous they may be. However, one of them may implicitly or explicitly dominate in the proclaimed objectives of public research funding. This can only be assessed qualitatively and contextually.

B.8 Investment targets

Public research funding may tend to favour a specific type of investment in the innovation system among the following:

- support to *human and social capital formation* in the innovation process, by promoting training and mobility for individual researchers or research teams, or research collaboration and the formation of knowledge and innovation networks;
- building *research infrastructures*, usually of public ownership;
- provision of *loans and guarantees*, aiming to shield research performers against the uncertainty which is inherent in the innovation process;
- provision of direct or indirect *industrial subsidies* to private firms, including small and medium enterprises (SMEs), or to state-owned enterprises for developing or enhancing their innovative activities;
- *leveraging private investment* in innovative activities, e.g. by fomenting public-private partnerships in innovative activities and joint ventures between public and private R&D performers, or in combination with other policy incentives, e.g. tax advantages or exemptions (which are not sensu stricto part of the public research-funding apparatus).

In the first two cases, government intervention in the innovation system is *competition-neutral* in the sense that it supports 'pre-competitive' research and the public-good aspects of technological knowledge production. In the other cases, government

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intervention is more intrusive, as public funds are used for the direct or indirect support of competitive and private sector activities. This exceeds the conventional limits of RTDI policy and enters the field of industrial policy.

Similarly to the case of criterion B.7, in a large and complex innovation system all types of public research funding investment targets may co-exist, but one or a few of them may be more dominant than the others. This criterion can be assessed qualitatively and contextually, as well as by quantitative indicators.

C Governance Structure

This class of criteria examines the principal modalities of public research funding allocation, and the degree of centralisation and coherence of the governance structure of the public research-funding apparatus.

C.1 Allocation modality

In paragraph 2.3.2 we examined the main types of public research funding instruments, namely project-, programme-, and performer- funding grants, which constitute the public research-funding apparatuses. Any type of public research funding instrument may be implemented according to one of the following three types of allocation modalities, which also constitute a typological characteristic of the public research-funding apparatus:

- *Fixed block allocation* is a public research-funding allocation modality usually for the coverage of current costs (salaries and supplies) or, less commonly, fixed-asset investments of public research-performing organisations. This type of allocation is not subject to evaluation and selection, and it is usually the dominant modality in developing countries with embryonic or emerging innovation systems, which lack an 'evaluation culture'. It is also very common in developed countries with established innovation systems, but is gradually receding in favour of competitive allocation. Its advantages are that it does not require complex management structures, and so it involves low transaction costs, and reduced complexity, which allows more effective institutional planning; it is suitable for capacity building, since it is non-competitive and can easily accommodate policy-makers' distributional concerns; and it is also suitable for funding basic research conducted by academic or public research institutions.
- *Competitive allocation* is a public research-funding allocation modality subject to evaluation and selection of projects or performers. This type of allocation modality increases the transaction costs of governance of the innovation system, and entails that the funding authorities dispose significant cognitive resources for evaluation purposes. On the positive side, it permits the funder to set explicit targets and specific objectives, whereas in the case of fixed block funding the objectives are primarily set by the beneficiary; and it leads to improved performance, increased transparency in the formulation and implementation of RTDI policy and in the allocation of funding, and more meritocracy.
- *Conditional block allocation* is a hybrid modality of public research-funding allocation, which consists in the provision of block funding to research performers subject to systematic evaluation (usually ex post). There are various versions of this allocation modality, such as performance-dependent institutional funding, which requires the periodic evaluation of the past performance of publically funded research organisations and higher education institutions, usually on the basis of measurable research output (e.g. scientometric indicators); or performance-related

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contracts, which are more forward-looking in that the allocation of public research funding is tied to the achievement of specific targets explicitly set in the contracts.

A public research-funding apparatus may simultaneously employ all three types of allocation modalities. In more advanced innovation systems the general tendency is, however, to gradually replace fixed block allocation with competitive or conditional block allocation.

C.2 Distribution of competences

This criterion refers to the way competences in the allocation of public research funding are distributed among the various stakeholders involved in the design and implementation of RTDI policy. A common trend in the governance of national innovation systems is *decentralisation*. This may take various forms and be motivated by different underlying policy objectives. *Agencification* is a form of decentralisation, whereby the upper echelons of government (e.g. ministries) remain charged with the tasks of RTDI policy formulation, including policy design and general budgetary planning, while the responsibility for policy implementation is devolved to relatively autonomous agencies at a lower level of governance, which often need to coordinate funding instruments from different sources (including different ministries). This increases accountability, and potentially brings policy-makers closer to R&D performers, allows for more specialised and thematically focused interventions, and better knowledge from the side of the policy-maker; on the other hand it leads to the increased fragmentation of the innovation system governance, and to myriads of coordination problems. It may also reduce the strategic orientation of public research funding and increase short-termism.[32] A different decentralisation tendency, rather common in Scandinavian countries, is the *regionalisation* of RTDI policy, which is often also coupled with increased agencification.

On the basis of this criterion we distinguish the following types of governance structures of the public research-funding apparatuses:

- *centralised* governance structure, whereby the responsibility of public research funding allocation lies with a unitary actor, typically a department of the central/ federal government (e.g. a ministry of technology, etc.);
- *regionalised* governance structure, whereby public research funding allocation competences are delegated to sub-national authorities (e.g. regional authorities);
- *agencified* governance structure, whereby the competences for public research funding allocation are decentralised to various types of agencies, including public bodies, independent bodies, trusts, etc., with ‘independent’ lines of funding;
- *foreign-controlled* governance structure, when the principal source of public research funding are aid donors, intergovernmental bodies, etc., typically in low-income developing countries.

The assessment of this criterion is contextual.

[32] OECD (2005: 53-54).

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D Evaluation Function

Evaluation is a crucial function of an innovation system, which involves the systematic and objective assessment of the design, implementation, outcome and impact of an on-going or completed project, programme or policy, or the quality of a research performer. It is intended to determine the relevance, utility, efficiency, and effectiveness of public research funding, the transparency and meritocracy of its allocation procedures, and the impact and sustainability of its effects.

The evaluation function is not equally developed and consistently applied in all innovation systems. Embryonic innovation systems, for instance, may lack this function altogether; but even when this function exists in established innovation systems, its design, scope and influence may vastly differ from one system to another.

There are three types of evaluation processes according to their position in the life cycle of the evaluation object (project, programme or policy):

- *ex ante* (or *prospective*) *evaluation* is the assessment of the likely outcome and impacts, as well as the projected relevance and utility of a new project, programme or policy on the basis of monitoring and evaluation information from earlier exercises at the beginning of the object's life cycle;
- *ex post evaluation* is the assessment of the efficiency, effectiveness, outcome and impact of a project, programme or policy immediately or some time after the completion of its life cycle, with the aim to identify the factors of its success or failure, to assess the sustainability of its outcomes and impacts, and to draw conclusions that may inform other projects and programmes;
- *interim evaluation* is essentially an ex post evaluation conducted after the conclusion of a phase in the life cycle of a project, programme or policy with the aim to provide insight for the potential revision of the project, programme or policy.

Depending on the aim of the evaluation the following two types can be distinguished:

- *formative evaluation*, which is usually conducted during the implementation phase of projects, programmes or policies with the aim to assess their implementation and to improve their performance (similarly to the 'interim' evaluation above);
- *summative* (or *impact*) *evaluation*, which is conducted after the completion of a project, programme or policy (or a phase thereof) with the aim to determine the extent to which anticipated outcomes were produced.

There are three distinct types of 'evaluation objects', which define corresponding types of evaluation functions as follows:

- *Evaluation of public research funding instruments* involves the ex ante or ex post assessment of their efficiency, efficacy, and effectiveness as an integral stage of the RTDI policy design process. This function is meaningful when it has the potential to lead to policy revision and policy learning. Despite the fact that in more established innovation systems evaluation is increasingly becoming an indispensable function of their public research-funding apparatuses, formal institutional (e.g. legally binding) provisions for policy revision subject to evaluation are not so prevalent yet. Moreover, it is not uncommon for ex post evaluation to be used for the legitimisation of existing policies rather than for their revision.
- *Evaluation of publicly funded research project proposals* is essentially a selection procedure based on the ex ante assessment of research project proposals for public funding. This procedure is forward-looking in that it assesses the potential of a research project to be successful in generating useful, new technological knowledge.

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This type of evaluation introduces a touch of competitiveness to public research funding.

- *Evaluation of publicly funded R&D performers* is also a selection procedure applied on individual researchers or research teams, and organisations, including higher education institutions, public research institutes, research-performing state-owned enterprises and private firms, etc. This type of ex post evaluation targets 'excellence', and best practices, and is essentially backward-looking in that it involves the assessment of past performance of research-conducting entities. For this reason it is more risk-averse and path dependent than research project evaluation, and therefore less friendly towards new entrants and potentially less open to radical innovation.

D.1 Systemic integration of evaluation function

Evaluation is increasingly becoming a 'conditio sine qua non' for the provision of public research funding to R&D performers, and an indispensable phase in the life cycle of publicly funded projects, programmes or policy instruments involved in the innovation process. In some innovation systems evaluation has become an institutionalised function of their public research-funding apparatuses, while in others it is still conducted on an ad hoc basis, often serving the purpose of ex post legitimisation of policy choices.

On the basis of the institutional bindingness and the degree of systemisation of the evaluation function in public research-funding apparatuses the following three types can be distinguished:

- *institutionalised* evaluation function, which is carried out mandatorily, by regulation or even by law, on a specified timeframe;
- *ad hoc* evaluation function, which may be conducted regularly but circumstantially without being an institutionally established element of the public research-funding sub-system;
- no established evaluation function; evaluation is conducted exceptionally and its results do not determine or affect the allocation of public research funding; this is more common in embryonic or emerging innovation systems.

D.2 Independence of evaluators

This dichotomous criterion examines whether the evaluators of publicly funded RTDI-related projects, programmes, policy instruments and performers are independent from the funding authorities.

It should be clarified that totally independent evaluation function on all the dimensions of a public research-funding apparatus, and especially on policy instruments, is a rarity. For this reason, this criterion examines pragmatically whether there exists a general 'culture' of independent and objective evaluation, free from conflicts of interest. On that basis the following two types can be identified:

- *independent* evaluation, predominantly conducted by independent experts or expert groups;
- *internal* evaluation conducted by specialised services of the funding authorities, or directly outsourced to professional evaluators who maintain a contractual relationship with the funding authorities.

Box 1 below summarises the taxonomic criteria, the identified types by criterion, and the relevant indicator types.

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Box 1: Taxonomic criteria, types by criterion, and related indicators

CLASSES		CRITERIA		TYPES BY CRITERION	INDICATOR TYPES
A	**National Innovation System**	A. 1	State involvement	state-led	Quantitative
				market-driven	
		A. 2	Research intensity	high	Quantitative
				low	
		A. 3	Distance to WTF	frontrunner	Quantitative
				established	
				emerging	
				embryonic	
		A. 4	Global position	hub	Quantitative (relational)
				broker	
				partaker	
				island or leaf	
		A. 5	Internal division of labour	extensive and cohesive (polyculture)	Qualitative (contextual), quantitative
				intensive and cohesive (oligoculture)	
				extensive and slack	
				limited	
B	**Objectives and Priorities**	B. 1	Intervention rationale	counteractive	Qualitative (contextual)
				proactive	
		B. 2	Diversity	diversified	Quantitative, Qualitative (categorical)
				concentrated	
				dispersed	
		B. 3	Directionality	strategically directed	Qualitative (contextual)
				oriented	
				non-oriented	
		B. 4	Contextuality	endogenously determined	Qualitative (contextual)
				emulated	
				externally dictated	
		B. 5	Responsiveness to challenges	responsive	Qualitative (contextual), quantitative
				unresponsive	
		B. 6	Appropriability	pre-competitive	Quantitative
				quasi-competitive	
				competitive	
		B. 7	Distributional implications	connectivity	Qualitative (categorical)
				concentration	
				cohesion	
		B. 8	Investment targets	human and social capital formation	Quantitative, qualitative (contextual)
				research infrastructures	
				loans and guarantees	
				industrial subsidies	
				leveraging	
C	**Governance Structure**	C. 1	Allocation modality	Fixed block allocation	Qualitative (categorical)
				Conditional block allocation	

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				Competitive allocation	
		C.2	Competence distribution	centralised	Qualitative (contextual)
				regionalised	
				agencified	
				foreign-controlled	
D	**Evaluation Function**	D.1	Systemic integration	institutionalised	Qualitative (contextual)
				ad hoc	
				none	
		D.2	Independence	independent	Qualitative (categorical)
				internal	

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Annex: Case-study sample assessment

Box 2: Typological assessment of case-study sample **(**tentative)

	AU	**BR**	**CA**	**FR**	**IN**	**KE**	**MY**	**RU**	**SE**	**UG**	**UK**	**TZ**	**ZA**
A.1	market-driven	state-led	market-driven	state-led	state-led	state-dominated	market-driven	state-led	market-driven	state-dominated	state-dominated	state-dominated	market-driven
A.2	medium	medium	medium	medium	medium	low	low	medium	high	low	medium	low	medium
A.3	established	emerging	frontrunner	frontrunner	emerging	embryonic	emerging	emerging	frontrunner	embryonic	established	embryonic	emerging
A.4	partaker	broker	partaker	hub	partaker	island	partaker	broker	hub	island	hub	island	broker
A.5	extensive-cohesive	extensive-cohesive	extensive-cohesive	extensive-cohesive	extensive-slack	limited	intensive-cohesive	intensive-cohesive	extensive-cohesive	limited	extensive-cohesive	limited	extensive-slack
B.1	counteractive	proactive	counteractive	counteractive	proactive		counteractive	proactive	counteractive	counteractive	counteractive	counteractive	counteractive
B.2	concentrated	diversified	diversified	diversified	concentrated	dispersed	concentrated	concentrated	diversified	dispersed	diversified	dispersed	dispersed
B.3	strategically directed	strategically directed	oriented	strategically directed	strategically oriented	oriented	oriented	strategically directed	oriented	non-oriented	oriented	non-oriented	non-oriented
B.4	endogenous	endogenous	endogenous	endogenous	emulated	emulated	emulated	endogenous	endogenous	dictated	endogenous	dictated	emulated
B.5	responsive	responsive	responsive	responsive	responsive	responsive	unresponsive	unresponsive	responsive	responsive	responsive	responsive	unresponsive
B.6	pre-competitive	quasi-competitive	pre-competitive	quasi-competitive	competitive	pre-competitive	quasi-competitive	quasi-competitive	pre-competitive		pre-competitive	pre-competitive	pre-competitive
B.		connectivity	connectivit	connectivity	concentratio		concentrat	concentratio	connectivit		connectivit		

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7			y		n		ion	n	y		y		
B.8		human-social capital											
C.1	competitive	competitive	competitive	fixed block	fixed block	fixed block	competitive	fixed block	conditional block	fixed block	conditional block	fixed block	fixed block
C.2	agencified	regionalised	regionalised	centralised	centralised		centralised	centralised	agencified	agencified	agencified	agencified	centralised
D.1	institutionalised	institutionalised	institutionalised		ad hoc	ad hoc	ad hoc	ad hoc	institutionalised	none	institutionalised	none	ad hoc
D.2	independent	internal	independent		internal	internal	internal	internal	independent		independent		internal

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