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Agricultural science research impact in the Eastern European Union Member States

Improving agricultural research impact is an important goal for the European Union (EU). The EU Framework 7 project Impresa studied the process of research impact across Europe, and this article selects and discusses results drawn from the 11 Eastern EU Member States. The major methods used were a survey of the levels and trends of research expenditures by the public and private sectors, case studies identifying impact pathways of individual science-based innovations, and quantitative analyses of the relationship between research investments and their final impacts. The conclusions drawn are that, despite the potentially high payback from public investments in agricultural science, insufficient resources are being invested by the post-2004 EU accession countries, and improvements in innovation capacity and networking should enhance the efficiency of research impact.

Keywords: research and innovation policy, Central and Eastern Europe, impact evaluation

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Introduction

The European Union's (EU) long-term growth policy gives a prominent role to research-based innovation. Initially, the Lisbon Strategy aimed for a competitive and dynamic knowledge-based economy. Its successor, the Europe 2020 Strategy, has targeted smart, sustainable and inclusive growth. In Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia, collectively referred to here as the Eastern EU Member States, agriculture is economically relatively more important than elsewhere in the EU, but its performance in terms of productivity, environmental impact and spatial and social equity could be considerably improved. Understanding the agricultural science base, from which innovation in agriculture should predominantly arise, is thus an important first step in enhancing innovation and beneficial impacts within the sector. It is therefore of some concern that relatively little is known overall about the impact of agricultural science in Europe. In the ex-ante impact assessment of the reformed Common Agricultural Policy (CAP) introduced in 2014, the annex on research and innovation noted that "it is not possible to draw a complete picture of the overall (agricultural research) effort since there are no data on private investments" (EC, 2011, p.5).

A substantial amount of activity is devoted understanding the impacts of science on innovation and the benefits to wider society in low-income countries (particularly in relation to the Millennium Development Goals: see, for example, CGIAR, 2005). Much less effort has been made in Europe, at least until the European Commission funded the Impresa (Impact of Research on EU Agriculture) project in 2013, which has examined the economic, social and environmental impacts of scientific research on agriculture across Europe. Its objectives were two-fold. The first was to describe the contemporary evolution of public and private agricultural research (bearing in mind that recent scientific and supply chain developments blur the boundaries of the discipline, as traditionally defined). The second was to explore its resulting impacts, using a variety of qualitative and quantitative approaches. It surveyed trends, sources and objectives of agricultural research across Europe, to establish the range, degree of integration and effectiveness of research activities. It selected a number of regional case studies to represent agro-ecological and socio-economic diversity for investigation of the causal framework of case-specific individual research-based innovations. Using a variety of modelling approaches, it also assessed the aggregate effect of agricultural science research on farming productivity, recognising also that, embedded in a 'European model of farming', additional policy goals relate to social, cultural and environmental targets. Pathways to impact, whether implicit or directly observed, rely heavily on effective knowledge sharing, and consequent stimulation of innovation, through the Agricultural Knowledge and Innovation System (AKIS) in all countries studied.

This article draws on the Impresa project's results to address specific issues for agricultural science and its translation into innovation and impacts in the Eastern EU Member States. Gorton *et al.* (2009) outlined the rural economic divergences between these countries and the rest of the EU. They had larger, less wealthy rural populations exposed to more likelihood of being unemployed and, if so, to be in long-term unemployment. Primary and manufacturing activities were more dominant but the services sector was underrepresented. Where rural people work in agriculture, they are less productive but work in a sector that contributes relatively more to national income than elsewhere in the EU; they worked on farms which in terms of average size were much smaller. While there is substantial variation, the most recent figures show that these 11 Member States employ 51 per cent of the EU labour force working in agriculture, contribute 29 per cent of total EU land utilised by agriculture, and produce 14 per cent of gross agricultural value added in the EU. Yet in terms of total public budget allocations for agricultural science, spending was only 6 per cent of the EU total, and an average of 0.017 per cent of Gross Domestic Product (GDP), a little over three-quarters of the EU average of 0.023 per cent.[1]

These data represent structural problems for economies with low agricultural productivity where science could contribute innovative technological solutions, whereas research investment is concentrated elsewhere in the EU. In the cen-

[1] Figures are sourced from Eurostat and relate to 2014.

tral planning period, especially in the final quarter of the twentieth century, solid agricultural output growth had been achieved, mainly as a result of heavy capital investment, and consolidation of production into large state farms and cooperatives during the central planning period. However, this went into reverse in the 1990s (Ciaian and Swinnen, 2009), and a bimodal structure of farm holdings resulted, with very large capital-intensive holdings at one end of the spectrum and very small part-time or subsistence plots at the other. Importantly, the agricultural research and dissemination system that existed prior to transition was relatively large, well-funded but bureaucratically unwieldy. Its priorities and programmes were set through interaction between the individual interests of research institutions and central planning authorities which set the national objectives for agriculture (Csaki, 1998). Hence, it was "appropriate to large-scale farming and geared to the relative prices of the communist period, which were considerably different from those of the present" (Sarris *et al*., 1999, p.323), and thus served the needs of neither branch of the dual production structure that emerged after transition.

Thus, understanding of the context and relevance of agricultural science in the more recently acceded EU Member States is required to address political barriers to solution of their problems. To achieve this, the article is organised into three main sections. The following section outlines the results of the Impresa project's research in the Eastern EU Member States, and this is followed by an examination of the project's overall results as they apply to these countries. The final section discusses the implications that arise and provides some conclusions to support future policy development, both for the Member States concerned and also for the EU as a whole.

Agricultural research in the Eastern EU Member States

Official Eurostat data on agricultural science research expenditure are incomplete. The most relevant measure of activity is classification by socio-economic purpose (NABS: Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets). Data over the period 2008-2014 are entirely absent for two countries (the Czech Republic and Latvia), and are only fully available for business enterprise, government and higher education sectors in four countries (Table 1). Overall, for the three sectors and over seven years, 33 per cent of observations are absent. The overall picture is one of modest growth in expenditures (data are in current price terms and inflation is likely to have reduced real spending). However, in per capita terms and as a percentage of GDP, there is still some way to go in terms of catching up with leading European nations, especially given the proportionately larger problems that they face.

Research investment

Gaps in research expenditure data are significant because complete series are necessary for analysis of their impact on productivity, an important measure of their effectiveness. Where data are missing, it is sometimes possible to supplement them from national sources, although under-reporting is a significant problem. For this reason, and also because the definitions used do not necessarily capture the fast-moving scope of contemporary science for agriculture, with its spillovers from biosciences, robotics and remote sensing, a survey was undertaken to supplement the Eurostat data. It aimed to complement and enhance the available Eurostat information with information on expenditures from alternative sources. It took advantage of the opportunity also to explore the structure of the agricultural science and innovation system in each country. This provided information about structural changes in the conduct of agricultural science across Europe and investigated perceptions of senior scientists and managers about future prospects for the discipline.

This survey covered 20 European countries, and a synthesis of its results is available in Chartier *et al*. (2014). A small number of countries (Germany, Spain, the United Kingdom, Italy and France) are responsible for over 70 per cent of public agricultural science budget allocations, and a substantial minority account for less than 5 per cent. Hence these larger countries were complemented with a representative selection of the other 27 countries then in the European Single Market (the EU, EAA and Switzerland). Seven Eastern EU Member States were surveyed: Bulgaria, the Czech Republic, Hungary, Latvia, Poland, Romania and Slovenia (see, respectively, Slavova *et al*., 2014; Ratinger, 2014; Fieldsend, 2014; Zēverte-Rivža *et al*., 2014; Podlaska, 2014; Ibna, 2014 and Juvančič and Erjavec, 2014).

The findings filled gaps and provided elaboration on the aggregate data presented in Table 1. The data collection strategy focused on identifying alternative indicative sources for missing Eurostat data. The diverse information sources used and varying data availabilities in individual Member States preclude the presentation of results in a consistent format to complement Table 1. Consequently, the situation in each country needs to be discussed separately prior to developing an overall conclusion with regard to Eastern European agricultural research investment. In two of the countries studied (Hungary and Slovenia), all information on agricultural research expenditure is available. However, while in Hungary the quality of this data is assessed as good, in Slovenia some concerns are raised concerning private enterprise research financing data, in terms of reliability and how well it reflects and increasingly complex underlying pattern of activity.

In Bulgaria, information on agricultural research expenditure is available for Private Enterprise and Government, but not for Higher Education. This is because of the wide discretion available to universities regarding how much of their budgets should be devoted to research, from 0.5 to 10 per cent for research in total, and diverse sources of funding which include state subsidy, EU Cohesion and Structural Funds and funding from international (i.e. EU RTD or similar projects) and national research programmes. So, for example, data from annual financial reports show that for the three specialist universities relating to forestry, agronomy and food technology allocated EUR 0.29, 0.30 and 0.22 million in 2008, 2010 and 2012 respectively. In Romania, Eurostat data are currently fully available only up to 2010, as

Business enterprise expenditures are missing for subsequent years. The survey produced no clear evidence for trends in these expenditures after 2010, although the sentiments of key informants indicate that public financing, which is declining, influences private expenditures on agricultural research which are also likely to be declining.

The NABS division of research expenditures by socioeconomic nomenclature more accurately describes contemporary

Table 1: Agricultural R&D Expenditure by NABS* in the Eastern European Union Member States, 2008-2014

Member State	Measure of expenditure		2008	2009	2010	2011	2012	2013	2014
Bulgaria	Gross expenditure (EUR million)		19.5	26.9	19.3	20.4	18.2	20.4	17.8
	Gross expenditure (% GDP)		0.052	0.072	0.051	0.049	0.043	0.048	0.042
	Gross expenditure (EUR per inhabitant)		2.6	3.6	2.6	2.8	2.5	2.8	2.5
	Of which:	Business enterprise (EUR million)	0.7	2.6	:	3.6	1.7	:	3.8
		Government (EUR million)	18.7	23.8	16.2	16.2	16.2	16.6	13.7
		Higher education (EUR million)	:	:	:	:	:	:	:
Croatia	Gross expenditure (EUR million)		37.3	35.7	30.6	33.0	30.4	26.0	25.4
	Gross expenditure (% GDP)		0.077	0.079	0.068	0.074	0.069	0.060	0.059
	Gross expenditure (EUR per inhabitant)		8.6	8.3	7.1	7.7	7.1	6.1	6.0
	Of which:	Business enterprise (EUR million)	10.1	9.3	6.3	8.7	6.0	2.0	2.1
		Government (EUR million)	4.9	5.8	6.2	5.9	6.0	5.6	5.5
		Higher education (EUR million)	22.2	20.6	18.1	18.3	18.5	18.5	17.9
Estonia	Gross expenditure (EUR million)		8.6	8.5	9.8	15.8	17.4	16.3	14.2
	Gross expenditure (% GDP)		0.052	0.060	0.067	0.095	0.097	0.086	0.072
	Gross expenditure (EUR per inhabitant)		6.4	6.4	7.4	11.9	13.1	12.3	10.8
	Of which:	Business enterprise (EUR million)	0.3	0.0	0.1	0.1	0.1	0.2	0.1
		Government (EUR million)	2.2	2.4	2.7	2.5	2.6	1.7	1.9
		Higher education (EUR million)	6.1	5.9	7.0	13.3	14.7	14.4	12.2
Hungary	Gross expenditure (EUR million)		81.2	79.1	77.9	84.7	86.2	106.3	97.0
	Gross expenditure (% GDP)		0.075	0.084	0.079	0.084	0.087	0.105	0.092
	Gross expenditure (EUR per inhabitant)		8.1	7.9	7.8	8.5	8.7	10.7	9.8
	Of which:	Business enterprise (EUR million)	18.9	18.9	26.3	32.7	41.1	60.8	45.0
		Government (EUR million)	37.1	33.1	31.5	31.3	26.9	29.4	34.9
		Higher education (EUR million)	25.2	27.1	20.2	20.7	18.3	16.0	17.2
Lithuania	Gross expenditure (EUR million)		17.1	14.3	11.4	13.6	8.3	13.8	16.9
	Gross expenditure (% GDP)		0.052	0.053	0.041	0.044	0.025	0.039	0.046
	Gross expenditure (EUR per inhabitant)		5.3	4.5	3.6	4.5	2.7	4.6	5.7
	Of which:	Business enterprise (EUR million)	:	:	:	:	:	:	:
		Government (EUR million)	9.4	6.9	5.3	7.0	:	8.1	8.2
		Higher education (EUR million)	7.6	7.4	6.1	6.6	8.3	5.6	8.6
Poland	Gross expenditure (EUR million)		:	:	:	:	:	:	:
	Gross expenditure (% GDP)		:	:	:	:	:	:	:
	Gross expenditure (EUR per inhabitant)		:	:	:	:	:	:	:
	Of which:	Business enterprise (EUR million)	:	:	:	:	:	:	:
		Government (EUR million)	:	102.4	112.9	103.9	104.1	96.7	104.1
		Higher education (EUR million)	:	:	:	:	:	:	:
Romania	Gross expenditure (EUR million)		59.6	38.2	40.5	:	:	:	:
	Gross expenditure (% GDP)		0.042	0.032	0.032	:	:	:	:
	Gross expenditure (EUR per inhabitant)		2.9	1.9	2.0	:	:	:	:
	Of which:	Business enterprise (EUR million)	26.2	19.1	11.6	:	:	:	:
		Government (EUR million)	11.5	6.9	15.7	24.5	21.8	22.8	27.2
		Higher education (EUR million)	21.8	12.1	12.9	5.4	7.6	11.0	5.9
Slovakia	Gross expenditure (EUR million)		40.4	13.9	20.6	27.0	30.6	9.3	37.9
	Gross expenditure (% GDP)		0.061	0.022	0.031	0.038	0.042	0.013	0.050
	Gross expenditure (EUR per inhabitant)		7.5	2.6	3.8	5.0	5.7	1.7	7.0
	Of which:	Business enterprise (EUR million)	24.2	0.9	1.5	1.5	1.5	1.5	1.6
		Government (EUR million)	13.6	9.4	15.9	20.7	20.1	2.8	29.3
		Higher education (EUR million)	2.6	3.6	3.2	4.8	8.9	5.0	7.0
Slovenia	Gross expenditure (EUR million)		11.2	12.7	12.8	15.5	18.0	16.4	16.4
	Gross expenditure (% GDP)		0.029	0.035	0.035	0.042	0.050	0.046	0.044
	Gross expenditure (EUR per inhabitant)		5.6	6.2	6.2	7.5	8.8	7.9	7.9
	Of which:	Business enterprise (EUR million)	1.6	2.1	2.2	4.4	6.1	5.4	5.5
		Government (EUR million)	4.7	5.1	4.9	3.8	4.6	3.5	6.2
		Higher education (EUR million)	4.8	5.5	5.7	7.2	7.2	7.5	4.6

* Nomenclature for the Analysis and Comparison of Science Budgets and Programmes 2007
: Data not available
Source: Eurostat

Table 2: Agricultural R&D expenditure by FOS* in selected Eastern European Union Member States, 2008-2014.

Member State	Measure of expenditure		2008	2009	2010	2011	2012	2013	2014
Czech Republic	Gross expenditure (EUR million)		80.7	80.3	76.8	93.1	94.8	66.5	80.0
	Gross expenditure (% GDP)		0.050	0.054	0.049	0.057	0.059	0.042	0.051
	Gross expenditure (EUR per inhabitant)		7.8	7.7	7.3	8.9	9	6.3	7.6
	Of which:	Business enterprise (EUR million)	23.8	23.4	23.0	28.2	27.3	17.2	29.5
		Government (EUR million)	31.8	29.3	28.4	31.6	20.2	18.8	24.4
		Higher education (EUR million)	24.6	27.1	25.1	33.0	47.2	30.5	25.9
Latvia	Gross expenditure (EUR million)		14.1	6.5	11.1	12.7	:	:	:
	Gross expenditure (% GDP)		0.058	0.035	0.063	0.063	:	:	:
	Gross expenditure (EUR per inhabitant)		6.4	3.0	5.3	6.1	:	:	:
	Of which:	Business enterprise (EUR million)	0.1	0.3	0.3	1.0	:	:	:
		Government (EUR million)	9.4	4.4	6.1	8.1	11.1	10.3	9.3
		Higher education (EUR million)	4.6	1.8	4.8	3.7	4.2	4.1	5.2
Poland	Gross expenditure (EUR million)		156.3	131.8	199.9	202.2	159.0	175.7	246.6
	Gross expenditure (% GDP)		0.043	0.042	0.055	0.053	0.041	0.045	0.060
	Gross expenditure (EUR per inhabitant)		4.1	3.5	5.3	5.3	4.2	4.6	6.5
	Of which:	Business enterprise (EUR million)	15.8	12.1	16.0	26.2	23.7	25.6	78.4
		Government (EUR million)	115.0	83.3	123.8	:	:	:	100.6
		Higher education (EUR million)	25.6	36.4	60.1	61.1	48.4	51.1	67.4

* Fields of Science 2007
: Data not available
Source: Eurostat

research, contrasting with the more widely used Fields of Science classification which does not allow a 'value chain' approach: research on food and beverages, bioproducts, biomaterials or biofuels are classified in categories other than agriculture. However, although for the Czech Republic, Latvia and Poland the NABS measure is missing, expenditure classified by the more traditional Field of Science measure is mostly available, except for Latvian Private Enterprise research expenditures from 2011 onwards (Table 2). However, the scale of these is likely to have remained very small, relative to Government and Higher Education expenditures in Latvia.

It is not possible to identify an accurate overall trend in agricultural research expenditures across the Eastern EU Member States, although in individual countries rising, falling or broadly stable levels of expenditure can be discerned. As well as changing overall research expenditure, there were shifts occurring in the form in which expenditures were made and the topics covered. Core public funding for agricultural science seems to be everywhere being reduced and increasingly large proportions of budgets are distributed through programmes of competitive calls for proposals. For example, in Bulgaria core funding is now insufficient to cover operating costs of agricultural science institutes and they must rely on winning competitive projects in order to remain viable. Conversely, however, data reporting may underestimate total research income of institutes as sources other than state subsidies are not always reported; for example, divergence between Eurostat and national sources which can be attributed to this was evident in Romania. Compensation for declining research funding by greater utilisation of EU sources, such as Operational or Framework Programmes, is common elsewhere, for example in Latvia and in Hungary.

Two Member States, the Czech Republic and Poland, reported rising agricultural expenditures and strengthening expenditure on research by the private sector. In both countries this is associated with a general increase in research expenditure; in the former, however, agricultural science is receiving a diminishing share compared with other research areas. In the latter, requirements for business participation in the 'Complex Sustainable Systems' programme have been a stimulant for this interest. In most other countries surveyed, though, business expenditures on agricultural research were small in comparison to public funding. In Slovenia, private funding of agricultural research is worryingly low, due either to underdevelopment, failure to recognise the investment need, or margins that are too low to generate investment, any of which would be cause for concern. In Hungary, tax advantages temporarily boosted public-private research partnerships for agricultural science institutes, but recent restructuring of the tax system has reduced investment from that source.

Transition from the original Soviet model of Academies of Science is still ongoing, and for many countries government agricultural research institutes are still the main channel for research investment. Often research in Higher Education institutes is undertaken through cross-subsidisation from teaching revenues, or funded from outside sources. In Hungary much effort is being devoted to the restructuring of institutes under the overall framework of the National Agricultural Research and Innovation Centre (NAIK), although a consequence of this has been delay in developing an official research strategy for agriculture. In this and other countries surveyed, a process of restructuring to create more efficient frameworks to conduct agricultural research is in progress, often with a focus on reducing administrative costs.

The type of research being undertaken has almost entirely shifted from basic to applied, and in some circumstances is at the technical and near market end of applied research. Nevertheless some basic research continues to be conducted. A shift in publicly-funded research themes can also be identified. While food safety and productivity remain research topics of interest, most of the countries surveyed are placing more emphasis on natural resource management, biodiversity conservation, adaptation to and mitigation of climate change, and bioeconomy production.

Future prospects are viewed with some pessimism. In Bulgaria, agriculture is absent from the National Roadmap for Research; declining government expenditure is unlikely to be compensated by a private sector mostly composed of small businesses lacking entrepreneurial culture, skills or motivation. In Latvia, Slovenia and Romania, less emphasis is expected on agricultural science in public research in future, compounding the problem of weak private sector interest. Poor strategic orientation and ineffective ex-post evaluation systems also hamper the performance of the research systems in these countries.

While expenditure data on scientific research on agriculture are generally better in Eastern EU Member States than elsewhere in the EU, there are still some significant gaps, and the more detailed perspective that this survey has uncovered identifies substantial concerns for the future, particularly with regard to the weakness of private sector engagement. The government sector appears to be diminishing in relative importance and the institutional structure is not yet able to focus resources on farm-level needs in order to shape research activity, or to develop, disseminate and implement appropriate innovations.

Detailed study of an innovation process: the Ecostop® plate

A methodological framework for detailed assessment of the impacts of specific agricultural science research projects has been developed for the Impresa project. In order to develop and test the approach, it was applied to six previously-developed innovations, selected from across a number of EU Member States. The method adopted was based on Participatory Impact Pathway Analysis (or PIPA: Springer-Heinze *et al*., 2003; Douthwaite *et al*., 2007). PIPA challenged the previously dominant logical framework approach to evaluation (described, for example, by Coleman, 1987) which represented the innovation process as a single causal chain, linking activities, outputs, outcomes and impacts in a chronological sequence. While retaining these elements of the process, PIPA instead recognises that a number of sequences can be identified, feedback loops can exist, and innovation can combine with important contextual factors to explain the change process more effectively.

Mixed methods were used in case study analyses to define and validate innovation pathways from initial research to overall impact. However, unlike the ex-ante orientation of the original version, an ex-post version was applied, outcome harvesting was developed as a supplementary validation approach, and more emphasis was placed on the role of the actor network than in the original method (see Schmid *et al*., 2016 for further details). The approach had the advantage of identifying enabling and hindering factors in respect of the development of trust, networks and role of economic and institutional frameworks, and also the existence of both unintended and unexpected effects.

Six case studies were conducted by the Impresa project, in Bulgaria, France, Germany, Italy (2) and the UK. All cases used the same investigative procedure. Initially, potential cases were screened for suitability, by identifying actors and other stakeholders, original research questions and potential impacts. Working with stakeholders, an initial impact pathway map was developed, refined and validated from triangulation of a range of forms of qualitative and quantitative data. The resulting innovation impact pathway was discussed in a feedback round with stakeholders, from which conclusions were drawn for both research practice and public policy development.

Only the Bulgaria case study, development of the Ecostop® plate to treat Varroatosis in bees (Box 1), is relevant to this paper, although it should be noted that the German case study (Hülemeyer and Sterly, 2016) was carried out on the territory of the former GDR. The challenge for the Bulgarian case study analysis was to understand the success of this innovation in a post-socialist context. Interaction with the stakeholder group described in Box 1 produced the impact pathway map set out in Figure 1, which categorises the events and their timing in order to produce the impacts from the original innovation.

The way in which the research influenced the final economic impacts can most plausibly be described through five key enabling factors. Firstly, a typology of existing drugs, their constituents, use and effects was produced to support development of a new product to counter Varroatosis resistance in synthetic medicines. From this, possible links between drug characteristics and resistance development proved important, mainly because essential oils appeared to have lower resistance risk than conventional treatments, and these informed the laboratory and clinical trials that adjusted the substances, the carrier, and the product package. Secondly, the research team integrated two important network structures, veterinary scientists and the beekeeping communities. Their integration played a role in understanding beekeeper practices and transmitting relevant feedback. The most important outcomes from this networking were identification of the need for an easy-to-use product and the

Box 1: Development of the Ecostop® plate.

Beekeeping is an important agricultural sector in Bulgaria (Koprivlenski *et al*., 2015) which has grown significantly over recent years. As elsewhere internationally, it faces a major challenge from the parasitic Varroa mite. This problem has worsened as the mite has been steadily acquiring resistance to existing medicines, most of which contain substances that are harmful for both bees and humans. The innovation chosen for study was a privately-funded and research-based treatment for Varroatosis, the Ecostop® plate. Two previously publicly-employed veterinarians, with complementary expertise in in pharmacology and biomineralogy, established a commercial enterprise which developed this alternative to conventional pesticides. It is based on essential oils impregnated into a mineral carrier. These are entirely natural substances, harmless to bees, which do not engender resistance. The innovation has achieved high penetration of the domestic market and growing international sales on the basis of limited private investment, in the absence of public funding for research and limited administrative capacity.

The plate was developed in collaboration with farmers and a network of other scientists, particularly apiculturists. Both main actors had worked together in the state sector, from the 1980s on, to develop precursor anti-Varroa products. From this they had developed a network, one which was not based on formal organisational structures but on professional and private social ties, which evolved as the foundation for their commercial enterprise. The structure of this actor network is hierarchical and self-contained with respect to expertise and control of information flows. The close involvement of beekeepers in it assisted product development, and was crucial for subsequent diffusion and adoption. The high level of informal trust between actors was necessary because confidence in post-communist public institutions is minimal, and consequently their effectiveness is weak.

Source: Slavova *et al*. (2016)

confidence gained from opinion leaders which helped to promote uptake. The third factor was technical. Adjustment between substances and carrier took four and a half years to develop from prototype to final product. This produced a unique carrier, a plate that needs to be introduced only once a year, producing gradual evaporation of the substance in the hive over the entire period necessary for treatment. Once established as a viable product, it was certified for organic beekeeping. Conventional beekeepers also found it useful because of its non-toxicity, effectiveness and timesaving. It also involves zero waste, a further beneficial environmental impact. Fourthly, leading beekeepers were closely involved in trialling the product. The prototype problems would not have been recognised as quickly without this engagement, and also dissemination of the product occurred rapidly as a result. The final factor was the adoption of the product for use by the National Beekeeping Programme. This provided significant subsidies for its use.

However, the inherent riskiness in scientific product development constituted a barrier, compounded by the negative role of the institutional framework. The Ecostop inventors made a number of applications for public funding, unsuccessful for two reasons that they describe: the high cost of consultancy to prepare the applications and the corrupt payments needed for the project to secure public support. In the event the enterprise was established on the basis of private funding only. Other major barriers were experienced in dissemination of the product. New markets outside Bulgaria in other EU Member States have been difficult to access, as registration costs are prohibitively high. Also, within Bulgaria, producer conservatism and black market sales of imitation products constrained sales growth.

The nature of the product complicates the assessment of the impacts. It is a successful, radical innovation and has contributed to maintenance and development of producer incomes through maintaining bee health, with further benefits to nature conservation and pollination as an ecosystem service, although only when applied with other appropriate anti-Varroa methods. Its introduction is also relatively recent and as a result it may be too soon to assess the full range of impacts, primary and secondary, positive and negative.

Many of the lessons that arise from this case study are shared with those from the other five case studies undertaken elsewhere in the EU. In essence, successful impact from an innovation arises from the existence of an influential and motivated individual (or individuals); a favourable context of

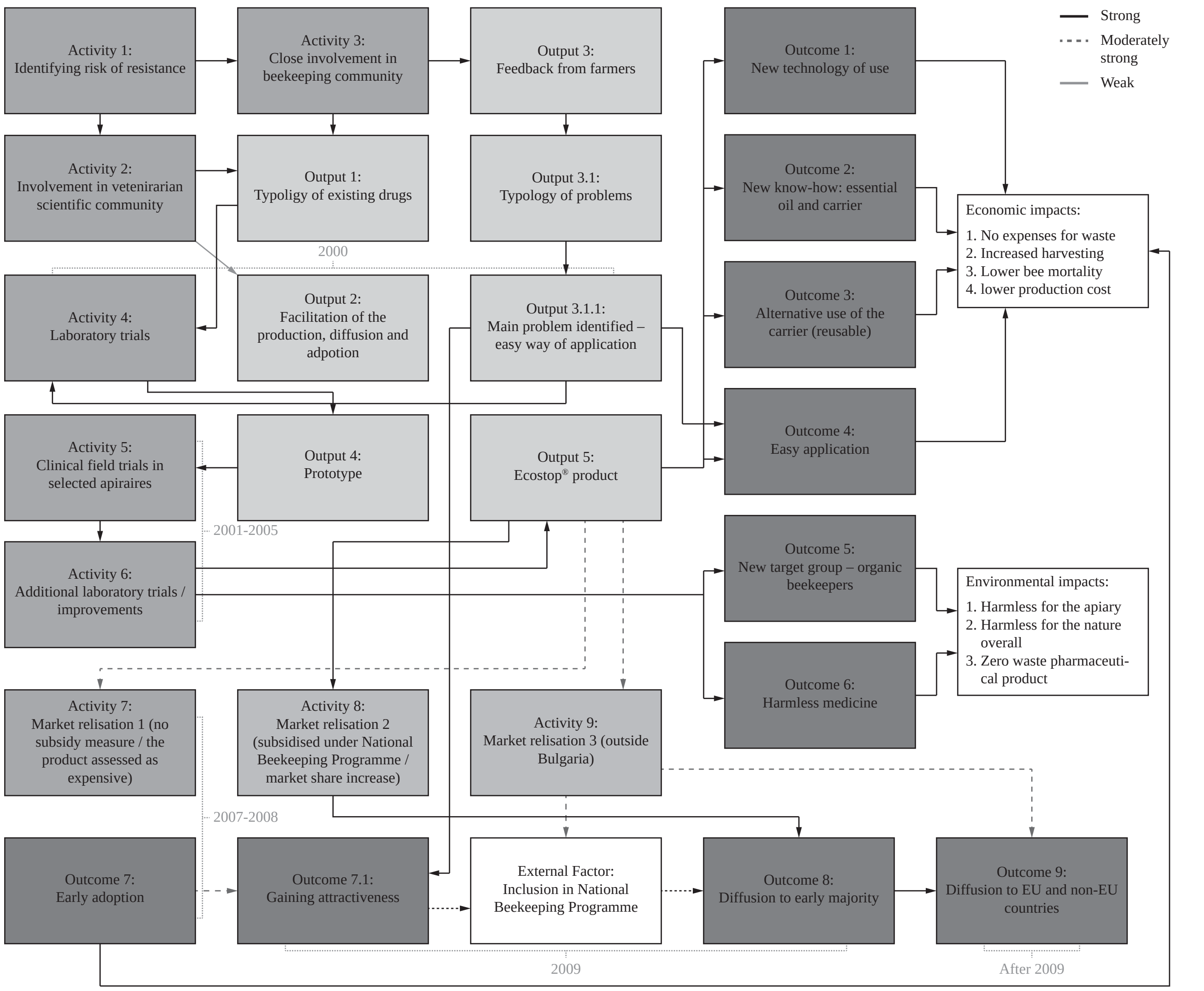

Figure 1: The Ecostop® Innovation Impact Pathway Map.

Source: Slavova *et al.* (2016)

trust among actors to foster networks and collaboration; and economic incentives facilitating the impact pathway. These issues are revisited in the concluding section of this article.

Quantifying research impacts: an Eastern EU Member States perspective

The impacts of scientific research on agricultural productivity growth have been the subject of a voluminous literature (summarised by Alston *et al*., 2000; and more recently in Mogues *et al*., 2012). In essence, changes in agricultural total factor productivity (TFP) are affected by a range of factors, including (both public and private) investment in agricultural research. However, in the particular context of the agricultural sector, composed of large numbers of small farm businesses with heterogeneous agro-climatic and structural factors influencing production, the full effect of science-derived innovation occurs some years after it is originally introduced. To account fully for this effect, and to control for other influences on productivity such as the weather, a knowledge stock approach is generally used. This assumes that in any particular period the effect of research can be represented by a weighted sum of previous research expenditures (also taking into account spill-overs from research conducted internationally, or embodied in imported inputs). For statistical efficiency, these historically-weighted effects are assumed to have a weighting pattern that follows a smooth curved function, and then econometric judgment is used to determine the shape and length that provides the best fit to the data. Further decomposition of the results allows calculation of the Internal Rate of Return (IRR) on research expenditures.[2]

In general terms, such studies confirm that lags between expenditure and their effects on productivity are lengthy: in the USA case, a minimum of 35 years rising to 50 years, with peak effects in year 24 (Alston *et al*., 2010). While rates of return vary considerably, Mogues *et al*. (2012, p.41) found that “Comprehensive meta-analyses spanning the second half of the 20th century show that the majority of estimates of internal rates of return … to investments in agricultural research are greater than 20 per cent, and a substantial 40 per cent of estimates find an IRR greater than 60 per cent”.

Such studies require data series that extend over several decades, whereas – as noted above – in Europe as a whole and for many EU Member States, availability of data is intermittent and is also potentially unreliable. A further difficulty is that (especially over the last three decades) much research expenditure has been devoted to ameliorating the adverse environmental impacts of farming, which has tended to offset productivity increases.

Hence there have been few attempts to measure the impact of European agricultural research on productivity and, unsurprisingly, no analysis has yet been undertaken for the EU as a whole. Five studies in individual European countries of this type can be identified: for Italy, Esposti and Pierani (2003); for the United Kingdom, Thirtle *et al*. (2004), Piesse and Thirtle (2010); and for France, Butault *et al*. (2015); the report of Ratinger and Kristkova (2015) on the Czech Republic is the sole national study from the Eastern EU. These estimate national internal rates of return to be between 14 and 32 per cent.

Impresa conducted two studies to quantify the aggregate impact of European agricultural research. The first analysis addressed the impact of public expenditure solely on productivity. Vollaro *et al*. (2016) addressed the difficulty of insufficiently lengthy data series through use of a panel-data econometric approach, combining 16 countries over a number of time periods. However, this required countries to have sufficient standardised expenditure data and thus excluded any of the Eastern EU Member States. Expenditure data were based on government budget predictions, with production and input measures drawn from FAOSTAT. Two specifications were deployed, with production and TFP as dependent variables. In general terms, the results confirm the substantial contribution of European agricultural research to productivity increases, with a time lag of between 9-18 years and a Marginal Internal Rate of Return (MIRR) estimated at 7-15 per cent over the period 1980-2010. The MIRR is an average indication of impacts of agricultural research indicating that, because of differences in the volume and scope of their agricultural research activities, returns could be higher or lower in individual countries.

To account for the multiple effects of research, the second analysis (Bartolini *et al*., 2016) used a structural equation modelling approach to characterise causal links based on impact pathway analysis. The causal chain involved relationships between inputs of public and private research expenditure, via a number of outputs and outcomes, to impacts on renewable energy production, health, rural incomes and unemployment, as well as on productivity. Again, a selection of 14 countries was made, none of which was an Eastern EU Member State. The results showed that government-funded and private agricultural research expenditures affect competitiveness, environment and social welfare through different pathways, although the strength of influence of government expenditure is greater than that of business enterprise investment. The latter mainly contributes to added value increase, whereas the pathways of the former are more complex, and mainly support improvements in rural quality of life. The transmission of social welfare effects depends strongly on the type of research and the institutional environment in which it is performed.

Since none of these results were based on observations from Eastern EU Member States, none of these can be safely be inferred to apply to them. This neglect partly reflects the adverse bias noted in the introduction to this article, but there is a deeper concern with respect to the structural break involved in the transition from centrally-planned to market economies that began early in the 1990s. As Ratinger and Kristkova (2015) observe, in common with other formerly centrally-planned economies, the Czech Republic experienced a severe reduction in agricultural output, inflows of foreign capital and technology, and restructuring of land ownership in the years following 1989. Their approach involved using employment data as a proxy for expenditure prior to transition and correcting for the shakeout of non-scientific personnel working in research prior to transition. This

[2] Technically, the IRR is the rate of interest that “when used to discount all cash flows resulting from an investment, will equate the present value of the cash receipts to the present value of the cash outlays” (Drury, 2008, p.298).

provided 38 years of data, a relatively short period compared to previously-conducted studies. They used an error correction model to deal with cointegration in the time series. On that basis, and using 15-year gamma distribution lag to estimate the change in knowledge stocks, they estimated an average IRR of 40 per cent; when foreign R&D spillovers are taken into account, the average they calculated fell to just over 30 per cent.

The changing nature of agricultural research infrastructures before and after transition is a dramatic illustration of a more deep-seated problem in quantitative estimation of the relationship between research and its impacts. The Eastern EU case shows that research expenditures only serve as approximations for scientific effort. Consequently, when measured over very long time frames, they might be quite unstable, due to structural changes such as transition, but also substantial shifts in the technology of science (for example, as affected by information technologies), the entry of multinationals into domains that were traditionally publicly financed, and the diminishing proportion of overall research spending that addresses productivity enhancement. All could lead to underestimation of the elasticity of productivity with respect to research expenditure.

It is highly likely that (in Eastern EU Member States as elsewhere) time lags between expenditure and impact on productivity are long, and rates of return to public research are substantial. The unsatisfying conclusion, though, is that it is very difficult to measure these effects, but without such simple numerical arguments it is more difficult to convince policymakers of the value of investing public resources in this way.

Towards a European agricultural science impact strategy

The results described in the previous section were combined with others from elsewhere in the EU to develop an overall perspective on agricultural science impact and to draw general conclusions and recommendations for research practice and policy (for a summary, see Impresa, 2016). These reflect the continuing importance of agricultural science, in the face of the so-called 'agricultural trilemma' (Steinbuks and Hertel, 2016). Research investment is fundamental to alleviating the tricky trade-offs between the concurrent challenges of achieving food security for a growing global population, adapting to climate change, and reducing natural resource degradation. Because of significant market and coordination failures in the agricultural sector, the state needs to play a leading role in this science; the failures include, but are not limited to, the imperfect competition characterising industries both upstream and downstream of farming in the agri-food value chain, which exerts a cost-price squeeze and reduces resources for investment; the public good nature of research and the free-rider problems that it involves; and the positive external environmental benefits which are achieved from improved agricultural practices.

So despite caveats that need to be made on very high rates of return to investment in agricultural science, these denote in a practical way the substantial social benefit that expenditure brings. Disturbingly though, in Eastern Member States as elsewhere in the EU, trends in expenditure are declining, despite a doubling of the relevant agricultural science budget in the Horizon 2020 programme. While overall research spending is growing (from which agricultural science also gains) in a few Eastern EU Member States, this is from a low base, and even here the catch-up process to equal the spending levels of the larger EU Member States will be protracted. Hence, problems that can be resolved through applied science are increasing, while resources available are declining, or at best at a standstill.

Impresa's main evidence-based recommendations to address the need to improve impact efficiency can be clustered into two separate themes. These are associated with, respectively, improvement of understanding of the scale and scope of agricultural research activity in Europe, and by inference, development of policy frameworks that improve the impact of that activity.

The first set of recommendations relate to gaining better quality information about scale and scope of agricultural science in Europe. This should start with, but not be limited to, enriched information about public and private investment spending. However, there are limits on how much additional burden can be placed on Member States' collection of statistics and their onward transmission to Eurostat, particularly because of the current policy of reducing administrative burdens on the private sector (EC, 2012). However, as the Impresa project has demonstrated, it is possible to obtain, quickly and cheaply, less formal information which is sufficient for most policy impact evaluation and review purposes. Supplementing the official sources of statistics might be achieved either through an annual survey of public research organisations or from an annual report on research investments based on a survey of the Ministries responsible for research in Member States. The former has the advantage that a small number of the largest organisations in the Government and Higher Education sectors perform a large proportion of agricultural research. Using the principle of least effort, close monitoring of expenditure trends and other key agricultural R&D indicators, such as human resources, is possible. The latter could include a qualitative assessment of recent trends in research expenditures, financing, and human resources, complemented by a commentary on how these developments affect future agricultural research activity. Either would provide a 'light touch' approach to provide essential information for monitoring research topics and priorities, while at the same time producing a consistent overview of EU investments in agricultural research.

The second set of recommendations stems from the need for improved awareness of the complex pathways through which science-based innovations are translated into impacts. The AKIS, in many respects, is more complex in comparison to other sectors characterised in the innovation literature; translation of science-based innovation into scaled-out impacts depends on enabling factors being present and on hindering factors being overcome. Specific and relevant outputs are necessary but not sufficient; there is also a need to support development of actors' innovation capacities, and promote users' ability to adapt innovations to specific contexts. This needs more effective capacity building and networking between agricultural scientists and other actors and stakeholders; wider engagement of stakeholders in research programming and evaluation, as well as encouragement of feedback from public and private advisors; and targeting funds for innovation brokerage. More integration between research and innovation support instruments (in particular with EU Structural Funds and the Rural Development Programmes) would release resources to fund this.

In developing the case study impact evaluation approach, the Impresa project team experienced considerable difficulty in obtaining data about research programmes after they were completed. Funders need to require, and research institutions need to develop, effective information based on a standardised structured framework,[3] particularly for projects involving private companies. Acquiring these at early stage to monitor research outputs is a priority.

Impact where it is most needed: the Eastern EU Member States

The recommendations of the previous section are of especial importance to the Eastern EU Member States, whose agri-food sectors differ from those of their counterparts in three main ways. They differ in terms of the type of outputs that are produced. In broad agro-climatic terms (Bouma, 2005), the conditions for plant and animal production are influenced by cold, relatively wet winters and mild, dry summers in the North-east zone, and the cold relatively dry winters and warm dry to occasionally wet summers in the Central zone. Within these zones local production conditions are also influenced by variation in soil types (Tóth *et al*., 2013), so that there are higher shares of grains in output than in the Western EU Member States, and correspondingly lower shares of fruit and vegetable produce, vines and livestock products. They differ in the way in which outputs are produced, in terms of landholding and infrastructures. While rapid re-establishment of a family farming system was expected to occur as a result of transition, de-collectivisation of agriculture produced a structure of farm holdings that is quite distinct from those in the west of Europe (Maurel, 2015) and perverse distributional effects resulting in from the adoption CAP payments after EU accession (Swain, 2013). They also differ in the more important role that agricultural and related food chain activities play in terms of income and employment, even after nearly two decades of economic transition. The legacy of central planning is still evident and, as a consequence, the main lessons of the Impresa project will be harder to implement.

In contrast, the majority of agricultural science research effort (in France, Germany and the United Kingdom) is initiated, and applied, in conditions that are quite different to those existing in the Eastern EU Member States. While the main preoccupation may be to maintain and enhance the aggregate impact of agricultural research in the EU, this major spatial imbalance should not be ignored. Nevertheless, the options available collectively to Eastern EU Member State governments for better targeting of overall EU agricultural research effort are limited.

To avoid the so-called ‘Periphery Paradox’ which suggests that prioritisation of innovation policy is not accompanied by related policy capacity or policy effectiveness (Kattel and Primi, 2012), pressures to downgrade agricultural science budgets should be resisted; the activities these fund should also become more effective. To address the first point, further investigations of the social value of agricultural research, similar to that of Ratinger and Kristkover (2015), are needed. With regard to the second point, a significant contribution could be by a shift of focus suggested in the previous section, instituting a ‘culture of impact’ in national research institutions, practices and policies. That requires recognition of the need to support capacity development that allows the key players to function effectively, and to establish resources within programmes to develop the soft factors that support innovation. Further, improvements could arise from coordinating their national programmes and projects to focus on activities tailored to their specific agro-climatic context, avoiding overlaps and mismatches. Finally, political collaboration, led through the activities of the Visegrad Group, is needed to secure a greater share of European research and development funds. The role of agricultural development in completing the economic transition process should not be neglected, particularly as climate change, food price volatility and agro-environmental quality are also of proportionately higher priorities for the Eastern EU Member States.

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[3] For instance, see Commission Recommendation C(2012) 4890 final on access to and preservation of scientific information.

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