ELSEVIER

Agricultural Economics 21 (1999) 1–18

AGRICULTURAL
ECONOMICS

The organization of agricultural research in western developed countries

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Received 24 June 1998; received in revised form 1 February 1999; accepted 19 March 1999

Abstract

This paper reviews agricultural research structural and organizational changes in western developed countries, examines new financing prospects for agricultural research, and provides some tentative conclusions about which organizations are best positioned to provide services for the twenty-first century. Given that these countries face many similar economic, political, scientific, and agroclimatic factors and fiscal issues, we can expect a set of similar new developments that have potentially important and widespread long-run implications. After three common developments are outlined, principles of impure public good financing are applied leading to the following agricultural science policy recommendations: (i) new political jurisdictions should be formed to finance research, e.g. new alliances across countries and subregions within large countries; (ii) intellectual property rights should be strengthened to increase the total amount and share of total (public and private) agricultural research that is privately financed and conducted, i.e. the private sector should find it profitable to undertake a large share of applied research but not be expected to finance public-sector agricultural research; and (iii) the public sector should redirect its research efforts increasingly to areas that are socially worthwhile, but not privately undertaken, e.g. in the basic and pretechnology areas, on environmental, resources, food safety and human nutrition, and policy. Finally, large countries that have developed a system of shared public and private financing and performance and decentralized public support of agricultural research seem best positioned for meeting the needs of the twenty-first century. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Agricultural science policy; Research funding; Agricultural research; Developed countries; Impure public goods; Optimal decentralization; Alliances; Intellectual property rights; New developments

1. Introduction

Agricultural research has been shown to be a socially productive activity and public agricultural research has been shown to have generally high social rates of return (Evenson, forthcoming). In western developed countries, agricultural research, both financing and performing, is an activity shared by the public and private sectors. In particular, organized public agricultural research has been in place for a relatively long time in these countries, but the organization and funding situation is not the same across all of them. In almost all of these countries, a crushing national debt has caused implementation of national government fiscal austerity, which means growing

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PII: S0169-5150(99)00014-6

competition for uses of scarce public funds. These countries also face rapid scientific advances in biotechnology, reduced price supports and trade barriers, and declining enrollments in colleges of agriculture. This means that agriculture is facing significant structural adjustment (OECD, 1995). These are major reasons why western developed countries have undertaken a review of the funding and organization of agricultural research.

The objective of this paper is to review agricultural-research structural and organizational changes in western developed countries, to examine new financing prospects for agricultural research, and to provide some tentative conclusions about which organizations seem to be better positioned to provide services for the twenty-first century. Since western developed countries have similar political–economic systems, produce similar temperate-zone agricultural commodities, have relatively well-developed public and private agricultural-research sectors, and are relatively open to trade, we suggest that large national debts, advancing frontiers of science, reduced agricultural college enrolments, and reduced trade barriers can be expected to lead to a set of new developments that have potentially important and widespread long-run implications. This paper builds upon recent assessments of agricultural research policies by Huffman and Just (1994) Huffman and Just (1999); Alston et al. (1998); Byerlee and Alex, 1998. The story unfolds in Sections 2–4.

2. Agricultural research in western developed countries

In western developed countries, the development and organization of agricultural research has been conditioned by political, economic, resource-environmental, and scientific conditions.

2.1. Background on the countries

The particular western developed countries that are the focus of this paper are the two developed North American countries—the United States and Canada, fifteen European Union (EU) countries—Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom; and the non-EU country of Switzerland. These 18 countries had a weighted average annual per capita gross domestic product (ppp measure) in 1992 of US$ 19 500, ranging from a high of US$ 23 220 for the United States to a low of c. US$ 9000 for Greece and Portugal (World Resources Institute, 1997). For these countries, the 18-country average share of the agricultural sector in gross domestic product was 2.4% in 1993. The only countries whose agricultural share deviated by a large margin are Portugal (15%) and Greece (21%). The share of the labor force employed in agriculture is also low with an 18-country average in 1995 of 4.8%. Countries within this set that have unusually large agricultural labor force shares are Spain (12%), Ireland (14%), Portugal (18%), and Greece (23%). These 18 countries spend a significant amount on agricultural research relative to gross domestic product produced in agriculture, an average of about 2% in 1993. These countries have a well-developed public and private agricultural research system, and the performance of agricultural research is split about equally between the public and private sectors (Alston et al., 1998).

The size of agriculture and public agricultural research expenditures differs greatly across the 18 countries. The U.S. has 420 million hectares of agricultural land in 1993 (Table 1), and the other 17 countries have only 216 million ha. The largest of the other 17 are Canada (73 million ha), and France and Spain (ca. 30 million ha). Nine of the countries have <5 million ha (Netherlands, Sweden, Norway, Finland, Denmark, Portugal, Switzerland, Belgium, and Austria). The eight largest public agricultural research systems ranked by (ppp) research expenditures in 1993 were: the U.S., France, Canada, United Kingdom, Germany, Italy, Netherlands, and Spain (see Table 1). The ranking has changed some over time; in 1971, Canada was second, Germany third, France fourth, the U.K. fifth, and the Netherlands sixth. The size of the public agricultural research system in the other ten countries is significantly smaller. Among the eight largest national agricultural research systems, the French, Italian, Dutch, and U.K. systems are highly centralized in financing and administering of public agricultural research, and the U.S. and German systems are most decentralized. Because of the small size of the smallest ten national systems,

Table 1
The size of national agricultural research systems of 18 western developed countries and U.S. State Agricultural Experiment Stations: based on 1993 Public Agricultural Research Expenditures

I. National Systems:

countries	expenditures (mil 1985 ppp dollars)	land area[a] (mil ha)	countries	expenditures (mil 1985 ppp dollars)	land area (mil ha)
United States	2054.3	419.5	Sweden	138.3	3.4
France	503.5	30.2	Norway	105.3	1.0
Canada	466.4	73.3	Finland	64.2	2.7
United Kingdom	370.8	17.2	Denmark	59.6	2.7
Italy	360.6	16.2	Portugal	59.4	4.0
Germany [b]	332.8	12.7	Switzerland	50.2	1.6
Netherlands	226.7	2.0	Belgium	36.2	1.5
Spain	214.2	30.0	Greece	31.5	8.7
			Ireland	27.9	5.6
			Austria	27.5	3.5

II. U.S. State Agricultural Experiment Stations ($ mil 1985):

Group I (>US$ 54.3)	Group II (US$ 40.1–54.3)	Group III (US$ 26.2–40.2)		Group IV (US$ 12.2–26.2)		Group V (<US$ 12.2)	
California	Wisconsin	Nebraska	Arizona	Missouri	Kentucky	Montana	Nevada
Texas	N. Carolina	Indiana	Louisiana	Alabama	Tennessee	S. Dakota	Vermont
Florida	Michigan	Georgia	Illinois	Arkansas	New Jersey	New Mexico	Wyoming
New York	Iowa	Virginia	Ohio	Colorado	Hawaii	Maine	Alaska
	Minnesota	Oregon	Pennsylvania	S. Carolina	Maryland	Massachusetts	New Hampshire
		Kansas	Washington	Oklahoma	Idaho	Delaware	Rhode Island
			Mississippi	N. Dakota	Connecticut	W. Virginia	
					Utah		

[a] Area in arable land, permanent crops, and permanent pasture.
[b] Only for West Germany.
Source: Pardey, Roseboom, and Craig (for national public agricultural research expenditures), FAO 1994 (for farm land data). USDA 1994 (for expenditure and ranking of U.S. state agricultural experiment stations).

Table 2
Indicators of public agricultural research intensity of agriculture in western developed countries: 1971, 1981, amf 1993

Countries/regions	Real expenditures (1985) ppp dollars) per ha of cropland [a]			Public research expenditures per value added in agriculture (%)	
	1971	1981	1993	1973–1978	1986–1993
	(1)	(2)	(3)	(4)	(5)
Western Europe					
Austria	11.72	13.96	18.36	0.4	0.6
Belgium	34.58	57.07	45.59	1.4	1.6
Denmark	13.22	14.45	23.47	0.9	1.5
Finland	8.70	15.39	24.88	1.4	2.2
France	15.94	21.67	25.90	0.9	1.6
Germany [b]	38.16	40.06	44.87	1.0	1.7
Greece	6.06	12.40	9.02	0.4	0.4
Ireland	26.24	30.96	30.23	1.1	0.8
Italy	5.50	15.15	30.40	0.2	0.5
Netherlands	158.84	246.76	242.72	1.9	1.0
Norway	40.69	70.05	118.31	2.5	4.8
Portugal	7.61	9.35	18.80	–	1.2
Spain	2.41	4.81	10.90	0.3	0.5
Sweden	18.91	27.40	49.75	1.4	2.4
Switzerland	89.35	89.05	107.49	1.1	0.9
United Kingdom	37.99	53.14	60.52	2.3	3.0
Subgroup	16.24	23.01	30.85	—	—
North America					
Canada	8.10	9.81	10.27	3.0	5.6
United States	6.50	8.50	10.94	0.8	1.3
Subgroup	6.80	8.75	10.81	–	–
18 countries	9.41	12.59	16.14		

[a] Arable land and land in perennial crops (trees, vines, etc.).
[b] In columns (1)–(3) only (West) Germany; but in columns (4) and (5), (West) Germany through 1990 and unified Germany for 1991.
Source: Columns (1)–(3): public research expenditures are from Table 1 and land use from FAO data (FAO, 1977, 1992, 1994). Columns (4) and (5): OECD 1995, p. 28.

they also tend to be quite centralized in the financing and administration of public agricultural research.

The intensity of public agricultural research differs across the 18 countries, but the differences seem small when intensity is measured relative to the value of agricultural production rather than per unit of farm land (see Table 2). Using share-of-production intensity, Canada, Norway, and the U.K. stand out as having high research intensities (>3% in 1993). Greece, Italy, Austria, Spain, Ireland, and Switzerland spend very little by this standard (<0.9%), but the U.S. also ranks low at 10th among the 18 countries (with 1.3% in 1993). When research intensity is measured as expenditures per unit of farmland, the Netherlands ranks at the top by a large margin (US$ 243 per ha, in 1985 prices), and it spends more than twice as much as the second biggest spenders, Norway (US$ 118 per ha) and Switzerland (US$ 107 per ha). The median expenditure for these 18 countries is US$ 30 per ha in 1993. Greece, Spain, Canada, and the U.S. are ranked at the bottom, spending only US$ 9–11 per ha in 1993.

2.2. *The structure and organization of agricultural research*

In all countries, the national government finances and conducts agricultural research. Since 1984, the EU has also financed a small amount of joint or cooperative research in member countries, but it does not operate any institutions for conducting research. In the U.S. in 1995, the federal government financed 56.7% of public agricultural research (for USDA research agencies, non-land grant institutions receiving USDA contracts and cooperative agreements, and state agricultural experiment stations (SAES) and other affiliated state institutions; see USDA, 1996). The U.S. Department of Agriculture conducts research, both at centralized facilities in the Washington, D.C. area and >150 research institutions scattered across the country. The agricultural research system organized under the 50-state land-grant universities is much larger than the research system of the USDA. The USDA research agencies spend about one-third and the state land-grant system spends about two-thirds of the total public agricultural research dollars.

The extent of regional, state, or provincial government financing differs greatly between North America and Western Europe. In North America, state or provincial governments have significant taxing powers and are significant financiers of public agricultural research. In the U.S. in 1995, the fifty state governments financed about 32% of total public agricultural research which are allocated as institutional grants to state agricultural experiment stations and other affiliated institutions, whereas the private sector accounted for a small share of the funding of public agricultural research (ca. 13%).

In Canada, public agricultural research has been largely funded by the federal government (about two-thirds), and the provincial governments provide a smaller amount (about one-third) of the funding (McEwen and Milligan, 1994; Carew, 1998). The private sector has historically not undertaken much research or contributed significantly to financing agricultural research in public institutions. The performance of public agricultural research is primarily by the federal government in 18 agri-food research centers (or experiment stations). The National Research Council (NRC) also conducts biotechnology research related to cereals, oilseeds, and legumes in western Canada, e.g. NRC—with funds provided by federal, provincial, and industry collaborators—focuses on enhancing value-added benefits to agri-food production. The provinces of Alberta, Ontario, and Quebec also conduct agricultural research. These three provinces plus British Columbia, Saskatchewan, Manitoba, and Nova Scotia support agricultural research at their provincial universities (Guitard, 1985; Carew, 1998). Agricultural experiment stations, both provincial and federal, have tended to be administratively separate from agricultural colleges and university facilities even when they are located at a university.

In Europe, excluding Germany, the taxing power resides with national governments, and for the most part regional, state, or provincial governments have limited taxing power. The EU also collects revenues in three major parts: a tax on each member country's value-added, a tax on each member country's gross national product, and EU custom duties and levies against non-member countries (European Commission, 1996). A small share of these revenues is allocated to cooperative research requiring joint participation by institutions in two or more member countries. In 1993, 3.4% of EU expenditures were allocated to research of all types. The institutions that participate in these competitively awarded research funds are primarily private companies, public and private research centers, and higher education institutes (Geuna, 1996, 1998).

In France, most public funds for agricultural research come from the national government, and a small amount comes from ca. 22 regional governments. All public agricultural research is planned and administered in two national institutes—INRA (agriculture) and CEMAGREF (machinery)—which do not have close links with the universities. In the national institutes, the national government funds scientists' salaries and part of the cost of experimentation. In INRA, the funds for experimentation come partly from systematic/program funding and partly from competitive sources. The Central National Scientific Research Institute funds research in biotechnology and other general science areas. The private sector provides some of the current expense cost of experimentation through public–private partnerships (Lemarie, 1998).

In Italy, public agricultural research is financed primarily by the central government through the National Research Council, the Ministry of Agriculture, the Ministry of Research and Universities, and the Ministry of Industry and Trade. Regional governments play a secondary role, but a recent referendum has transferred public agricultural matters from the Ministry of Agriculture to the twenty regional governments (Santanello, 1998). In Italy, there is virtually no private sector funding of research in public institutions.

In the United Kingdom, the national government through the Ministry of Agriculture, the Biotechnology and Biological Science Research Institute (BBSRI), and the Higher Education Institutes (HEIs) provides most of the public funding of agricultural research. Provincial governments in Scotland, Wales, and Northern Ireland provide a small amount (Thirtle et al., 1997). The eight regional governments of England, however, provide no funds. In 1993–1994, the U.K. government provided ca. 77% of the funding for public agricultural research institutions (Thirtle et al., 1997). The provincial governments provided another 17%, and the private sector provided ca. 5%.[1] Public agricultural research is performed primarily in national institutes and laboratories that are not directly connected with universities. Scotland's quasi-independent agricultural research institute and state public funds provided to the Scottish Agricultural Colleges and Queens University, respectively, are exceptions.

In the Netherlands, all public funding of agricultural research is by the national government, and public agricultural research is performed in national institutes, experiment stations, and Wageningen Agricultural University. The Dutch Ministry of Agriculture, Nature Management, and Fisheries is currently responsible for agricultural research, extension, and education. During 1972–1981, the National Agricultural Research Council also played a major role in policy formulation and coordination. During this period considerable duplication of planning efforts existed, but in 1981, the Directorate of Agricultural Research in the Ministry took charge (Roseboom and Ruttan, 1998). Since 1995, agricultural research policy formation has been assigned to the Directorate of Science and Knowledge Transfer within the Ministry. This Directorate funds or purchases research primarily at the National Agricultural Research Department, the Organization for Applied Research in Agriculture (largely, nine experiment stations), and Wageningen Agricultural University. With the creation of the Directorate of Science and Knowledge Transfer, the Ministry adopted a unified agricultural knowledge system covering agricultural research, extension, and education (Roseboom and Ruttan, 1998). Beginning in 1997, these institutions were integrated under the Knowledge Center at Wageningen (now named Wageningen University and Research Center).

In 1986, the Dutch government made a decision to dramatically increase private sector involvement in agricultural research and extension. The private sector is entering into partnerships with the public agricultural research institutes and is providing either regular or contract research funds. In Spain, the national government is the source of most public funds for agricultural research, and the 17 state (autonomia) governments have very limited taxing power. In 1993, the central government provided 61% of the funds for public agricultural research and state governments provided 34%. The private sector is not involved significantly in the financing of public agricultural research, accounting for only 1.4% of funds for public agricultural research in 1993 (Alfranca, 1998). The Spanish Ministry of Agriculture is the primary institution for conducting public agricultural research, but a few state governments are developing their own research institutes.

Germany provides a major exception to other Western European approaches to financing and organizing agricultural research. The financing of public agricultural research is ca. 50% by the national government and 50% by 16 state (or Laender) governments. Very little funding of public agricultural research is obtained from the private sector. Also, agricultural research is conducted in national (federal) agricultural research institutes and in university institutes that are under Laender/states authority. In Germany, agricultural research in federal institutes is federally funded and in Laender/state institutes is co-financed by the federal and respective Laender governments. A large share of the public funds are allocated directly to the universities and research institutes as institutional funding. The federal government also contributes to a system of research grants that are allocated in a competitive process to scientists, some of which go to agricultural research (Tangermann, 1998).

2.3. *New developments in agricultural research policies*

Three new developments in agricultural research policies of western developed countries are notable and important.

[1]Some public funds are allocated to support research in the private sector.

2.3.1. *Development 1: The rate of growth of public agricultural research expenditures has been reduced significantly*

During 1971–1981, the annual (compound) average growth rate of real agricultural research expenditures for these 18 western developed countries was a relatively large 2.9%, 3.2% for the Western European countries and 2.6% for the North American countries (Table 3). For all of the countries except Germany, the growth rate was positive. During 1981–1993, the growth rate for public agricultural research expenditures, however, was significantly lower by about one percentage point—1.9% for all 18 countries, 2.2% for the Western European countries, and 1.6% for the North American countries. During this latter period, three countries (Belgium, Greece, and Ireland) had negative growth in agricultural research expenditure, the U.K. had no net growth, and Canada had an average growth rate of only 0.26%. Over the two combined periods, Germany has almost no net growth in public agricultural research expenditures.

The funding problems in Germany arise from the federal government and state governments, all reducing funding significantly because of budget deficits or fiscal problems mainly associated with the unification of Germany. At the Laender level, the reductions are also related to a significant decrease in the number of students in schools of agriculture, and the tendency for state governments to cut resources for research in parallel with the reduction in student numbers (Tangermann, 1998).

2.3.2. *Development 2: Traditional national (or central) government funding sources for agricultural research are reducing systematic funding, including formula or program funding, and increasingly emphasizing centrally controlled competitive grant programs*

This new direction is especially apparent in the United Kingdom and less in the United States and Germany. During 1972–1982, most of the U.K. public agricultural research funds were allocated non-competitively by the Ministry of Agriculture, Food, and Fisheries on a program basis (Thirtle et al., 1997). The latest major redirection of U.K. public agricultural research started in 1982. As a result, some applied research institutions were sold to the private sector, e.g. the National Seed Development Organization, the Liscombe Experimental Husbandry Farm, and part of the Plant Breeding Institute. The national government cut ear-marked or program funding for institutes and laboratories that were engaged in 'near market' and 'agricultural productivity enhancing' research and increased funding for the Higher Education Institutes (HEI) and the Biotechnology and Biological Science Research Institute (BBSRI). The latter two institutes primarily operate competitive grants programs in 'basic science' and in 'public-interest' research focused on food safety and environmental issues. Scientists from a broad set of institutions are eligible to bid on HEI and BBSRI projects. In 1993–1994, competitive grant funds for agricultural research increased to 20% of public funds allocated to agricultural research (but 80% continue to be allocated as program funds or block grants to agricultural research institutions). (See Thirtle et al., 1997.)

In the U.S., the composition of the 'regular federal' funding (i.e. Cooperative States Research Service, CSRS, or Cooperative States Research, Education, and Extension Service, CSREES) and mechanism for allocating federal funds to the state agricultural experiment station system (and other cooperating state institutions) have changed.[2] In 1887, when the SAES system was first given formal national government funding by passage of the Hatch Act, ≈82% of the funding for the SAES system were from regular federal funds. This share trended downward to 65% in 1900, 22% in 1960, and 14% in 1990 but were larger in 1995 (15%).

The exact mechanism for distributing 'regular federal' funds has changed over time (Huffman and Evenson, 1993, pp. 21–23; Alston and Pardey, 1996, Chap. 2; Committee on the Future of the Colleges of Agriculture in the Land Grant University System, 1995). Historically, a legislated formula for allocating federal appropriations to the SAES system has been central to national government funding of public agricultural research. Initially, every state received an equal-sized national government appropriation, but over the period 1935–1955, the formula was modified to also depend on a state's share of total U.S. farm population and total U.S. rural people. After

[2] In the U.S. and Canada, agricultural science policy developed long before general science policy, and it has continued to be separate.

Table 3
Expenditures on Public Agricultural Research and Rate of Growth (constant 1993 ppp): Western Developed Countries, 1971, 1981, 1993

Countries/region	Level (US$ mil)			Rate of growth (%)	
	1971	1981	1993	1971–1981	1981–1993
Western Europe					
Austria	19.7	23.0	27.5	1.55	1.49
Belgium	31.4	47.2	36.2	4.08	−2.21
Denmark	35.2	38.3	59.6	0.84	3.69
Finland	23.2	39.1	64.2	5.22	4.13
France	298.0	410.0	503.5	3.19	1.71
Germany [a]	308.6	299.8	332.8	−0.29	0.87
Greece	23.7	49.0	31.5	7.26	−3.68
Ireland	29.7	33.9	27.9	1.32	−1.62
Italy	68.3	188.2	360.6	10.14	5.42
Netherlands	134.7	202.1	226.7	4.06	0.96
Norway	32.8	58.0	105.3	5.70	4.97
Portugal	28.3	29.4	59.4	0.38	5.86
Spain	51.0	98.6	214.2	6.59	6.47
Sweden	57.7	81.1	138.3	3.40	4.45
Swiss	34.4	36.6	50.2	0.62	2.63
United Kingdom	274.5	371.0	370.8	3.01	−0.00
Subtotal	1451.2	2005.3	2608.7	3.23	2.19
North America					
Canada	354.7	452.3	466.4	2.43	0.26
United States	1,235.6	1,620.4	2,054.3	2.71	1.98
Subtotal	1,590.3	2,072.7	2,520.7	2.65	1.63
Total 18 countries	3,041.5	4,078.0	5,129.4	2.93	1.91

[a] Only for (West) Germany.
Source: Pardey, Roseboom, and Craig, 1998.

strong encouragement from the National Research Council, the USDA initiated a Competitive Grants Programs in 1977. Its funding increased substantially, beginning with the National Research Initiative (NRI) in 1986. The NRI competition is open to all public and private researchers.

In 1900, virtually all of the 64% of SAES funding from the national government came in the form of USDA formula/program funds (Huffman and Evenson, 1993). While the national formula funded share of SAES federal revenue fell to 56% in 1980 and 32% in 1996 (USDA, 1996), the share of regular-federal funds distributed by competitive grants increased from 0% in 1980 to 8.6% in 1990 and 16.6% in 1996 (Huffman and Evenson, 1993; Huffman and Just, 1999). Hence, 'regular federal' funds for agricultural research are being allocated increasingly by competitive grants and less by formula or block grants to states.

In Germany, the change in funding of public agricultural research toward more competitive funding was not the result of a direct but rather by indirect policy. With a gradual reduction of institutional financed public agricultural research, researchers have increasingly turned elsewhere for funding, especially to competitive sources for possible funds, e.g. the German Research Association which funds a broad range of research.

2.3.3. Development 3: Public agricultural research scientists are being encouraged to pursue non-traditional sources of funding, such as outside departments or ministers of agriculture in national governments and private corporations and producer (commodity or cooperative) groups

The trend is strongest in the United Kingdom, the U.S., France, the Netherlands, and Canada. In the

United Kingdom, the recent redirection of agricultural research funds away from the Ministry of Agriculture, Food, and Fisheries to the Higher Education Institutes (HEI) and establishment of new statutory bodies (commodity groups) to fund agricultural research represents a new emphasis on non-traditional agricultural research funding (Smith, 1996; Thirtle et al., 1997). In 1993–1994, the HEI funds represented 15% of expenditures on U.K. public agricultural research, which was considerably larger than the 5.5% share in 1987–1988.

In the U.S., at both the state and federal level, non-traditional sources of resources and technology transfer have been developed recently. Over the past two decades, SAES scientists in the U.S. have turned increasingly to 'non-regular federal' and private sector sources. In 1960, the share of SAES system funding coming from non-traditional federal government sources was 5.7%, and it has increased to 12% in 1970, (1980, 1990), and then to 15% in 1996 (see Huffman and Just, 1999). These funds were distributed by the USDA in contracts and cooperative agreements and by the National Institutes of Health, the U.S. Agency for International Development, the National Science Foundation, the U.S. Department of Health and Human Services, the Public Health Service, and other agencies primarily by competitive grants.

During the past decade, U.S. federal laboratories have increased the amount of collaborative research with the private sector. The 1986 Technology Transfer Act established a mechanism, a CRADA, through which federal and non-federal researchers could collaborate (Fuglie et al., 1996, p. 55). This legislation permits federal laboratories to enter into CRADAs with universities, private companies, non-federal government entities, etc. The principle objective of a CRADA, however, is to link the pretechnology research capacity of federal laboratories with the commercial research and marketing expertise of the private sector. Under a CRADA, a federal laboratory may provide personnel, equipment, and laboratory privileges. A collaborator with a federal laboratory may contribute funds directly to a federal laboratory and the cooperating institution receives the right of first refusal to any joint discovery and may be given exclusive access to data from a joint project (Fuglie et al., 1996, p. 56). CRADA activity has increased rapidly after 1987, but private sector CRADA resources are <1% of the budget of the Agricultural Research Service of the USDA (Cole, 1998).

In France, the growth of systematic/program funding for research in national institutes has not been fast enough to cover the rising cost of experimentation. Scientists are now encouraged to undertake cooperative or joint venture projects with public (regional governmental) and private sector partners (Lemarie, 1998). In the Netherlands, a large increase has occurred in the number of public—private partnerships for agricultural research, including the private sector investments at Wageningen University and Research Center (Oskam, 1998). In Italy, funding of public agricultural research by the National Research Council, Ministry of Industry and Trade, and Ministry of Research and Universities represent non-traditional sources.

In Canada, since the early 1980s, commodity, producer, processor, and trade associations have been collecting funds for financing agricultural research. These groups include the Canadian Horticultural Council, the Canola Council of Canada, the Brewing and Malting Barley Research Institute, and the Canadian and Western Grains Councils (Guitard, 1985). However, a new agricultural research policy was established in 1994 to encourage the private-sector firms and organizations to fund more research. The new program is the Matching Investment Initiative (MII). Under this program, the federal government matches up to dollar-for-dollar the private sector's contributions to joint research ventures. The federal component of the funding can be less than the private sector's contribution, but it can match both, the cash and in-kind contributions. The MII was implemented by the federal government to offset declines in federal funding for agricultural research. Also, new funds for public research are coming from provincial governments (e.g. Alberta) and commodity check-off programs for wheat, barley, and beef (Carew, 1998).

Although there is clearly increased emphasis on obtaining private sector funding for public agricultural research institutions, the share of the total funds that these research institutions receive from the private sector remains small. Among the western developed countries, the U.S. seems to be the leader in its share of private-sector funding of public agricultural research, 7.5% in 1960, 9.2% in 1980, and 13% in 1996. Private sector funding of research in public institutions raises a number of political-economic issues that do not appear in private-sector funding of its own activities (Huffman and Just, 1999).

3. New Financing Prospects for Agricultural Research

Given the structure and organization of agricultural research and recent developments in agricultural research policy in western developed countries, this section examines new financing prospects for agricultural research. The emphasis is on financing for impure public goods.

3.1. New political institutions and alliances

Some agricultural research produces pure public goods, meaning that innovations are non-rival (being indivisible) and non-excludable (being costly to selectively withhold). For example, the scientific discoveries of hybrid corn by Shull and East in 1907–1908 created a pure (multinational) public good. The use of this techniques is non-rival (e.g. it is not used up) and access to use of the basic idea once it was published is unlimited. Furthermore, because the scientific innovation was an abstract concept and not embodied in any particular product, material, or process, it was not patentable. Because of limited appropriability, the private sector will not finance this type of research or will grossly underfund it (see Huffman and Just, 1999). Hence, the public sector needs to play a major role in the provision of research producing pure public goods.

Much agricultural research, however, produces impure public goods which are partially excludable. Access to benefits of research may have a geographical dimension, (e.g. local, regional, national, or international), usefulness may be limited to particular plant or animal species (i.e. industry-specific), or strong intellectual property rights may be politically, economically, and legally feasible—giving owners sole right to control or license an innovation's use for a fixed period.

Some examples illustrate partial excludability of benefits for scientific innovations. First, consider the public agricultural research at Kansas State University that led to a new hard red winter wheat variety in 1995 that was uniquely adapted to Kansas growing conditions and widely adopted by Kansas farmers in 1996 and 1997. The new variety replaced some acreage of older hard red winter wheat varieties in the surrounding states of Oklahoma, Colorado, and Nebraska, but in other states, the new variety was either not good enough to dislodge older varieties or hard red winter wheat is not grown. Second, Monsanto discovered and patented a Roundup Ready soybean variety. U.S. patent law limits the use of this technology for 20 years by other soybean seed producers and soybean growers, i.e. they must contract with Monsanto for its use. However, because of imperfect information about the demand for Roundup Ready soybean varieties, costly and imperfect enforcement of patent rights, and limited patent life, the benefits of Monsanto's research are only partially excludable to other firms over the long term. These are practical examples of methods by which partial excludability is obtained.

3.1.1. Political and Economic Jurisdictions

Positive externalities or spillovers are common with research and other public goods. When a public good, say a scientific innovation, provides benefits outside the political jurisdiction that finances/provides it, and no compensation is paid by outsiders, positive externalities in the form of spillovers occur. Spillovers occur when the economic jurisdiction crosses political boundaries. For agricultural research (and other public goods), it is important to distinguish between 'political or deciding' and 'economic or benefitting' jurisdictions (Cornes and Sandler, 1996; Olson, 1969, 1986). Serious social inefficiency arises either when an economic jurisdiction is broader than the political jurisdiction (as above) or when the economic jurisdiction is a small subpart of a larger political jurisdiction and provision is by collective action (Olson, 1969, 1986), i.e. a local public good.

As illustrated by the above review, financing and conducting agricultural research can be administered by the same or separate institutions, e.g. can be done 'in-house' or 'contracted out'. With public (or private) financing, research can be undertaken by either public or private enterprises. Mechanisms for allocating research funds among enterprises include competitive grants based on research proposals, research contracts, or formula/block grant allocations.[3] The institutional mechanisms for bringing financial resources and the scientific enterprise together differ between the public and private sectors. However, private firms typically finance and invest in research when they can expect to increase their own profits, especially though the development of new commercial products, materials, and processes. Firms have little incentive to promote the 'public interest.' For example, Zucker and Darby (1997) discuss research adjustments and changes in the pharmaceutical industry resulting from the biotechnology revolution. For research to be potentially profitable for the private sector, innovations must be of a type that can be protected by patents, breeders' rights, or trade secrets. Much agricultural research is not of this type, or if it can be protected by intellectual property rights (IPRs), it yields too low a rate of return for the private sector to be interested in undertaking it. Thus, society will be better off if the public sector correctly identifies and finances agricultural research that produces impure public goods and are not produced by the private sector optimally.

Some believe central planning, financing, and administering of public agricultural research according to national priorities is the most efficient organizational structure for providing public agricultural research. This suggests a unitary national agricultural research system rather than a federalistic one. The principles of fiscal equivalence (Olson, 1969, 1986), however, cast serious doubt on efficiency of a national organizational structure. Under the principle of fiscal equivalence, the efficient provision of public agricultural research is achieved when the geographical location of beneficiaries of public agricultural research (the 'domain') coincides perfectly with the geographical boundaries of the political jurisdiction providing/financing the agricultural research. For example, federal funding of public agricultural research projects in the United States would be efficient only when the boundaries of the benefactors match exactly the whole United States. Such public innovations are appropriately financed by national tax collections. In all other cases, some other political jurisdiction would best be given authority for financing public agricultural research.

[3]See Huffman and Just (1999) for an examination of the efficiency of alternative funding mechanisms.

When public agricultural research produces a pure national public good, financing it by one state/province within the national political jurisdiction is also socially inefficient. In this case, research creates positive economic externalities for producers or residents in other states (when no compensation is paid). When the domain of the public good from research innovations is national or multi-state/province, but the financing is by one subunit without side payments, e.g. a state/province, local public financing will be suboptimal. Thus, only when agricultural research produces innovations that are national public goods, national government provision of agricultural research is socially optimal. This, however, does not necessarily imply that agricultural research should be conducted 'in-house'.

In most 'large' countries, however, great geoclimatic, environmental, and/or resource heterogeneity exist and some locations are much closer to markets than others. Different localities have a comparative advantage, and specialize, in particular agricultural commodities. For example, producers in one area may benefit because their profits and comparative advantage in producing the commodity with new technology is favorably affected, producers in some other areas may see their profits and comparative advantage erode as a result of market impacts, and producers in other areas may be unaffected. For example, the development of hybrid corn has caused corn production in the United States to become more concentrated in the Corn Belt and for states on the 'fringe' of the Corn Belt to lose out (see Griliches, 1957, 1960; Huffman and Evenson, 1993, Chap. 6). Hence, research innovations that are commodity specific will tend to be impure or local public goods. Furthermore, for many but not all of these commodity-specific innovations, the domain or location of beneficiaries is beyond the control of the political and legal system, i.e. they cannot be effectively protected by patents, breeders' rights, or copyrights. In these cases, the exclusion of non-payers is also infeasible. Under these conditions, private provision is socially inefficient, but also public provision by a unitary political jurisdiction, e.g. national government, is also socially inefficient.

Olson (1986) calls this situation an economic 'internality,' because the political jurisdiction is far larger than the exogenous domain of the 'local' public good. Here, the suboptimality arises because the social benefits from providing a local public good of exogenous domain can greatly exceed its cost; but with a unitary national political jurisdiction, the number of losers from national taxes to finance the local public good far exceeds the number of gainers from the innovation. When public expenditures are decided by collective action through direct or indirect representational voting, e.g. majority rule, a majority of the population (and voters) will not be in favor of financing a local public good. Although political logrolling and competitive interest group theories (Niskanew, 1971; Mueller, 1996, pp. 82–84) sometimes permit a more optimistic outcome to national financing of local public goods, the transaction costs and other difficulties of such political outcomes are considerable (Olson, 1986). Thus, when agricultural research produces local public goods, the provision is socially most efficient when the political and economic jurisdictions coincide perfectly and local political jurisdictions provide financing. In large countries, this means that national financing and planning are sub-optimal.

With the principle of fiscal equivalence, boundaries of the political or financing jurisdiction for agricultural innovations should coincide perfectly with the boundaries of the beneficiaries of that agricultural research. This means that the political jurisdictions for financing agricultural research should be formed around the boundaries of the beneficiaries and not driven by traditional political boundaries, e.g. states, nations, and may involve a multi-level and possibly overlapping mosaic of political jurisdictions. Such political jurisdictions might be groups of counties, a state, groups of states, a nation, or even groups of nations.

In particular, with agricultural research innovations providing varying degrees of publicness, the principle of fiscal equivalence implies that subgroups of countries in the EU should form political jurisdictions for financing research that benefits their consumers and producers (but not the producers and consumers of other countries), e.g. one group might consist of Sweden, Norway, and Finland. Another group might consist of Spain, Italy, Greece, and Portugal, and another consist of Denmark, the Netherlands, and Belgium. The EU is the appropriate political jurisdiction for agricultural research that has beneficiaries in all EU countries. The U.S. and Canada seem likely to benefit from the formation of new international political jurisdictions to finance agricultural research providing benefits to both these countries, e.g. on apples, potatoes, cereals.[4] It also seems likely that some types of agricultural research provide benefits across western developed countries, and a new political institution is needed for financing it.

Switzerland is in a unique position of being a non-EU member, but being surrounded by EU members and having a relatively small agricultural sector. This makes cross-country cooperation more difficult, and Switzerland is most likely becoming increasingly a free or easy rider (Cornes and Sandler, 1996) on public agricultural research financed by the EU and EU member countries.

For the countries that are geographically large and agriculturally diverse, e.g. the U.S., Canada, France, U.K., Spain, Germany, and Italy, much of applied agricultural research has local benefits which implies that regional political jurisdictions, such as individual states/provinces, or groups of states/provinces, are the appropriate financing jurisdiction for obtaining efficient funding. Currently, the U.S., Germany, Canada, and Spain have significant state or provincial government funding of public agricultural research, and the 'state' agricultural experiment stations are the primary recipients of these funds (see Table 1 for some size comparisons).[5] Also, in the U.S., part of the federal funds for agricultural research are to be allocated for regional or multistate research. The 1955 Amended Hatch Act requires that 25% of regular federal government appropriations for agricultural research be allocated to regional research, namely research invol-

[4]A pilot research collaborative agreement was signed recently by the USDA, ARS and Agri-Food Canada to undertake R&D of mutual benefit to both countries, focused initially on fusarium head blight in cereals and late blight in potatoes. Also, the Washington State Apple Commission and the Pacific Agri-Food Research Center in British Columbia are cooperating on apple research (Carew, 1998).

[5]For comparison, the state agricultural experiment stations were grouped into five–six classes based on their 1992 research expenditures. All the territorial experiment stations were eliminated, and where a state had more than one experiment station, the expenditures were combined. Because of the skewed size distribution, three SAES size groups were formed for those SAES having larger than system average expenditures in 1993, and two SAES size groups were formed for those SAES having smaller expenditures.

ving the cooperation of SAES scientists in two or more states working on common research issues. This program, however, does not meet perfectly the Olson fiscal equivalence criteria because the political jurisdiction is really the national rather regional governments.

Very little regional government funding of public agricultural research occurs in the U.K., France, and Italy. In these countries, the potential exists for increased efficiency of public agricultural research financing by giving the state/provincial governments a much greater role. Italy, however, seems to be moving in this direction with the recent referendum giving regional governments authority on issues dealing with agriculture (Santanello, 1998).

None of these eight large countries, however, has regional political jurisdictions that effectively span groups of states/provinces for the specific purpose of financing public agricultural research. We suggest that the creation of new regional political jurisdictions having responsibility for financing agricultural research and benefitting their respective residents would be a move toward fiscal equivalence, greater social efficiency of the funding of agricultural research, and increased funding for public agricultural research. Hence, we suggest an optimal pattern of political jurisdictions for financing agricultural research would look like a mosaic of overlapping jurisdictions. It would not be a national government except in small countries.

3.1.2. Clientele and clubs

Some scientific discoveries have beneficiaries that are not defined geographically, and Olson (1986) suggests calling them the 'clientele', and Cornes and Sandler (1996) suggest calling them a 'club.' With public agricultural research funded by collective action, scattered research clientele (or club members) increases greatly the transactions cost of organizing to finance agricultural research, and as the number of members in the clientele group or club grows, the free- or easy-rider problem generally causes the group to lose it power and to become political ineffective (Olson, 1965; Mueller, 1996; Cornes and Sandler, 1996). For these clientele groups to be politically effective, they must solve the free-rider problem.

One solution to the free-rider problem is to obtain federal legislation requiring participation of target-group members. In the U.S., the 1985 farm bill permitted agricultural commodity groups to hold a referendum for coverage by mandatory commodity check-off programs to finance commodity promotion and agricultural research. A commodity group is then designated to manage the check-off funds, e.g., the National Pork Council, the National Corn Growers Association, National Soybean Association, National Cattlemen's Association. Also, in the recent round of U.K. government reforms focused on research, statutory bodies were enabled by national legislation to impose mandatory levies on agricultural output, e.g. cereals, milk, horticulture, sugar, apples, potatoes, and meat and livestock, to support commodity promotion and 'near-market' research (Thirtle et al., 1997).

Private interest-group financing of public agricultural research is socially efficient, if (1) all of the beneficiaries of the research are included in the 'group', and (2) the private financing does not adversely affect the amount of public resources allocated to other socially worthwhile agricultural research, including crowding out other funds. Unfortunately, one or both of these conditions are seldom met. First, the (potential) beneficiaries of agricultural research are generally much larger than any particular commodity group (or corporation). Over the long-run, a large share of the benefits of public agricultural research goes to consumers (see Alston et al., 1995). In contrast, a large share of the benefits of private sector agricultural research goes to the companies financing and conducting the research. Second, research as a production process has a large amount of ex ante uncertainty and public institutions that are under financial distress frequently look favorably on almost any outside source of funding. Thus, a private group is frequently able to contract with a public research institute to undertake a project for less than the expected cost which creates joint public-private financing. Hence, public funds that would otherwise have gone to other public agricultural research projects are redirected by the joint venture.

From a public interest perspective, the key issue is the size of the social payoff for the joint public-private venture vs. purely publicly financed projects which are foregone by the redirection of public resources to the joint venture project. If the opportunity cost is low, then the redirection is socially good, but if the opportunity cost is high, society is worse off by these joint public-private ventures than if no private funding of public agricultural research occurred. In particular, the opportunity cost may be large in situations where public funds are not allocated to different types of research so as to equalize the expected marginal return.

Ulrich et al. (1986) provide empirical evidence showing that the social opportunity cost was high in the case of joint private–public funding of malting barley research in Canadian public agricultural research institutions (i.e. Agriculture Canada and the provincial universities). They found that both, the public and private sectors gained from the joint venture funding of malting barley research (i.e. positive private and social rates of return), but the social opportunity cost was very high because the joint venture favored the private interests of the malting and brewing industry over the social interest. The social rate of return would have been 40% higher on the foregone public research to improve feed grain yields of barley (even after compensating the malting and brewing industry for benefits they would not have obtained from the joint venture).

Hence, increased use of public–private partnerships or joint ventures can increase or decrease social welfare, and when they reduce social welfare, the collective willingness of taxpayers to finance agricultural research in public institutions can be expected to dissolve. Although public research institutions in western developed countries are turning increasingly to the private sector for financial resources, which may ease their fiscal problems in the short-run, the long-run consequences may be a reduction in the willingness of the public to finance public agricultural research and, thereby, worsen the fiscal squeeze that many public agricultural research institutions are facing.

3.2. *Stronger IPRs and stronger private incentives*

The relative importance of private agricultural R&D differs across western developed countries. When the private sector undertakes a larger role in the production of scientific innovations, the demands on the public sector are reduced and the nature of the social need changes. The private sector's share is relatively large (>50%) in the United Kingdom, the Netherlands, the U.S., Germany, and France but small (<30%) in Portugal, Greece, Ireland, and Canada (Pardey et al., 1998; Alston et al., 1998). Both, governmental policies and market forces greatly affect the incentives for private sector investment in agricultural R&D.

Public policies have several different types of effects. First, government farm commodity and agricultural trade policies affect the market prices for final commodities and inputs, the price elasticities of aggregate supply of agricultural output and demand for agricultural inputs. Hence, they affect the expected profitability of farmers' adopting new technologies and the derived demand for them. Second, environmental, resource, public health, and food safety policies change the cost structure of firms and (or) influence consumer demand for final products. Third, public investments in general, and pretechnology research in particular, produce new innovations, and some of them provide good commercial opportunities for private-sector development and marketing. Fourth, national (and international) laws provide the mechanisms for definition, enforcement, and transfer of IPRs (Evenson, 1984).

IPRs include patents, breeders' rights, copyrights, trademarks, and trade secrets. The patent, which provides protection for embodied inventions, is the key IPR for private sector innovation in agriculture of western developed countries. A holder of a patent on an invention in a particular country is given the right by the granting country to exclude others from the unauthorized use, sale, or manufacture of the invention for a finite period, generally 20 years. These rights, however, apply only within the boundaries of the granting country, and only through international patent right exchange agreements do they have power in other countries.

The Patent applicant must disclose or remove from secrecy the essential features of the invention so as to 'enable' others to make or use the invention (Huffman and Evenson, 1993, Chap. 5). Disclosure has two main purposes. In return for granting a limited monopoly position to the inventor for 20 years, the nature of the invention is revealed which facilitates accumulation of the stock of knowledge and exchanges among innovators and scientists, and second, a country establishes strong incentives for private sector finance and conduct of R&D. Patent laws generally exempt abstract or non-embodied ideas and concepts from protection. Thus, for an invention embodied in a product, process, or biological materials, the holder of a patent can use or license its use. This gives the owner the right to an income stream from the commercialization of inventions or from licensing it to others. However, if a country has ineffective procedures for protecting patent rights, the size of the potential income stream from inventions is greatly reduced and might be zero.

Patent rights for the 18 western developed countries of this study have been strengthened over the past two decades, and this has increased the economic incentives for private R&D. The strength of patents across the 18 countries can be compared using a patent rights index developed by Ginarte and Park (1997). The overall index is derived from five separate indexes for: (1) extent of coverage; (2) membership in international patent agreements; (3) provisions for loss of protection; (4) enforcement mechanisms; and (5) duration of protection. For example, loss of protection means 'working' requirements, compulsory licensing, and revocation of patents. 'Duration' is the share of 20 years that a granting country gives protection. Each of the five components was given a value between 0 and 1 by the authors for each country and year, and a country's patent-rights index is the summation over these values, taking values between 0 and 5.

The values of the patent rights index, 1960–1990, for western developed countries are presented in Table 4. First, the mean patent rights index value for the 18 western developed countries is significantly higher than the average value for a set of 111 high-, middle-, and low-income countries, being 22% higher in 1960 and 36% higher in 1990. Second, the patent rights index for the western developed countries has increased rapidly since 1975. The mean of the index increased slowly during 1960–1975 (an average rate of 0.7% per year) and more rapidly during 1975–1990 (an annual average of 1.1% per year). Third, the U.S., Austria, the Netherlands, and Italy standout because of their high patent-rights index values (over 1975–

Table 4
National indexes of patent rights, 1960–1990

Country/Region	1960	1965	1970	1975	1980	1985	1990
Western Europe							
Austria	3.38	3.38	3.48	3.48	3.81	3.81	4.24
Belgium	3.05	3.38	3.38	3.38	3.38	4.05	3.90
Denmark	2.33	2.66	2.80	2.80	3.62	3.76	3.90
Finland	1.99	1.99	2.14	2.14	2.95	2.95	2.95
France	2.76	3.10	3.24	3.24	3.90	3.90	3.90
Germany	2.33	2.66	3.09	3.09	3.86	3.71	3.71
Greece	2.46	2.46	2.46	2.46	2.46	2.46	2.32
Ireland	2.23	2.56	2.99	2.99	2.99	2.99	2.99
Italy	2.99	3.32	3.32	3.46	3.71	4.05	4.05
Netherlands	2.95	3.29	3.61	3.47	4.24	4.24	4.24
Norway	2.66	2.66	2.80	2.80	3.29	3.29	3.29
Portugal	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Spain	2.95	3.29	3.29	3.29	3.29	3.29	3.62
Sweden	2.33	2.66	2.80	2.80	3.47	3.47	3.90
Switzerland	2.38	2.71	3.14	3.14	3.80	3.80	3.80
United Kingdom	2.70	3.04	3.04	3.04	3.57	3.57	3.57
subgroup mean	2.60	2.82	2.97	2.97	3.39	3.46	3.52
North America							
Canada	2.76	2.76	2.76	2.76	2.76	2.76	2.76
United States	3.86	3.86	3.86	3.86	4.19	4.52	4.52
subgroup mean	3.31	3.31	3.31	3.31	3.48	3.64	3.64
Mean:							
All above countries	2.68	2.87	3.01	3.01	3.40	3.47	3.53
111 countries	2.13	2.22	2.27	2.28	2.40	2.44	2.46

*Source:*Adapted from Ginarte and Park 1997.

1990), and Portugal, Greece, and Ireland standout because of their usually low values. Fourth, although most of the western developed countries have strengthened their patents rights over 1960–1990, the index values for Canada and Portugal are unchanged and the index value of Greece actually declined from 1985 to 1990.

Ginarte and Park (1997) have shown that a strong patent rights index is a necessary but not sufficient condition for rapid economic growth of countries. The strength of IPRs is, however, a key factor in determining the willingness of the private sector to finance its own agricultural research. For example, in the U.S. where patent protection for chemicals is very strong, the private sector has produced a large stream of new agricultural chemicals since 1960 (Ollinger and Fernandez-Cornejo, 1995). Also, since new breeders' rights were defined for crop varieties and, hence, strengthened by the 1970 Plant Variety Protection Act, using Plant Variety Protection Certificates, the rate of private sector release of new soybean varieties has greatly increased, and the private seed companies have replaced public-sector plant breeders as the primary breeders of new commercially successful soybean varieties (Huffman and Evenson, 1994; Fuglie et al., 1996, pp. 37–39).

Although the patent-rights index of the western developed countries are generally large, most of the countries have the potential to further strengthen these rights, and in a few countries, e.g. Portugal, Greece, Canada, and Finland, the potential is large. In countries where the size of the market is small, the private sector is, however, likely to be less responsive to strengthening IPRs than in countries where the potential market is large. By having strong IPRs, the private sector can provide a large share of its own research needs and, thereby, reduce and change the composition of the research society needs to finance through the public sector.

4. Conclusions and implications

This paper has reviewed some of the important structural and organization changes in agricultural research of western developed countries and examined new funding prospects. Some conclusions and recommendations follow. First, new political jurisdictions should be formed for the purpose of financing agricultural research. These jurisdictions can include new alliances across countries and subregions within large countries. Small countries should look actively for potential alliances with other, especially larger countries, that they can join. They are too small, in most cases, to capture significant benefits from pretechnology and general science research supporting agriculture. Furthermore, they should have open markets to benefit from the technical advances made in other countries. Within large countries, we see no problem with overlapping political jurisdictions; they have worked well for the provision of many other local public goods and services.

Second, intellectual property rights should be strengthened to increase the share of agricultural research that is financed and conducted in the private sector. This would make it possible for the private sector to provide more of its own research needs, and we believe that this is the best direction for the private sector resources for research to be channeled. Hence, we are pessimistic about the potential for private sector financing of agricultural research in public institutions, except when private companies or groups make unrestricted grants as in Revlon's support of cancer research at the UCLA Medical School. Otherwise, private-sector financing of joint ventures that look like good opportunities seem likely to come at high social cost. The private interests of companies and commodity groups are seldom well aligned with the social good or public interest. Thus, joint public–private research ventures frequently create a major conflict with the interests of taxpayers supporting public agricultural research institutions. Furthermore, when funds are not allocated to equalize social returns at the margin, joint public–private ventures can come at a high opportunity cost when they redirect public funds to areas that have a lower (although perhaps positive) social rate of return. Third, the private sector seldom finds it profitable to invest in pretechnology and general scientific research and in certain areas of applied research, e.g. research on environmental, resource, food safety and human nutrition, agricultural policy, and minor crops. With the private sector taking on a larger share of the total agricultural research needs, this frees up public funds for research that can be focused on pure public goods and other socially important, but privately unprofitable, areas.

Overall, we believe that agricultural R&D systems of 'large countries' that have developed as a system of shared public and private financing and performance and as decentralized public support of public research institutions, e.g. the U.S. and Germany, are best positioned for meeting the R&D needs of their residents in the twenty-first century. These systems are better positioned to meet the changing demand for local or impure public goods than the national financed, administered, and conducted systems, e.g. France, and are large enough to obtain many of the benefits from more basic or pretechnology research. National government agricultural research frequently operates under the restrictions imposed by funding legislation that ties research expenditures to particular commodities and particular locations. Small countries can improve their access to new technological innovations by forming new political alliances with other countries, being open to technology transfer, and to imports of technically enhanced goods.

Acknowledgements

The authors are indebted to Phil Pardey for making data available on real public agricultural research expenditures for the 18 western developed countries of this study, the late Mancur Olson for valuable suggestions, Arie Oskam, Bruce Gardner, and Richard Carew for helpful comments, and participants in seminars at the World Bank and the University of Maryland. They greatly appreciate the assistance of several individuals who provided country-specific information on the organization of agricultural research and new developments in agricultural research policies: Richard Carew, Canada; Stephane Lemarie, France; Stefan Tangermann and Joachim von Braun, Germany; Vittorio Santanello, Italy; Arie Oskam, the Netherlands; and Oscar Alfrance, Spain. They also benefitted from a discussion with Darrell Cole, Assistant Area Director, Beltsville Area, ARS, USDA. The authors accept responsibility for any misinterpretation of information on various national agricultural research systems. They are also indebted to Iowa State University and the University of Maryland for financial assistance, especially for the support of a faculty improvement leave by Huffman during the spring semester 1998.

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