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Knowledge, Technology and Innovations for a Bio-based Economy: Lessons from the Past, Challenges for the Future

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Abstract. The paper presents an evolutionary perspective on how Agricultural Knowledge and Innovation Systems (AKIS) have adapted over time to new challenges and technological paradigm and trajectories. Starting from a conventional science-based approach and the robust empirical evidence supporting it, the analysis highlights the emergence of some system failures and the need for new conceptualization and design of the AKIS. Particularly concentrating on developed countries' agenda, we then discuss how, along this evolutionary pattern, bioeconomy emerges as the convergence of traditional sectors as a result of these new technological trajectories. Finally, some implications for the EU policies are drawn.

Key-words. Agricultural knowledge and innovation system, productivity, R&D, bioeconomy

JEL-codes. Q16, O30

1. Introduction

The object of this paper is the Agricultural Knowledge and Innovation System (AKIS), that is, "the set of agricultural organisations and/or persons, and the links and interactions between them, engaged in the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilisation of knowledge and information, with the purpose of working synergistically to support decision making, problem solving and innovation in agriculture" (Röling and Engel, 1991; see also Poppe, 2012b). The aim of this paper is to analyze the conceptual and organizational evolution of this system and its gradual adaptation to progressively changing contexts and scenarios. In this respect, the paper also aims at discussing the main implications of this evolution in terms of institutional and policy changes.

The structure of the paper pursues this objective by firstly reviewing the contribution that the literature has attributed to the AKIS in determining, over the last century, a remarkable growth of factor productivity in agriculture (section 2), then drawing attention to the criticisms that have gradually emerged in that respect, particularly considering the new challenges and the new technological paradigm that the AKIS is now facing (section 3). This evolution results in a substantial widening of the scope of the system, from the strict boundaries of the agricultural sector to the broader contours of the so-called *bioeconomy* (section

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4). Paying particular attention to EU policies, the final section outlines the steps that have been taken and the initiatives that are being proposed to build an EU-level knowledge and innovation system in accordance with the afore-mentioned evolutionary process.

2. An institutional success: the long-term agricultural productivity growth

Last century experienced a remarkable growth of agricultural production at a global level (Alston *et al.*, 2010a). Such a strong increase in agricultural supply counterbalanced the large growth of global food demand, thus allowing for stable and relatively declining agricultural prices (Alston *et al.*, 2009b, 2010b), and it has been almost entirely generated by a major increase in agricultural factor productivity (Fuglie, 2010).

Table 1 reports the growth rate of land and agricultural labour productivity during the second half of the last century. Land productivity growth was initially quite homogeneous between developing and high-income countries. Then, a significant drop in growth rates was observed in the latter during the last decades of the period, while it continued to remain stable in developing countries (Pardey and Pingali, 2010). Labour productivity growth, on the contrary, does not show any decline, and it is much higher in high-income countries due to a more intense loss of agricultural labour force. A significant part of this productivity growth can be attributed to massive capital intensification, that is, the increase of capital endowment per unit of agricultural labour and land. However, capital intensification has been just one of the drivers of factor productivity growth. The other major driver has been technological progress (Fuglie, 2010).

Total Factor Productivity (TFP) provides a measure of productivity growth that does not depend on the intensification of some production factors. Therefore, it expresses that part of growth that can be exclusively attributed to a purely technological component.[2] We may observe (Table 2) that agricultural TFP growth rates continued to rise in both developed and developing countries up to the last decade of the last century. Then, a slight decline occurred in the last period, but this can be almost entirely attributed to developed countries and especially to the top producing areas worldwide, that is, North-America and Europe. Here, the drop in the TFP growth rate is remarkable and has been widely emphasized and investigated (also known as *agricultural productivity slowdown*) (Alston and Pardey, 2009).

However, it remains true that world agriculture really experienced a huge productivity step forward during the second half of the last century. Worldwide, in about 50 years, land productivity increased by almost 150%, agricultural labour productivity by almost 75%, and agricultural TFP by about 55%. A sort of "slow magic" (Pardey and Beintema, 2001) occurred which can be identified in the continuous and incessant scientific and technological progress that brought innovations into agricultural production. This in turn allowed world agriculture, or its richer part, to escape the trap of food shortage: using the words of Alston *et al.* (2009a), Mendel (the capacity to improve crop yields) eventually prevailed on Malthus (the food shortage induced by population pressure).

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[2] Regardless how it is actually calculated or estimated, Total Factor Productivity (sometime also called Multi Factor Productivity) is an index that expresses the ratio between an aggregate index of outputs and an aggregate index of inputs. Therefore, TFP growth expresses the increase in aggregate output production obtained from a given level of aggregate input use: it measures that part of output growth not explained by a higher factors' use (Ball and Norton, 2002).

Unquestionably, both major drivers of productivity growth (capital intensification and technological change) have been considerably favoured by policies that strongly promoted agricultural production either through price support or direct coupled payments. In the EU, in particular, the Common Agricultural Policy (CAP) provided the farmers with robust incentives to invest in new capital and to introduce technological innovations, together with increasing technical prescriptions that oriented the direction of this capitalisation and innovation process. Accordingly, the gradual shift observed since the eighties from these agricultural policies towards progressively decoupled or extensification-oriented support may have played a role in the observed productivity slowdown. Nonetheless, the influence of agricultural policies (and of the CAP, in particular) on agricultural technological change and productivity may be more complex and not unidirectional[3] and is well beyond the scope of this paper that only focuses on AKIS policies, i.e., those policies that explicitly promote agricultural research and innovation.[4]

Table 1. Land and agricultural labour productivity: average. annual growth rate (%), 1960-2005

	Land Productivity		Agricultural Labour Productivity	
	1960-1990	1991-2005	1960-1990	1991-2005
World	2.03	1.82	1.12	1.36
High-income countries	1.61	0.72	4.26	4.18
Middle-income countries	2.35	2.30	1.51	2.02
Low-income countries	2.00	2.39	0.46	1.03
China	2.81	4.50	2.29	4.45
USA	1.81	1.50	3.64	1.54

Source: Alston *et al.* (2010a).

Table 2. Avg. annual growth rates (%) of agricultural Total Factor Productivity (TFP), 1960-2007

	1960s	1970s	1980s	1990s	2000s
World	0.49	0.63	0.92	1.54	1.34
Developed countries	1.21	1.52	1.47	2.13	0.86
Transition countries	0.67	-0.26	0.25	0.73	1.92
Developing countries	0.18	0.54	1.66	2.30	1.98
USA and Canada	0.86	1.37	1.35	2.26	0.33
Europe (exc. FSU)	1.17	1.31	1.22	1.63	0.59

Source: Fuglie (2010).

[3] For instance, Esposti (2007) shows how a support coupled to agricultural production may, in fact, reduce agricultural labour productivity as it maintains within the sector the labour force that would otherwise move to other sectors.
[4] See Oskam and Stefanou (1997) for a more extensive view on this issue.

2.1. The role of public R&D

Starting with the fifties and sixties of the last century, most researchers and analysts identified the key engine of the above-mentioned productivity growth in a sequence of major mechanical, chemical and biological innovations and in the R&D investments that have generated or induced them. Early empirical studies supported the idea that relevant and appropriate R&D investments were the cause of those technological innovations that had a direct impact on agricultural productivity (Evenson, 2001). However, in the case of agricultural innovations, this research and innovative effort combined with other major factors that enabled or favoured their adoption and diffusion. In particular, two other driving forces have been the increasing amount of human capital embodied in agricultural labour force (*education*) (Huffman, 2001) and the (mostly public) provision of a set of services and institutions aimed at informing farmers about the existence of new technological solutions, as well as facilitating the learning process concerning their suitability and appropriate application (*extension*) (Evenson, 2001).

Of this "knowledge triangle" (*research, extension and education*),[5] the R&D component (and public research, in particular) has been largely considered prevalent and hierarchically dominant because it generated those results that eventually activated the other components. Table 3 (upper part) reports the growth rate of public agricultural R&D in real terms. Continuous growth in agricultural R&D investments over time is evident in both developed countries and developing or emerging countries (Beintema and Stads, 2008, 2010; Beintema, 2010). However, growth rates are regularly declining in developed countries and they are not entirely compensated by the higher growth of developing countries. At least until the last decade of the last century, the declining but still positive growth of agricultural R&D expenditure accompanied an increasing productivity (TFP) growth. Then, when the growth of R&D expenditure continued to decline, the TFP also started slowing down.

Whether this declining growth rate can also be observed in private agricultural R&D is more questionable. First of all, collecting comparable data on private agricultural R&D is challenging since it is difficult the define the boundaries of what "agricultural" R&D is across different countries and periods (Esposti, 2011).[6] Secondly, most of the evidence and discussion about the declining agricultural R&D growth rate has to do with public budget cuts observed, in real terms, in many countries in recent years. Nonetheless, despite the different patterns observed for private R&D with respect to public R&D (Huffman and Just, 1999), the arguments and implications about the R&D declining growth rate are usually extended to both components of the agricultural research effort. In particular, for both public and private research, the link between agricultural R&D investments and pro-

[5] Despite the recent conceptual and institutional developments that will be more extensively discussed in section 4, the prevalent representation of the AKIS remains the so-called "*knowledge triangle*" whose vertices are *research, education and extension* (OECD, 2012). The EU adopts a slightly different version, the three components being research, high education and innovation (European Commission, 2011).

[6] For instance, Alfranca and Huffman (2003) report quite different shares of private R&D on total national agricultural research for European countries: 60% for the UK, 25% for Italy, 10% for Germany and Spain. Pardey *et al.* (2006b), however, present slightly different data: in 2000, the private share was 71% in the UK, 54% in Germany, 54% in all OECD countries. With reference to 2000, Kirschke *et al.* (2011) indicate that the average private share is 54% in developed countries and only 6% in developing countries.

ductivity growth has been repeatedly and carefully investigated and confirmed by rigorous econometric models and estimates over the last decades and in recent years (Alston *et al.*, 2000; Evenson, 2001; Alston *et al.*, 2011).

In general terms, it can be concluded that this empirical literature emphasizes this cause-effect link between agricultural R&D expenditure and productivity growth so strongly that the existence of this direct link was seldom questioned.

Table 3. Cross-country comparison of public agricultural research expenditure (in real terms) and of Agricultural Research Intensity (ARI) (public and private R&D), 1976-2005

	1970s	1980s	1990s	2000s
Avg. annual R&D growth rates (%)[a]				
World	4.5[b]	2.0	1.7	1.5[b]
High-income countries	2.5[b]	2.1[b]	0.2[b]	1.1[b]
Low and Middle-income countries	7.0[b]	2.2	3.3	1.9[b]
USA	3.2	2.4	2.0	0.9[c]
France	-	3.9	-6.8	-
Germany	-	1.0	2.4	-
Total OECD	-	1.9	0.4	-
China	-	4.8	6.7	-
India	-	6.2	7.0	-
Agricultural Research Intensity (ARI)[d,g]				
High-income countries	1.94	3.01	4.19	5.38
Low and Middle-income countries	0.44[b]	0.53[b]	0.62	0.69
USA[e]	-	1.68	2.64	2.65
China[e]	-	0.41	0.35	0.40
India[e]	-	0.18	0.24	0.34
Italy[f]	-	-	0.75	1.20
France[f]	-	-	3.50	3.70
Germany[f]	-	-	4.10	4.10
Spain[f]	-	-	1.10	1.50
UK[c]	-	-	5.40	6.20

[a] Source: ASTI database
[b] Source: Author's elaborations on Pardey and Beintema (2001)
[c] Source: Author's elaborations on Pardey and Alston (2012)
[d] Source: Pardey and Pingali (2010)
[e] Source: Pardey *et al.* (2008)
[f] Source: Esposti *et al.* (2008)
[g] ARI data may be not consistent with data reported in the upper part of the Table, as this latter only concerns public agricultural R&D. A reliable cross-country comparable ARI, however, must include both private and public R&D.

2.2. A certain idea of the AKIS

This strong cause-effect relationship between investment in agricultural research (but also extension and education) and productivity growth postulates an underlying idea of the AKIS. In essence, this relationship was interpreted as a sort of "reduced form" specification of that complex and continuously evolving institutional process that handles and affects the creation, adoption and diffusion of agricultural innovations. Of this complex process, R&D and productivity performance are, somehow, the initial and the final stages, respectively. Though apparently this idea can be considered as an expression of the so-called linear model of innovation, it really wants to grasp the fact that, far from being a simple linear process, technological innovation is rather the product of a system. The numerosity and complexity of subjects, agents and relations involved in this institutional process not only make them a "system" (namely, the AKIS), but it also implies that an increase in R&D effort "upstream" can be converted into an improvement in the productivity performance "downstream" only if this "system" works correctly and effectively.[7]

Nonetheless, the pivotal role of R&D tends to postulate a *top-down flow of knowledge*. According to this idea, innovation is essentially *science-based*, i.e. a "ready-to-use" solution offered by science in favour of "downstream" applications, including agriculture. Therefore, this literature, more or less explicitly assumes or accepts a *science-based supply-side* idea of the AKIS (SS AKIS) (Falk *et al.*, 2010). This idea has found its major justification in the nature and intensity of technological growth experienced by global agriculture. A progress mostly made of process innovations that has enabled generalized yield increase (or reduction in factor use per unit of production), across many different applications and contexts. These process innovations mostly consisted in ready-to-use technology packages flowing *top-down* (from the research to the field), to be adopted in full without (or with a limited) specific adaptation or learning effort: new agricultural machinery, new chemical fertilizers, new active ingredients for weed control and pathogenic biological agents, and new crop varieties with higher yields or resistance.

Though the validity of this interpretation originally concerned the historical experience of developed countries, this SS perspective was applied also to less developed countries with the introduction of strongly *science-based* and essentially global innovations; that is, innovations coming from public research centres of international reputation (for example, International Agricultural Research Centres, IARCs) (Maredia and Raitzer, 2010) or from few high-level public or private research centres of technologically leading countries. This *global agricultural R&D* can be considered as the classic example of an SS AKIS that delivers key innovations from few centres of worldwide excellence into applied research and adapts them to the specific needs at the national or local level and, eventually to the farmers' adoption.

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[7] Given its systemic nature, drawing sectoral boundaries of this complex set of interacting agents is difficult. Eventually, agricultural is just one link along the food chain and this is particularly true in developed countries. The Knowledge and Innovation System, therefore, should be extended to include other relevant subjects along the food chain like, for instance, food industries and large retailers. Though some of these non-agricultural agents are implicitly included in the AKIS (industries supplying agricultural production factors, for instance, are major funders of private agricultural R&D), most of the literature reviewed and critically discussed here maintains its primary focus on the agricultural sector. For the sake of simplicity and of space limits, this preference is also maintained here.

At the same time, this prevalent SS perspective has dictated a coherent policy agenda. A proper policy did not only have to strongly focus on research but it was also expected to find solutions to the problems arising from this configuration, such as providing public research, stimulating and orienting private research, granting intellectual property rights on agricultural knowledge and innovations to some extent, stimulating technological spillovers across sectors and territories.

3. Success, failures and new challenges

3.1. The lessons we learned

The main lesson that can be learnt from the contribution of the SS AKIS to the global agricultural productivity growth is that it represents a case of institutional success. It depends on appropriate incentives, norms and regulations, that is, on the smooth functioning of what we can consider, in broad sense, formal and informal institutions.[8] This smooth functioning is expressed by the ability of the system to effectively manage that peculiar "good" represented by scientific and technological knowledge. We can summarize this success in terms of a properly designed AKIS that continuously *generates* new knowledge that can be gradually *incorporated* "downstream" (from research to production) in actual technological innovations but which can still continue to be *diffused* as public good.[9]

From an SS perspective, the origin of this entire institutional process is the production of scientific knowledge, largely unincorporated and "free" which acts as a pure public good. This knowledge can result in some large-scope technological solutions. These are sometimes incorporated in proprietary forms (e.g., patents) that make scientific knowledge assume the character of a private (or club) good (Oehmke *et al.*, 1999). In fact, however, the scope of these new technologies is so wide that it enables a host of specific (or sectoral) technological applications with little or no reciprocal rivalry. In practice, by virtue of this almost unlimited application potential, at this stage scientific knowledge tends to maintain a certain degree of public-good nature.[10] In the case of agriculture, at the origin of this process, there were revolutionary scientific results and theories (in mechanics and thermodynamics, chemistry, biology) that produced broad-spectrum technological solutions (for example internal combustion engine, industrial synthesis of chemicals, genetic hybridization), the so-called *General Purpose Technologies* (GPT),[11] which were later "appropriated" by the agricultural sector through some specific applications (Ruttan, 2008). These sector-specific technology applications become forms of knowledge with a higher degree of incorporation, that is of a more private nature. This is the case of conventional agricultural technological innovations *strictu sensu* that characterized the produc-

[8] For a detailed discussion on these different types of institutions see Parto (2003).

[9] Good examples of the reconstruction of the institutional success underlying the AKIS, especially in the USA experience, can be found in Pardey and Beintema (2001), Huffman and Evenson (2006), Alston *et al.* (2010c).

[10] The most emphasized example of the relevance of broad-spectrum public scientific and technological knowledge is the contribution of non-profit International Agricultural Research Centres, IARCs, to the so called Green Revolution of the 1960s and 1970s (Gardner and Lesser, 2003; Dalrymple, 2008; Brooks, 2011).

[11] "New and evolutionary growth theorists point out that the level of spillovers varies among sectors and technologies. They are thought to be greatest where there is a pervasive cluster of technologies or general purpose technologies" (Van Meijl and Soete 1995, p. 112).

tivity "miracle" of the last century: new fertilizers or pesticides, new agricultural machinery, new plant varieties (Pardey and Pingali, 2010).

Parallel to this "downstream" movement of scientific knowledge towards production applications, and to this gradual change in the nature of scientific and technological knowledge, another form of largely non-scientific, practical and contextual, and diffused knowledge is produced. It has a limited degree of incorporation and maintains a high degree of public nature though often "local" (that is, it concerns specific contexts, applications, conditions, etc.). A "*cloud of knowledge*" which is made up of information, training, and learning about a given technological solution, its scientific basis and its potential applications, but also of cases of successes and failures and of opinions and beliefs around it. If the core of this cloud is the prerogative of research and technological development, its larger edge is actually determined by a more composite set of stakeholders.

Despite this inherent complexity, the clearest support to this success, in terms of empirical evidence (decades of empirical studies on the relationship between agricultural R&D and productivity growth), are the high social returns to "knowledge" investments. Generalized high returns have been mostly found for public agricultural research, but also for private research, as well as for extension and education (Alston *et al.*, 2000; Evenson, 2001; Huffman, 2001; Huffman and Evenson, 2006; Alston, 2010). Alston *et al.* (2000) present a survey of more than 1800 estimates of the social rate of returns to research and extension investment obtained over time starting from 1953. They report quite high average returns of more than 80%. Although the authors stress the wide variability of estimates, it remains true that widespread high returns are considered a well-established and robust evidence. Evenson (2001) analyzes a large number of studies and estimates of the returns to investments in agricultural research reaching similar conclusions that are generalizable to different countries and contexts.

A main implication derived from this generalized empirical evidence is that the overall level of investment in these activities (mostly research and extension) is lower than the

Table 4. Estimated annual marginal internal rates of returns (%) to agricultural R&D and extension

	R&D only	Extension only	R&D+Extension
Alston *et al.* (2001) – various countries			
Mean	99	85	48
Highest	5,645	636	430
Lowest	-7	0,0	Negative
Evenson (2001) – various countries			
Median	49	41	45
Highest	285	215	119
Lowest	negative	0	0
Alston *et al.* (2011) – 48 USA states, various methodologies			
Mean	-	-	10-23
Highest	-	-	12-29
Lowest	-	-	8-15

socially desirable level (the *underinvestment hypothesis*; Esposti and Pierani, 2006). Even very recent studies, which take into account all the possible methodological complications in estimating these returns, confirm that "*agricultural productivity growth is worth many times more than the annual spending on agricultural R&D (including extensions)*" (Alston *et al.*, 2011, p. 1225). Therefore, "*most states (or countries) substantially underinvest in agricultural R&D*" (Alston *et al.*, 2011, p. 1225).

3.2. Some critical evidence: where and why does the system fail?

The underinvestment hypothesis has been revitalized by the slowdown in the growth of agricultural R&D expenditure that emerged in the last decades, especially in developed and technologically leading countries (Huffman and Just, 1999). On the one hand, this slowdown or decline in research expenditure reinforces the idea of underinvestment. On the other hand, it seems to provide a strong argument to explain the productivity slowdown observed in several developed countries. There are two implicit assumptions behind this interpretation. The first assumption is that the slowdown is real, that is, the computed TFP growth rate correctly measures the actual productivity performance. The second assumption is that the primary objective of agricultural R&D is to improve productivity performance as indicated by TFP growth. However, since the main target of agricultural R&D is actually shifting from strict productivity performance to other objectives (environmental quality and protection, risk reduction, etc.), measuring the returns to R&D based only on the basis of its impact on agricultural TFP may be misleading, and other evaluation methods should be preferred (Alston *et al.*, 1998).

If we accept these assumptions, however, there is an apparent contradiction between high returns to agricultural research, education and extension, and a slowdown in expenditure. This is one of the empirical facts that progressively brought out some more critical views on the real contribution of the SS AKIS to productivity growth and regarding the fact that such contribution has to be intended as a clear institutional success. Another clear contradiction concerns the relevance of agricultural technological spillovers, that would indicate a strong public nature of agricultural knowledge and innovation, and the lack of convergence in agricultural productivity, that would indicate, on the contrary, its prevalent private (or non-public) nature.

In support of a prevalent public-good nature, there is a large literature (see Johnson and Evenson, 1999, Schimmelpfennig and Thirtle, 1999; Esposti, 2002) showing the relevance and extent of agricultural technological spillovers both across sectors and countries. A consequence of technological spillovers and, more generally, of the public nature of knowledge, should be convergence in agricultural productivity. As they may rely on the same technology base, it is reasonable to expect that agriculture in different countries and territories tends towards common productivity levels. The empirical evidence, however, does not entirely support this convergence hypothesis. [12]

[12] It should be clarified, however, that a prevalent public nature of agricultural knowledge does not necessarily imply productivity convergence for two major reasons, both related to the heterogeneous agricultural conditions across countries and regions (Esposti, 2011). First of all, a permanent productivity gap may persist even with the same technology, simply because one country/region has a better environmental endowment (weather conditions, soil quality, etc.). Secondly, a given technological solution, though public, may have been designed for

Table 5 shows the results obtained by Ball *et al.* (2010) for the long-term multilateral comparison of agricultural TFP across the USA and EU countries. No undisputable path of convergence emerges. Some countries recover at least part of the productivity gap (as in the case of Spain), some others do not (as in the case of Italy).[13] Table 5 also shows the results obtained by Ball *et al.* (2002) who compared agricultural TFP across the USA states and the results presented by Pierani (2009) concerning long-term agricultural TFP convergence across Italian regions. In both cases we can conclude that, although weak catching-up processes may be observed, absolute TFP convergence is never actually achieved. Pierani (2009) concludes that convergence occurs but it is actually conditional: regions with lower initial TFP levels do catch up, but they converge towards different long-term TFP levels.

This comparison, across countries and regions, would reveal that there is no clear empirical support which gives the idea that agricultural productivity growth is based on a stock of knowledge and technological innovation behaving as a public good. On the contrary, it is rather evident that, besides significant technological spillovers, the generation of new knowledge and innovations maintains its specificity and remains an exclusive access for some countries (or territories). This implies that countries that produce new knowledge or innovation according to their own specific needs and objectives (*leader* countries) always retain a productivity advantage compared to countries that mostly adapt to their own needs technological solutions produced elsewhere (*follower* countries) (Pardey *et al.*, 2008).

Table 3 (lower part) compares the intensity of agricultural research (Agricultural Research Intensity, ARI) (Beintema and Elliott, 2011) across developed and developing countries. This indicator is the ratio of annual expenditure in agricultural R&D to agricultural value added or GDP. A sharp difference (Pardey *et al.*, 2006a, 2006b) emerges between the leader countries, i.e., those having a permanently higher TFP and showing a more research-intensive agriculture, and follower countries. As discussed in Esposti (2011), the presence of a public component together with a non-public component of agricultural knowledge and technological innovations may explain the apparent contradiction between large and persistent technological gaps and widespread technological spillovers. Thus, it explains the persistence of countries with a leader strategy (and AKIS) together with countries with a mostly adaptive follower strategy (and AKIS).

This failure to exploit all potential non-rival uses of the available stock of knowledge and technological innovation has also its counterpart in the comparison across different agricultural productions (Esposti, 2000; Alston *et al.*, 2010c). Some productions may remain largely excluded from the benefits induced by new technological solutions and, as a consequence, also territories or countries with a strong production specialization.[14]

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some specific conditions and, thus, may be more effective in some countries/regions than in others.

[13] For further details and evidence on agricultural TFP comparison, see: Craig *et al.* (1998), McCunn and Huffman (2000), Ball *et al.* (2001), Ball and Norton (2002; Part I), Ball *et al.* (2004), Liu *et al.* (2011). A broad empirical literature can be found on agricultural productivity convergence across regions and countries, in both Italian and EU cases. However, this literature mostly concentrates on partial factor productivity (agricultural labour productivity, in particular) and not on TFP convergence which is of major interest here (Sassi, 2009).

[14] According to the discussion above about the role of country/regional heterogeneity in preventing convergence, the lack of absolute convergence may not be necessarily intended as a system failure caused by the incomplete public nature of agricultural knowledge. In fact, knowledge can be public but with different effectiveness in heterogeneous conditions. In this sense, we may still conclude that there is a "failure to exploit all the potential non-

Table 5. Multilateral TFP comparison across countries, USA states and Italian regions

	Lowest TFP/ Highest TFP (initial year)	Lowest TFP/ Highest TFP (middle year)	Lowest TFP/ Highest TFP (final year)	Italian TFP/Highest TFP	Spanish TFP/ Highest TFP
Ball *et al.* (2010) (USA&EU countries, 1973-02)	0.39	0.55 (1988)	0.57	Initial year = 0.63 Middle year = 0.56 Final year = 0.57	Initial year = 0.44 Middle year = 0.77 Final year = 0.84
Ball *et al.* (2002) (USA states, 1960-96)	0.35	0.32 (1978)	0.32	-	-
Pierani (2009) (Italian regions, 1951-02)	0.36	0.47 (1980)	0.4	-	-

An immediate interpretation of these possible failures of the traditional SS AKIS focuses on the already mentioned underinvestment hypothesis. This failure is, in turn, determined by the inadequate management of the public-good nature of agricultural knowledge and innovation. Like all goods with a prevalent, or relevant, public-good nature, the provision (i.e., the investments) of agricultural research falls short of the optimal level that would be indicated by high social returns.[15] This interpretation evidently applies to public agricultural R&D whose main purpose is to generate knowledge with a high degree of "publicity", but it may also be valid for private R&D (for which high rates of return are observed, as well; Alston *et al.* 2000; Evenson, 2011) to the extent that its results are not entirely appropriable.

According to this interpretation, the observed reduction in the agricultural R&D investment rate in many countries would express a tendency to act as free-riders, i.e., to benefit from technological solutions developed in other contexts only focusing, whenever possible, on adaptation to their own specific conditions. It is a sort of the *tragedy of the commons* involving the international dimension of AKIS especially with regard to the high-level research (Pardey *et al.*, 2008).[16]

This tendency would also explain the diminishing returns of these investments (Alston, 2010). It tends to produce just additive and incremental knowledge and innovations, less adoptable and adaptable in different contexts than those in which they are produced. From this perspective, productivity slowdown and lack of convergence in agricultural productivity (both across countries or regions and different agricultural productions) are just results of this progressive deterioration of the global and largely public components of the AKIS.

rival uses" not because of the public/private nature of knowledge but because of the irreducible heterogeneity of agricultural conditions.

[15] "These institutional failures continue to impose very large opportunity costs on individual states and the nation as a whole" (Alston *et al.*, 2011, p.1276).

[16] This argument, combined with the observed reduction of public agricultural R&D growth rate, should lead to a reduction in technological spillovers. However, the empirical evidence provided so far does not support this interpretation. It may be just a matter of time as it takes years for observed spillovers to respond to the decline in R&D growth. As for TFP and R&D returns calculation, major measurement problems may also arise as to how technological spillovers are computed and attributed to agricultural productivity (Johnson and Evenson, 1999).

Nonetheless, his interpretation of system failures does not raise substantial doubts about the validity of the SS AKIS or about its capacity to cope with future challenges. Its major limits or failures depend on the public nature of knowledge and innovation and not on where this new knowledge and innovation comes from, that is, on its strongly science-based and supply-side design. However, we can also put forward a less immediate, and conventional, interpretation of these system failures. It consists in questioning the classical SS design of the AKIS. The key argument of this critique is that most of the large productivity gains observed in the past decades at both global and local levels are not due to contributions of science and research that have been then transferred and adapted "downstream" towards productive uses. Looking inside the "black box" of agricultural innovations, it turns out that this role has often been over-emphasized by focusing on few successful cases. But what really underlies the "miracle" of agricultural productivity growth, the actual engine of agricultural innovation, is what has been previously termed as the "cloud of knowledge". Therefore, the knowledge and innovation that the AKIS is expected to produce, diffuse and adopt is not necessarily scientific knowledge of academic rank or knowledge embedded in some proprietary technology. More often, and more critically, it is a widespread collective and practical knowledge and, though sometimes tacit, informal and local, it tends to be free and public to any possible extent.[17]

In this respect, the biggest institutional failure of an SS AKIS rather lies in having focused its attention (and most resources) on a limited portion of the process, the generation and application of that kind of scientific-technological knowledge, and on a conventional and limited idea of innovation. The productivity slowdown itself can be interpreted as a support to this analysis. Despite the huge and still growing investments in agricultural research, the outcome in terms of productivity is decreasing simply because not enough attention and effort have been directed to those factors that really gave impetus to productivity.

3.3. New challenges and diverging agendas

In the last decade, the need for a critical review of the design and the organization of the traditional SS AKIS has been strengthened by the new emerging challenges for global agriculture. On the one hand, the main challenge of the last century returns with a new urgency: the ability to produce enough food to feed a growing and more demanding population (Alston *et al.*, 2009b, 2010b). This is the never-ending challenge of agricultural technology, that of *food security* ("to feed the world") (Alston and Pardey, 2009; Freibauer *et al.*, 2011). But, compared to last century, today global agriculture faces a different landscape (Beddow *et al.*, 2010; Kirsten, 2010; Maracchi, 2010).

The above-mentioned productivity slowdown, the strong food consumption growth in emerging countries such as China, India and Russia (more than one-third of the

[17] Some sentences taken from Galiay (2010) clearly express the sense of this critique. "Lessons from case studies on AKS governance: […]overall, a failure to incorporate diverse values/norms in a common and shared vision", "partial in scientific advice, insufficient in risk assessment, insufficient in communication and dialogue", "lack of inclusiveness in framing issues and lack of sense of urgency". For a critical view of the traditional AKIS design, see also Glover (2012) and Ritter (2012). Werrij (2009) offers a further perspective on the failures of an AKIS strongly focused on high-level research and on the linear model of innovation. He also analyses the implications for a proper agricultural research policy within developed countries.

world population), and the recent turbulence in agricultural commodity markets - all these factors confirm that the challenge of *food security* has not been definitively won in the last century and now it tends to assume new dimensions (Huffman and Evenson, 2006; Kirschke *et al.*, 2011; Glover, 2012; Pardey and Alston, 2012; Ritter, 2012). Again paraphrasing Alston *et al.* (2009a), we can argue that Malthus is getting his revenge on Mendel: after a century in which agricultural technological progress (symbolized by crop genetic improvement) was able to meet the challenge of an increasing food demand, there are now legitimate doubts as to whether this success can be repeated. In fact, a large number of people worldwide did not win the challenge of food security in the past and are likely to suffer the greatest consequences of a renewed food shortage even in the future (Sadler, 2010).

But the real novelty with respect to the previous century is that this challenge can now be won only under specific conditions (and constraints). The main condition is environmental sustainability. Not only must the growth in supply obtained through further technological innovations be compatible from an environmental perspective, but agriculture is also expected to actively contribute to sustainable growth by playing a role with respect to the global environmental issues of the century (renewable energy, climate change mitigation, etc.) (Msangi *et al.*, 2009).

In fact, this first condition leads to a second fundamental requirement. The agriculture of the future must necessarily be multifunctional, i.e., it must have the ability to produce other non-food goods and services, of public or collective interest, in addition to food. These include environmental services that bring us back to sustainability. In affluent societies, in particular, post-industrial agriculture is expected to produce landscape and aesthetic values, cultural and recreational services, physical and mental health services, etc. Moreover, since agriculture is the first link in the food chain, it is expected to ensure *food safety* and *food quality*, i.e., health, nutritional, environmental and ethical safety of food as well as to ensure food origin and provenience.

Sustainability and multifunctionality, however, require knowledge and innovation of a different nature compared to the more conventional challenge of food security: more product innovations (or functional innovations, as discussed below) than process innovations; organizational and marketing innovations and not just technological innovations. Therefore, more complex innovations[18] and knowledge is required. No longer simply "Mendel against Malthus" but "much more than Mendel" (a wider idea of agricultural innovation) against "much more than Malthus' (more extensive needs to be met). Moreover, further productivity growth *strictu sensu* and sustainability and functionality can easily come into conflict. The actual risk is that, due to the difficulties encountered in defining an agenda that reconciles both these needs,[19] two different and diverging agendas eventually emerge (Pardey *et al.*, 2006b, p. 2). An *agenda for the new scarcity* which mostly concerns agriculture, people and countries for which the challenge of food security remains prevalent (Lele *et al.*, 2010; Beintema and Elliott, 2011; Kirschke *et al.*, 2011, p. 39); an

[18] See below the concept of *system innovation*.

[19] Several proposals have been put forward at various institutional levels, and especially by those international institutions dealing with these issues at global level (FAO, WB, IFPRI, etc.), in order to establish a strategy for an AKIS able to reconcile these potentially diverging needs; for example, that of *sustainable intensification* (House of Lords, 2011, ch. 1-3).

agenda for the post scarcity which mostly concerns more affluent countries in which food security seems secondary to the challenges of sustainability and multifunctionality.[20]

Given these diverging agendas, a spontaneous reorganization of the AKIS inevitably requires a diverging AKIS design. For a strategy that still focuses on the challenges of new scarcity, the basic idea is that of an SS AKIS with a strong global/international component and a greater attention to strengthen the diffusion of the benefits to countries, territories and agriculture hitherto excluded (AKIS/RD, 2000; Rivera *et al.*, 2005). For a strategy primarily focused on the challenges of post scarcity, a substantial rethinking and reorganization of the AKIS emerges as a priority.[21]

The higher complexity of innovations, required by agricultural sustainability and multifunctionality, depends on two aspects. First of all, these innovations are often intended to tackle very specific local issues and, even when issues are actually global (for instance, reduction in GHG emissions), the solutions must still be "local", that is, strongly place-based and tailored. Secondly, these innovations potentially involve a larger number of stakeholders. As they concern not only quantitative food production[22] but also many other aspects related to food (quality, safety, origin, etc.) and to non-food functions, the validity and acceptability of these innovations often depend on the proper involvement and contribution of all these stakeholders. These features imply a redesigned AKIS that is able to take advantage of new technological paradigms and opportunities, providing bottom-up together with top-down flows of knowledge, and which is pulled from the demand-side rather than exclusively pushed by the supply-side (Ritter, 2007; Hall, 2007; Moreddu, 2012).

4. Looking for a new model[23]

4.1. New technological paradigm and trajectories

Beside the new challenges, another major driver of this reorganization of the AKIS is the gradual emergence of a genuinely new technological paradigm and of new technological trajectories it generates (Freibauer *et al.*, 2011). Broadly speaking, the technological paradigm underlying the conventional SS AKIS was characterized by the progressive introduction of process innovations to meet the main need of that agricultural model: to produce more with fewer factors of production, i.e., to increase the productivity of agri-

[20] A major impulse to this shift of the agenda towards *post-scarcity issues* has been given by the evolution of the agricultural policy in developed countries. In the EU, in particular, the evolution of the CAP in the last two decades towards more conservative and low-impact objectives has significantly affected the creation and adoption of technological and organizational innovations by farmers and by all other relevant subjects (Oskam and Stefanou, 1997) and has therefore contributed to this need for a redesigned AKIS. Unfortunately, for a long period, this policy evolution did not coordinate with AKIS policies. Section 5 focuses on this aspect.
[21] For instance, Pardey *et al.* (2012) highlight that in 1985 69% of the research expenditure of the USA state experiment stations (SAES) was concentrated on projects aiming at improving productivity. Since then, this share has continuously been dropping down to 56% in 2007 (last observed year).
[22] As already mentioned, even if we limited our attention to innovations aimed at a purely quantitative increase in food production, they may still involve a larger number of subjects than farmers alone: food industries, retailers, etc. Nonetheless, the focus here is primarily on agriculture and, therefore, on farmers' innovations.
[23] Henceforth, the analysis will prevalently focus on those affluent countries (like the EU) whose agricultural sectors are mostly oriented towards post-scarcity agenda.

cultural inputs. The technological trajectories developed along this paradigm were mainly those of varietal innovations, animal genetics, chemistry, pharmaceuticals and plastics for agricultural use, and agricultural machinery.

Over the past two decades, a new technological paradigm has appeared. In fact, the new GPT that are currently becoming predominant, or are expected to prevail in the next few decades (ICT, microelectronics and nanotechnology, modern biotechnology, neuroscience, robotics, advanced materials, photonics) show an agricultural application potential of substantially different nature. In particular, they facilitate new innovative dimensions in addition to process innovation: product innovation and, above all, function (or functional) innovations. It is worth noticing that the introduction of a new agricultural business or function is mostly the outcome of an organizational or marketing innovation, and not so much of a technological innovation. However, these innovations often have a technological "activation", i.e., a technology component that enables or facilitates these new solutions. The new paradigm thus takes advantage of the capacity of the new GPT to improve this non-technological innovation potential. In this sense, such GPT are also known as Key Enabling Technologies (KET): while not central to the innovative solution they still enable them (European Commission, 2010b, p. 131).[24]

Therefore, the new paradigm opens a new space for functional innovation. Figure 1 depicts this innovative hyperspace (the *agricultural innovation hyperspace*). In the conventional technological paradigm, most innovations were process innovations and were intended to increase productivity, strictly intended as TFP (*Type I Productivity*). The advent of new technologies and of the hyper-consumer progressively expands the innovation space in the direction of product innovation (the *food innovation space*), a large ideal innovative space where new food products may find peculiar innovative combinations of functionality, convenience and naturalness (Esposti, 2009). But these same technological solutions also facilitate the organizational and managerial innovations that constitute the space of functional innovation through some combinations of sustainability and multi-functionality. All these latter innovations contribute to improve agricultural performance in terms of production of goods and services of private or collective utility and, eventually, in terms of agricultural income. But here productivity growth remains more elusive, difficult to measure and to compare. We can thus refer to this performance improvement as growth of *Functionality*[25] or, to keep the analogy with the standard notion of productivity, of *Type II Productivity*.

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[24] "KETs reflect the enabling nature of general purpose technologies that support widespread industrial deployment and provide significant economic improvement over existing complementary technologies" (Van Meijl and Soete, 1995, p112)"; "most general purpose technologies play the role of "enabling technologies", opening up new opportunities rather than offering complete, final solutions" (Bresnahan and Trajtenberg, 1995, p. 84). For instance, agrotourism, direct selling, organic agriculture have been among the most impacting innovations in EU agriculture in the last two decades. Strictly speaking, they are not technological innovations or, at least, they are not process innovations. They are product and, above all, functional innovations with a prevalent organizational and marketing content. Nonetheless, they have been facilitated by new technological solutions. For instance, agrotourism and direct selling have been strongly favoured by the advent of the web and, more generally, of the ICT (Information & Communication Technologies). Also, energy production from agricultural biomass is taking advantage of modern biotechnologies.

[25] The European Commission, for instance, refers to "soil functionality" when dealing with technological innovations that improve the whole productive capacity of soils (not only food, but also environmental functions) (European Commission, 2012a).

This new innovative space[26] is made up of continuous incremental improvements, problem-solving adaptations, tailored solutions, often drawn from (or along with) the final users, farmers or food producers, i.e., the demand-side of the AKIS. Therefore, these technological solutions are not produced as a ready-to-use invariable technological package. Any technological solution tends to be rather just a temporary stage in the continuous improvement and adaptation, within the networks of users, of an innovative idea originally developed for the solution of a specific problem and then diffused and made "collective". Therefore, we move from a *one-way closed-space SS paradigm* to a *multi-directional open space paradigm* that could be called *Permanent-beta Network* (PβN).

This paradigm shift is the eventual consequence of the change in the nature, in the frequency and in the direction of movement of the "object" of the system, that is, scientific and technological knowledge. Its nature evolves from well-delimitated final technological innovations to more "liquid" knowledge and solutions. Its frequency shifts from a discrete release of new technological innovations towards a continuous flow of incremental adaptations. As will be discussed in section 4.3., its prevalent direction of movement changes from an unidirectional movement, mostly generated by scientific knowledge, to a multidirectional and non-hierarchical movement across all agents and stakeholders involved.

This shift in technological paradigm gradually but deeply changes the fundamental properties of the knowledge and innovations system itself and it is expected to change its design, organization and functioning. Moreover, opening this potential innovation space towards a variety of new products and functions inevitably expands the traditional sectoral boundaries. This widening of sectoral boundaries, however, does not depend on the fact that food production, particularly in affluent societies, necessarily embraces all the other links along the food chain. The argument here is that, even though the focus remains on agriculture, the boundaries themselves of "agriculture" are becoming larger.

This expansion, in particular, makes agriculture overlap with, and therefore converge to, other sectors. This convergence of traditional sectors in broader and inclusive combination favoured, if not induced, by the new technological paradigm as well as by the new challenges, is now largely identified as the bio-based economy or *bioeconomy*.[27] In this dynamic and evolutionary perspective, bioeconomy is thus a stage of this evolutionary process from the old to the new technological paradigm and from the old to the new challenges; it is the innovative hyperspace represented in Figure 1.[28] As a consequence, the

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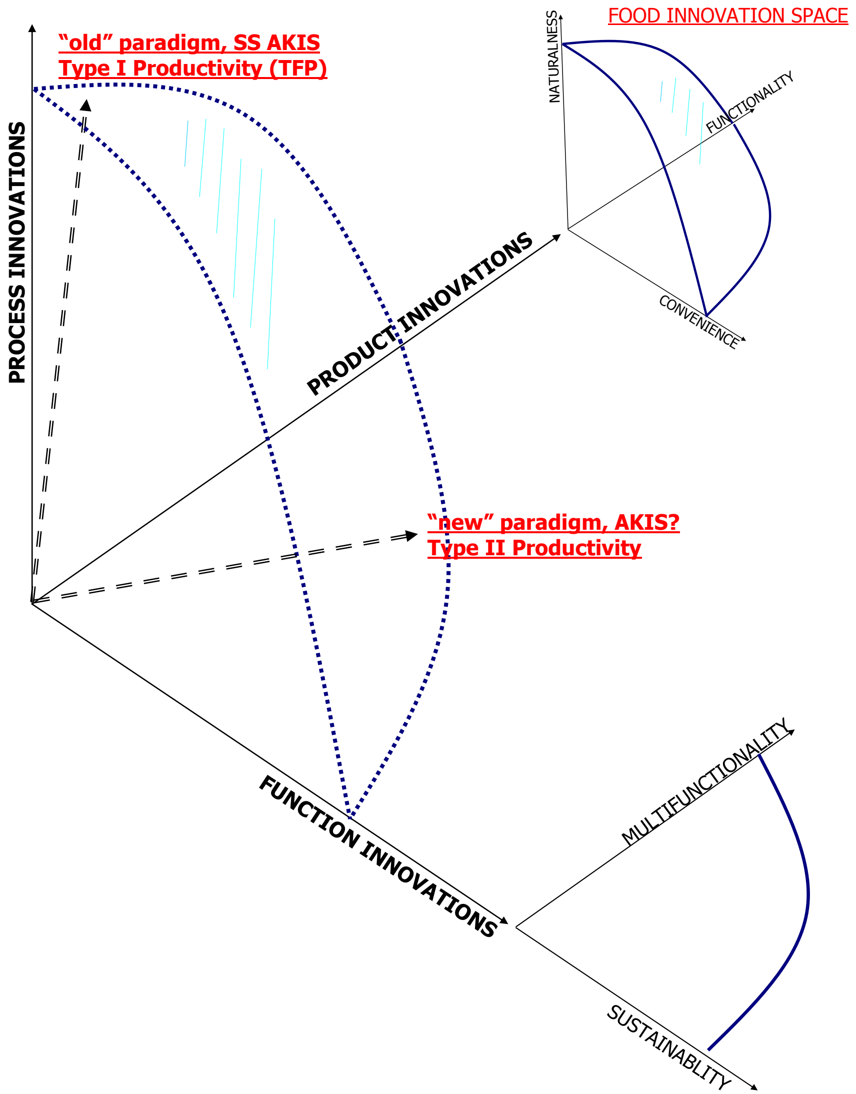
[26] In this respect, it seems inappropriate to think about future agriculture in terms of a choice between two contrasting trajectories; typically, *biotech* vs. *organic* agriculture (Neubauer, 2010). What really characterizes the future perspectives of agriculture is the occupation of all this innovation space, which is the combination and coexistence of all the viable technological trajectories.

[27] Several more or less concordant definitions of *bio-based economy* or *bioeconomy* have been proposed (European Commission, 2012e; Danish Presidency of the Council of the European Union, 2012). For more details, see http://ec.europa.eu/research/bioeconomy. However, it seems largely agreed that the concept itself of bioeconomy comes from the recent technological evolution: "The bioeconomy consists of all industries that use biological processes to produce products: food, fiber, green chemicals, pharmaceuticals, biofuels and energy. Agriculture and fermentation were the key elements of the traditional bioeconomy. The modern or new bioeconomy is based on our expanding knowledge of molecular and cell biology and takes advantage of information technology and nanotechnology" (from the call for papers of 128th EAAE Seminar) (http://www.economia.uniroma2.it/icabr-conference/sarea.php?p=15&sa=192).

[28] In this respect, bioeconomy is intended here in a wider perspective compared to conventional definitions. Conventional definitions mostly focus on the convergence of sectors whose production is based on biologi-

analysis of the knowledge and innovation system must necessarily expand its traditional sectoral scope (AKIS) towards these more inclusive and dynamic boundaries: the Knowledge and Innovation System for Bioeconomy (KISB).

Figure 1. The Agricultural Innovation Hyperspace



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cal processes (therefore with a strong emphasis on biotechnology). Here, in bioeconomy we also include those activities that are linked to these biological processes because they share with them the same resource base, in particular land. For instance, agrotourism, strictly speaking, is not a bio-based activity. Nonetheless, it is a *land-based activity* that can not be separated from bio-based activities that constitute conventional agriculture. For a discussion on a wider definition of bio-based economy or bioeconomy, see also Schmid *et al.* (2012).

4.2. Is agricultural TFP obsolete?

The prevalence of process innovations in the "old" technological paradigm implied that the agricultural innovation performance could be captured by a measure of productivity growth, i.e., TFP growth. TFP was intended, and still is, as a proxy of technological level and its growth as a proxy of technological progress. Gradually moving towards the new paradigm, however, the identification and implementation of a univocal appropriate measure expressing an innovative performance is more challenging. Along with "traditional" process innovations that increase the amount of product obtainable from a given amount of production factors (Type I Productivity), product and functional innovations mostly result in a performance improvement of different nature (Type II Productivity): new and better products but also more and better non-market goods and services which can be hardly measurable or observable.

Under these latter circumstances, the usual construction of aggregate indices of output and input to perform the calculation of TFP may face serious measurement difficulties. This is not a genuinely new problem in the literature. The intense debate on the so-called *productivity paradox*[29] (Brynjolfsson, 1993), developed especially in the nineties, concerned the problems encountered in TFP calculation whenever relevant quality improvements of both factors of production and products or services were observed. In this respect, the slowdown in TFP growth registered in USA and EU agriculture in recent decades (Table 2) could be considered as "our" productivity paradox. Whenever the sector began to move towards food safety & quality, environmental sustainability and multifunctionality, thus providing superior performance in terms of consumer satisfaction and social utility, the conventional measures of productivity reported a slowdown.

Evidently, passing from the "productivity slowdown" to the "paradox" emphasizes that what may appear as a declining performance, or even failure, of the knowledge and innovation system may be, at least in part, an artefact due to measurement errors or, to be more precise, to new and larger measurement errors induced by the evolution of the system itself. This also implies a more cautious interpretation of what emerges from TFP calculation and comparisons across space and time: the decline of TFP growth may be not necessarily an indicator of failure. It may rather (or also) be an indicator of structural changes in the nature of the system.

Two different approaches can be identified to cope with this methodological challenge. The first solution is to remain focused on the calculation of TFP as a primary and univocal proxy of productivity. Of course, this calculation must be adapted to take into account these product and function innovations. This implies a multi-output specification of the production process that admits quality heterogeneity, production of non-market services of collective interest (in essence, positive externalities) as well as of negative externalities (Oskam and Stefanou, 1997), and also admits that the production of all these market and non-market goods and services may show some degree of time-varying jointness (or non-separability) (Oskam and Stefanou, 1997; OECD , 2001).

Serious doubts can be raised on whether the neoclassical production theory (on which the concept and the calculation/estimation of the TFP is based) (Chambers, 1988),

[29] The productivity paradox is given by the massive introduction of ICT in most sectors, and mostly in services that apparently did not generate any impact in productivity figures.

is flexible and adaptable enough to properly take into account all these aspects. Several adjustment and extensions have been proposed within this production theory in this respect.[30] Nonetheless, it has still to be demonstrated that such complex and highly data-demanding adaptations really enable empirical productivity analysis with the same accuracy and comparability of the conventional TFP calculation.

Given these difficulties, an alternative option consists in recognizing that the traditional TFP calculation (as well as the underlying production theory), though valid, is not able to take full account of these kinds of innovation. In other words, productivity performance is made up of two different elements (see Figure 1): Type I Productivity (i.e., conventional TFP) capturing the productivity gains arising from process innovations; Type II Productivity (or Functionality) expressing performance improvement resulting from product and functional innovations. This second productivity type can be measured, in levels and growth rates, through a battery of indicators that accompany the traditional TFP. Therefore, an overall assessment and comparison of productivity performance will eventually be multicriteria. The literature on this second line of research is at an early stage (Ball and Norton, 2002, Part III; Esposti, 2008), but it represents a promising line of methodological and empirical study.

4.3. Towards a new model: from AKIS to KISB

The analysis carried out so far emphasizes the need of a re-definition and re-design of the AKIS mostly due to the substantial change in the nature and dynamics of the "object" of the system (knowledge and innovations). However, it remains difficult to illustrate in details which structure and features the system is actually going to assume along this evolutionary process. Eventually, the final outcome of this evolutionary process depends on how the involved agents and institutions will behave and adapt to the new context and how policies will accompany and condition this transition. This evolution still being largely in progress, incomplete, and country-specific, it seems only possible to outline some of its general characteristics and to provide some general guidelines for its proper design.

An uninterrupted international debate on purposes, limitations, needs and challenges of the AKIS started in the sixties (Bergeret, 2012, p. 9). This debate determined an evolution in the conceptualization of the AKIS and induced its progressive reform. Figure 2 outlines, very schematically and synthetically, the main stages of this reform process.[31] Conceptually, the key driver of this debate is the gradual emergence of the so-called *knowledge system thinking* (Röling, 1992), namely the belief, dictated by the evidence, that agricultural innovative performance is the final outcome of complex systemic interactions between different actors and institutions involved in the production and dis-

[30] For instance, a recent paper by Zuniga Gonzales (2012) proposes a Bio Economic-Oriented TFP (BTFP) where the TFP calculation is extended and adjusted to include production of other non-agricultural products (biofuels) obtained from farming activities. Kim *et al.* (2012) analyse farm-level productivity performances within a multi-output framework taking explicitly into account complementarities, scope economies and non-convexities associated to the diversification of farm activity. This approach may be interesting to evaluate the performance of multifunctional farms.

[31] For more details on the *knowledge system thinking* and on the progressive shift from AKS to AIS and AKIS, see Dockes *et al.* (2011), Poppe (2012b) and EU SCAR (2012).

semination of knowledge and in its incorporation into innovative technological solutions (Knickel *et al.*, 2009).

Even within this systemic logic, however, a *top-down* (SS) conceptualization of the AKIS was initially prevalent. At the top of the system there is scientific research whose production of knowledge and innovation flows downstream, through education and extension, up to final applications in agricultural production (*from Lab to field; LtoF*). The rise of the knowledge system thinking has progressively challenged this view in favour of an interpretation that emphasizes a stricter coordination and integration between the components of the "knowledge triangle" (research, education and extension) that eventually generates those various forms of knowledge and technological solutions to be finally transferred to producers. This was the original conceptualization of the AKS (Agricultural Knowledge System) (Poppe, 2012b) that essentially remains a top-down and supply-side representation, although not necessarily science-based (*from lab, classrooms and meeting rooms to field, LCMtoF*).

In fact, the next stage consisted in questioning the supply-side dominance in favour of a more active role of the demand-side (namely, farmers or final users). The peer interaction between users and the institutions of knowledge creation and diffusion eventually converts this knowledge into actual innovative practices (*knowledge&innovation system thinking*). This evolution determined a new conceptualization, that of the AIS (Agricultural Innovation System) (The World Bank, 2011), and, then, of the AKIS (Agricultural Knowledge and Innovation System) (Deschamps, 2011; Bergeret, 2012, p. 11-12; OECD, 2012) that emphasized the bi-directional interaction between supply and demand-side and the combination of top-down and bottom-up knowledge and information flows (*from lab to field, from field to lab, LtoF-FtoL*).

This view is essentially non-hierarchical, but based on the quantity and quality (i.e., intensity) of the interactions and flows of knowledge occurring within this system. This element is exalted further in the last stage of this conceptual and organizational evolutionary path. According to this perspective, the system is not an articulation of conceptual interacting components (as in the knowledge triangle: research, education, extension), but rather a network of real heterogeneous, autonomous but interdependent evolving subjects whose interaction is itself specific and dynamic. These subjects go beyond the traditional boundaries of the system, since in this context also consumer organizations, pressure groups and lobbies, opinion movements may become relevant. In short, the system is made of a wider range of stakeholders. What really structures and drives the system, therefore, is not some *ex-ante* allocation of functions and resources across conventional categories (research, extension, education), but the actual behaviour of these stakeholders, their choices, conflicts and cooperation. The system actually becomes an actively participated network operating both on a local and on a global scale (*from stakeholder to stakeholder, StoS*). [32]

This change in the conceptualization of the AKIS, and the consequent need to reform it accordingly, comes from the new challenges and paradigms outlined above. As they induce sectoral convergence, it is necessary to switch from a strictly agricultural perspective

[32] A clear example of this evolution is the concept of LINSA (Learning and Innovation Networks for Sustainable Agriculture) (CREPE, 2011; SOLINSA, 2012). See also Paffarini and Santucci (2009).

to a system open to all traditional sectors now converging into bioeconomy: from AKIS to KISB (Guillou, 2012). Moreover, while the conventional SS AKIS was based on an idea of knowledge codified into stable forms, thus allowing appropriate institutional arrangements to regulate its public/non-public nature, in the new paradigm, knowledge is a good with a much more complex nature and dynamics. An exemplary expression of this evolution is the concept of *system innovation*. This is a more complex and articulated idea of innovation which incorporates/hybridizes its different implications, the strictly technological content but also its organizational content as well as its social and environmental implications. System innovation inevitably and directly involves not only the supplier-user relationship but also consumers, citizens, agricultural-rural communities and institutions, etc. (Geels, 2005). A KISB with a strong network structure is the natural counterpart of this idea of innovation (EU SCAR, 2012).[33] It is a system where a *top-down* structure (SS KISB) should be replaced by a network structure (PβN KISB). This latter structure is eventually able to generate those complex system innovations by fostering not only research, dissemination and education, but also other critical processes for a successful innovation, that is, participation, experimentation, training and learning by doing and interacting.[34]

Designing the KISB as a network, however, does not immediately imply a well-functioning system. There are serious risks associated to a network structure. First of all, what is expected to be a well-functioning network in the conceptual design may eventually function as a highly fragmented and disorganized system, in practice, not able to self-organize and self-coordinate its activities (Klerkx and Proctor, 2013). In essence, it may behave as a system incapable of designing new technological trajectories because it produces and circulates incoherent fragments of knowledge and innovation instead of producing and circulating system innovations.

This new perspective may also be helpful to better understand what happened in EU agriculture in the last two decades. Most of the major successful novelties (for instance, agrotourism, organic agriculture, direct selling, agroenergy) are not usually considered as innovations because of their non-technological nature. However, they can be definitely regarded as product and function innovations and fit the concept of system innovation for which technology is often just a facilitating factor. For the most part, these innovations were generated spontaneously within local and specific contexts which then spread across the whole agricultural sector.

In analyzing these successful cases, the role of public policy should not be understated. Several policy interventions played a major role in favouring these product and functional innovations. The evolution of the CAP of the last two decades, in particular, contributed a lot. As the attention here focuses on AKIS/KISB policies, however, we must acknowledge that these successful novelties had little to do with the research and innovation policy. Research, as well as extension and education, certainly made their contribu-

[33] "System innovations are multi-factor, multi-actor and multi-level (multi-scaled) and can be only understood in terms of historical co-evolutionary process which link-up all these actors, factors and levels" (Geels, 2005). On *system innovation,* see also Barbier (2010) and Verguts *et al.* (2010).

[34] This idea of complex innovation (or system innovation) finds various expressions though all based on the same idea. For example, Hall (2011) proposes the concept of *agricultural innovation networks* to meet new challenges ("an increasingly complex agenda"). Along the same line, we find analogous or similar concepts: *collective intelligence*, *social innovation*, *multi-actor* (or *participative*) *innovation*, *innovation and learning networks* (Deschamps, 2011; Bergeret, 2012; Cristiano, 2012; EU SCAR, 2012; Klitgaard, 2012; Poppe, 2012b).

tion but not following a pre-determined strategy imposed by some pivotal institution. This contribution emerged gradually and spontaneously and accompanied the emergence of these innovations. Therefore, strictly speaking, it is not an institutional success, but rather the success of a system of permanent and high-quality relations. Therefore, these successful innovations are the result of the proper functioning of a network.

At the other extreme, consider a case that can be definitely regarded as a failure in the recent experience of many national KISB within the EU: the case of Genetically Modified (GM) crops. The national systems have invested significant resources in public (public universities hold several biotechnology patents) and private (clusters of highly innovative biotech firms) research, in high-level education and training (many university degree programs dedicated to modern agro-biotechnology), in information, dissemination and technical assistance (the remarkable effort of supplier firms, often multinational corporations, to inform and convince about the validity and viability of these technological solutions). Yet, all this effort has been almost completely lost in terms of final outcomes, that is, productive applications and productivity performance. It is definitely a system failure. Is it an institutional failure? Actually, institutions and agents made their deliberate choices within a legal framework (e.g., patent protection) and a set of incentives that were not fundamentally different compared to other countries where the advent of GM crops was more successful. It was rather a network failure. Many relevant stakeholders (e.g., consumers) as well as fundamental aspects of a proper network participation, discussion, and collective decision making were neglected. Most of the key actors and stakeholders operating within the network did not coordinate their choices and actions, and their interactions were not intense enough to avoid that all the innovative effort was dispersed and lost within the network due to actors' different needs, views and beliefs.

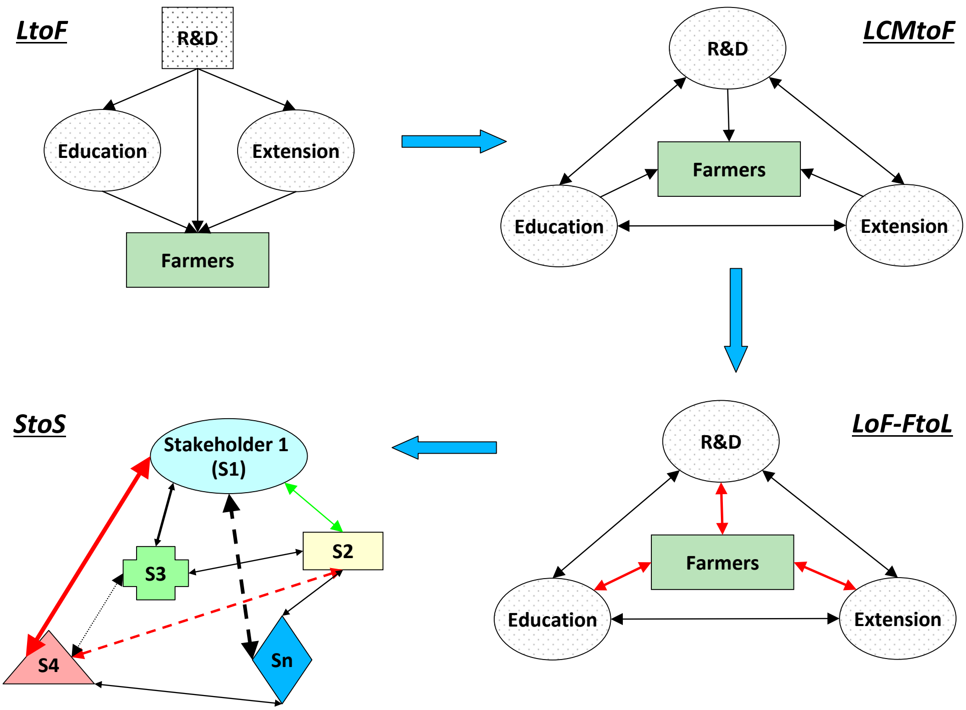
5. Some final considerations: a new policy design for the KISB

At this stage of the analysis, therefore, it is difficult to argue how the new system (the KISB) should be structured. As mentioned, its mostly spontaneous evolution is still in progress and depends on many heterogeneous interacting stakeholders. Moreover, properly outlining and designing a well-functioning network is more challenging than organizing a strongly hierarchical system. Nonetheless, the role of policies in this respect remains crucial especially within sectors (like agriculture) where policies, even when they do not explicitly focus on research and innovation, still strongly affect the behaviour of agents within the AKIS/KISB.

Therefore, to conclude the present analysis we attempt to draw some general conclusions about the most appropriate policy to induce, govern and influence the depicted evolutionary trajectory of the KISB. The attention concentrates on the EU policy. Not only because it directly concerns those developed countries whose agriculture and bioeconomy is of primary interest here, but mainly because the EU seems an exemplary case of the attempt to move in a direction consistent with the depicted evolution of the KISB and of the difficulties encountered in designing coherent and effective policies in this respect.

The ambition to build a common EU-wide KISB (European Commission, 2011) encounters two serious and mutually reinforcing coordination problems. The first coordination problem concerns the struggle of any European policy to harmonize and, gradually,

Figure 2. Evolution of the knowledge system thinking in the conceptualization of the AKIS



orient heterogeneous and specific national (and sometimes regional) policies (Materia, 2012; Poppe, 2012a). This harmonization effort, though needed, can not disregard heterogeneity, that is, the fact that there is no one-fits-all model of the KISB to which all EU countries and regions should easily converge. The second problem concerns the difficult coordination of the two main sectoral EU policies that directly or indirectly affect the KISB, namely the CAP and the EU Research Policy. If we consider the current design of these European policies, this latter coordination problem is less visible at present since the CAP contains only a limited number of measures (and resources) for the KISB, which are mostly concentrated in Axis 1 of the second pillar (Sotte, 2009).[35] On the contrary, inspired by the Lisbon Agenda, the current research policy already incorporates a number of ideas and initiatives that clearly focus on some key aspects of the depicted evolution of the system. In particular, under the Seventh Framework Programme (FP7) (i.e., the main line of research funding by the EU), one of the ten key areas, "*Food, Agriculture and Fisheries, and Biotechnology*", is specifically aimed at building a European *Knowledge Based Bio-Economy* (KBBE).[36] Nevertheless, this EU research policy design inevitably maintains a top-down (SS) perspective.

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[35] Sotte (2009) analyses the budget allocation of Italian Regions within their Rural Development Programmes across the different measures. Funds allocated to measures concerning innovation, education and training, extension, dissemination and technical assistance are just 6% of the total budget; quite close to funds allocated to generational turnover (5%), much less than funds spent on agro-environmental measures (32%).

[36] The KBBE budget is about 2 billion Euro of research funds, almost 4% of the total FP7 budget.

A more demand-side and bottom-up perspective should be provided by the CAP and, in particular, by its second pillar measures.[37] Improving this demand-side of the KISB and ensuring a closer matching with the supply side is one of the main purposes in reforming these EU policies for the period 2014-2020. The EU research policy continues along the line that has already been defined in the previous period. "Europe 2020" contains an ambitious programme of research funding ("Horizon 2020") (European Commission, 2011) in which the KBBE maintains a central position (European Commission, 2012a; Danish Presidency of the Council of the European Union, 2012) (http://ec.europa.eu/research/bioeconomy).[38] This research policy, however, is now adopted within a new framework, the *Innovation Union* initiative (http://ec.europa.eu/research/innovation-union/) (European Commission, 2010a). It is one of the key initiatives inspired by "Europe 2020" and its ambition is to make different EU policies (e.g., research and agricultural policies) converge towards the common goal of increasing the innovation capacity within the EU, in all countries and all sectors.

The Innovation Union initiative provides over 30 different actions. Of major interest here, it is the creation of thematic European Innovation Partnerships (EIP) to favour innovations on specific sectors and issues. One of these EIP concerns agriculture: the *European Innovation Partnership (EIP) for agricultural productivity and sustainability (EIP-A)* (Matthews, 2011). Though there is still an incomplete information on how this new instrument will work, the most recent communications of the EU Commission (European Commission, 2012a; 2012f) clarify its objectives, design and functioning. On this basis, EPI-A appears to be a real step forward in order to build a KISB in accordance with the discussed evolution, the new challenges and technological trajectories. On four aspects, in particular, the EIP-A seems to fully capture the evolution of the system (European Commission, 2012a; 2012f). First of all, it clearly acknowledges that agricultural innovations are expected to improve not only productivity in conventional sense (TFP) but also the performance with respect to other agricultural functions (*soil functionality*) (European Commission, 2012a, p. 4). Secondly, and related to the former point, the EIP-A seems consistent with a wider scope of the system moving from the strictly sectoral boundaries of agriculture to the bioeconomy, as clearly emphasised in many of the declared areas of innovative actions (European Commission, 2012a, p. 8-9). Thirdly, the EIP-A emphasises that the agricultural knowledge and innovation system has a prevalent network structure, weakly hierarchical and with many heterogeneous agents involved (European Commission, 2012a, p. 6). As a consequence, the current unsatisfying performance of the system should be intended as a network failure.[39] Finally, the initiative clearly aims at building the missing bridge between the EU research policy and the CAP (European Commission,

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[37] The potential contradiction between EU research policy on agriculture and the EU rural development policy emerges more clearly by looking at the actual figures. Neubauer (2010) reports data on the research projects funded under the Sixth Framework Programme in the areas of "agricultural biotechnology" and "organic agriculture". The former area has received total funding which is about four times the funding received by the latter. The second area, however, received much more support within the second pillar of the CAP (Sotte, 2009).

[38] In particular, agricultural issues are mostly framed within the objectives of *Food Safety* and *Sustainable Agriculture*. The resources dedicated to the KBBE during the entire period should amount to 4.5 billion Euros, more than double the budget for the KBBE in the FP7, but still just about 5% of the total budget of Horizon2020.

[39] "The scientists do not know what the farmers want and the farmers do not know what science does" (Matthews, 2011).

2012a, p. 7), that is, at coordinating and matching the top-down and bottom-up initiatives to eventually generate real innovative behaviours and choices.

Nonetheless, the novelty and these remarkable strengths of the EIP-A initiative may remain just good intentions if not accompanied by an appropriate design and implementation. At the moment, some weaknesses clearly emerge in this respect. The first problem concerns funding. The EIP-A by itself will have a very limited funding, as it is rather expected to mobilize and orient resources made available within Horizon2020 and the CAP (second pillar). In relative terms, however, these latter resources are still marginal. Within the current CAP reform proposals, this novel initiative will involve only a small portion of the budget (4.5 billion Euros corresponding to just over 1% of the total CAP budget). These resources will be dedicated to agricultural (or bioeconomy) research and will be managed with the clear objectives, rules and procedures of the EU Framework Program for research (European Commission, 2012a,b). Therefore, it may just represent a transfer of money from a EU policy to another, not necessarily a coordination between them. Eventually, the EIP-A might not be strong enough to counterbalance the institutional inertia of both EU research policy and the CAP.

On this latter aspect, a stronger contribution to reduce this inertia can be expected from the reform of the CAP's second pillar. The current proposal identifies the transfer of knowledge and the impulse to innovation as one of the six key horizontal priorities (European Commission, 2012d). On the actual contribution of this Rural Development Policy to the EIP-A initiative, however, other potential weaknesses can be identified. On the one hand, the CAP remains jealous of its strictly sectoral boundaries. Therefore, it is willing to accept, at least apparently, the integration with the research policy, but shows greater difficulty in opening to those other sectors that, together with agriculture, converge in the bioeconomy. While the EU research policy claims the KBBE, the CAP's emphasis on innovation remains almost exclusively confined within the traditional agricultural sector. On the other hand, the Rural Development Programmes are expected to bring all these interventions, coordinated by the EIP-A, into the local contexts where they may not meet similar and coordinated interventions at the national and local scale. More generally, the "local" KISB might not be ready to integrate this top-down impulse coming from the EU within their own bottom-up effort (Fieldsend, 2012).

The EU Commission seems aware of these potential weaknesses of the EIP-A and proposes an instrument to overcome the funding issues as well as the institutional inertia of the two EU policies the EIP-A is expected to coordinate. This instrument is the creation of Operational Groups (OG) that should transfer in practice all the strengths of the EIP-A initiative. OG should behave as innovation networks involving all the relevant stakeholders and working on all the possible relevant areas of the bioeconomy. Funded by both Horizon2020 and the second pillar of the CAP, OG will be asked to reduce the gap between scientists and farmers, thus improving the innovative performance of the EU agriculture and bioeconomy. While acknowledging that these OG may be of strategic relevance to make the EIP-A effective, however, there is still little information on how they will be brought together and how they will function in practice. Therefore, only next years will show whether the reformed design and implementation of the involved EU policies will really follow the declared objectives and will be able to meet the abovementioned expectations.

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