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Public vs. Private Agbiotech Research in the United States and European Union, 2002-2009

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We provide an in-depth analysis of biotechnology patents filed in the European Patent Office (EPO) and US Patent and Trademark Office (USPTO), building a comprehensive dataset of more than 7,000 patents for the period 2002 through 2009. Results show a larger number of patents filed with the USPTO than the EPO. The private sector is more market oriented and owns the majority of the intellectual property (IP) rights, while public research is mainly focused on innovations useful in specific agricultural landscapes. European research centers are more interested in obtaining IP protection in the United States. In the EPO, the public sector specializes in the categories of 'bioprocesses DNA scale,' 'pharmaceutical,' 'male sterility,' and 'yield.' Our results provide a basis for broader questions of science policy in agriculture, public-sector IP policies, and the design of more effective IP management strategies to maximize the exploitation of patented technologies in this industry.

Key words: agbiotech, intellectual property (IP), patents, public research.

Introduction

In the last decades, the structure of agricultural input industries has changed very rapidly. Private-sector investment in agricultural and food research and development (R&D) has grown dramatically, while public-sector investments have remained relatively constant. Private-sector plant breeding has been the fastest growing segment of the private research portfolio. Mergers, acquisitions, strategic alliances, and some divestiture have characterized this sector (Shoemaker et al., 2001). The number of patents on agricultural innovations has increased as a result of two events: (a) the intervention of the private sector and its need for intellectual property rights; (b) the 1980 Bayh-Dole Act, which enabled universities to access patent results of research financed with federal funds (Yancey & Stewart, 2007). R&D in the agricultural sector was traditionally provided by public research institutions (Alston, Pardey, & Taylor, 2001), but the recent introduction of innovative research tools and technologies—usually owned by private firms, which invest more in this field—allowed these research institutions to become the leading actors in agricultural inputs production.

Among new technologies, biotechnologies have many applications in agriculture, including diagnostics, vaccines and therapeutics for animal health, DNA fingerprinting, marker-assisted selection, intragenics, and genetic engineering to develop genetically modified (GM) plants (Beuzekom & Arundel, 2009). Over the past few decades, scientific discovery in agricultural biotechnology (agbiotech) has accelerated, and the use of patents and other intellectual property rights (IPRs) instruments has increased proportionally to the number of final agbiotech products on the markets.

Patents[1] are functional information tools that can be used to study changes within—and the development and transfer of—agricultural input innovations. Several studies examined the role of patents in the development and use of plant biotechnologies (i.e., plant transformation techniques and structural genomics), showing that patents are important in inducing private firms to develop these platform technologies. Patent protection boosted the commercialization of many GM varieties.

The impact of intellectual property (IP) protection on public research appears ambiguous. Some authors suggest that the adoption of IP protection instruments gives public research institutes the opportunity to raise funding and provides incentives to researchers to produce innovations. Moreover, although the use of IPRs may seem to be in conflict with the traditional role of universities (which is to create, sustain, and disseminate knowledge as a public good), it may be a way to increase social welfare. Maredia et al. (1999) argue that IP protection can be compatible with the mission of

1. *Patents are defined as documents issued by an authorized governmental agency, granting the right to the inventor to exclude anyone else from the production or use of a specific new device, apparatus, or process for a stated number of years.*

public organizations, especially in those cases where private firms under-invest in R&D due to small markets, high R&D costs, and technological complexity. The possibility of "revenue-driven" public research is reviewed by Rubenstein (2003), using USDA patenting activity as an example. Conclusions of Rubenstein's research indicate that licensing policies did not affect research agendas, nor did they limit potential social benefits.

Beginning with the seminal work of Schmookler (1966), many other authors found evidence of relationships between patent statistics and economic growth, technological change, R&D expenditures, and inventive activity (Commanor & Scherer, 1969; Griliches, 1990; Griliches, Pakes, & Hall, 1986; Hagedoorn & Cloodt, 2003).

However, the use of patent data presents some difficulties. For example the economic value of a patent may differ greatly depending on the type of the owner of the patent. Public and private sectors may have different reasons to apply for a patent. As simple patent counts may not properly measure technology output, estimates of patent values (which have a per se interest) can be used to weight raw patent counts (Austin, 1993; Schankerman & Pakes, 1986). A recent approach to this problem has been the use of patent citations as a proxy for the value of a patent (Jaffe, Trajtenberg, & Henderson, 1993). Despite these difficulties, patent statistics represent a very useful tool for the analysis of technical change.

Particularly relevant to our study is the analysis of Graff, Cullen, Bradford, Zilberman, and Bennet (2003), which counted the number of agbiotech patents granted internationally and disentangled the role of private, public, and private-public collaborations in producing agbiotech innovations. This study showed that the private sector played a major role in the overall production of agbiotech innovations, while the public sector specialized in fundamental research fields.

Our analysis contributes to the knowledge on patents related to agbiotech research in the international patent systems. To do so, great effort is required to identify and set up a classification of thousands of patents. This article provides a method of identification and a classification for agbiotech patents.

We present an updated view of agbiotech innovations filed in the patent systems of the two most significant innovation areas worldwide: the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO). We investigate the degree of collaboration between the public and the private sector and the concentration of patent ownership in agbiotech innovations between private firms and public institutions.

In the next section, we define the categories of agbiotech innovations and describe data collection and the methodology we used. Following that, we describe the results and discuss the economic and policy implications of our main findings. The analysis consists of three parts. First, we focus on the comparison between EPO and USPTO; second, we analyze the differences between the public and the private sector; and third, we study the research fields in which the public sector is specialized. The article concludes with a discussion of the policy implications.

Methodology

We analyze the agbiotech patents filed at the EPO and USPTO from 2002 to 2009. Following Graff et al. (2003), who examined the period 1982-2001, we classify agbiotech patents according to their technological areas and we compare the patent portfolios of the private and public sectors. Our analysis provides an updated picture of patents granted in the world's two major patent systems and assesses the degree of concentration and specialization of patent owners in order to evaluate the capacity to develop new agbiotech innovations.

We collected data on agbiotech patents by keyword extraction using the esp@cenet service,[2] Europe's network of patent databases provided by the EPO. Extraction of data was based on the International Patent Classification (IPC). We considered groups A01 (Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing), C12 (Biochemistry; […]; Microbiology; Enzymology; Mutation or Genetic Engineering), and other related subgroups. The final query is "(A01H1/08 or A01H4 or A01H5) and C12N15."

Aggregation of data is organized by manual selection[3] as follows: applicants of the new technology, organization owner of the patent (i.e., multinational firms, other private firms, academic or government organizations, or patent management companies), collaborations, origin (EPO or USTPO), publication date, and technological categories.[4] This organization allows a compari-

2. *Available at http://www.espacenet.com.*
3. *For example, about 500 patents were lacking a clear applicant, but through direct interrogation of other sources (such as the World Intellectual Property Organization [WIPO] and Cambia's Patent Lens), we identified the original applicant.*

son with the 1982-2001 data provided by Graff et al. (2003).

Data extraction was based on the national patent system from which the data came (EPO or USPTO). This approach permitted us to trace the innovations in the two different systems, to determine whether the innovations were patented in both systems, and to identify flows of innovation diffusion by taking into account the dates of filing. Furthermore, patents related to cultivars have been analyzed separately because they are patentable at the USPTO but not at the EPO.

To analyze the rate of concentration among firms and subcategories, we used two different methods. First, we computed the Concentration Ratio (CR4), defined as the share of patents held by the top four firms or subcategories. Second, we computed the Herfindahl Index (Hirschman, 1964), defined as

$$H = \sum_{i=1}^{N} S_i^2, \tag{1}$$

where N is the number of firms or categories and s_i is the share of patents from firm or category i. The Herfindahl Index (HI) ranges from $1/N$ to 1; a small index indicates a high degree of competitiveness in patent ownership, with no dominant inventors or categories.

To examine the degree of public-sector specialization for each country, our preferred index is the Revealed Technological Advantage Index (RTA), which was developed by Soete (1987); our preferred index at a patent's macro and subcategory level is the standardized version (SRTA), following Wintjes and Dunnewijk (2008). According to OECD (2009), this index is the most frequently used indicator for the identification of technology domains in patent data. We constructed the index in two steps. First we computed the RTA as

$$RTA = \frac{P_{ij} / \sum_j P_{ij}}{(\sum_i P_{ij} / \sum_i \sum_j P_{ij})}, \tag{2}$$

where P_{ij} is the number of public-sector patents in technological category i within country j. Second, we computed the Standardized Revealed Technological Advantage Index (SRTA).

4. *For a comprehensive explanation of technological categories based on US Department of Agriculture classification and European Classification (ECLA), see the Appendix.*

Table 1. Number of patents granted at EPO and USPTO by sector and collaboration, 2002-2009.

	EPO		USPTO	
	N°	%	N°	%
Total private sector	**1,111**	**62.5**	**2,581**	**62.9**
Multinational firms	676	38.0	1,663	40.5
Other private	435	24.5	922	22.5
Public sector	**424**	**23.8**	**1,244**	**30.3**
Total collaboration	**218**	**12.3**	**233**	**5.7**
Private-private	40	2.2	47	1.1
Private-public	102	5.7	101	2.5
Public-public	76	4.3	85	2.1
Independent inventors	**26**	**1.5**	**41**	**1.0**
Total	**1,779**	**100.0**	**4,103**	**100.0**

Source: based on ep.espacenet.com data

$$SRTA = \frac{(RTA - 1)}{(RTA + 1)} \tag{3}$$

The standardized index varies between -1 (no specialization) and 1 (complete specialization). This is conceptually similar to a revealed comparative advantage index, but as we only consider the two most important patent systems, it allows us to obtain information on the specialization of the public sector relatively to European and US patent systems.

Results and Discussion

EPO and USPTO, 2002-2009

The total number of patents analyzed during the 2002-2009 period was 7,469 (5,882 without cultivars); of these, 1,779 were filed in the EPO, and 5,690 (4,103 without cultivars) were filed in the USPTO. Analyzing the number of patents filed at the EPO and USPTO for type of inventor (private and public sectors, collaborations, and independent inventors; see Table 1) indicated a dominant role of the private sector both in the European and US patent systems. Indeed, the private sector overall accounted for 62.5% of the patents in the EPO and 62.9% in the USPTO. Roughly 40% of total patents granted in the two systems came from major multinational firms.[5] In the USPTO, 84% of cultivar patents

5. *This refers to the six biggest multinationals—Monsanto, Bayer, BASF, Dow AgroSciences, DuPont, and Syngenta—plus other acquired companies (i.e., CropDesign=BASF). Other private applicants include both independent inventors and other firms.*

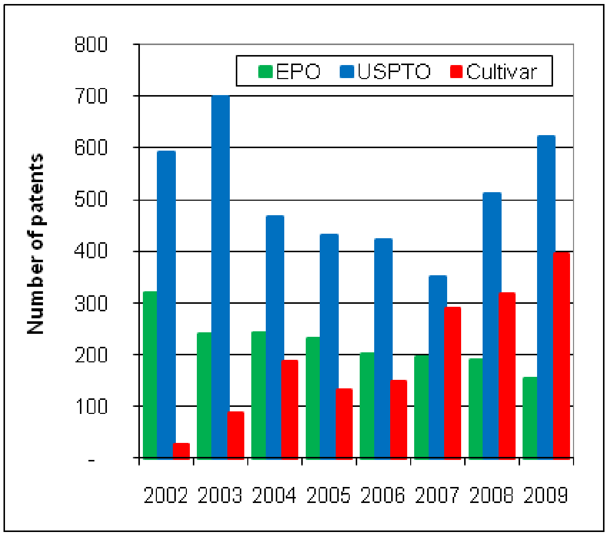

Figure 1. Annual trends in plant biotechnology IP, 2002-2009.

Source: Authors' calculations based on ep.espacenet.com data.

were granted to the private sector; of these patents, 68.7% were granted to multinational firms.

Counting the annual number of patents shows different patterns in the two systems (see Figure 1). The number of patents filed in the EPO displays a progressive decline, with significantly fewer patents in 2009 than in 2002. On the contrary, the number of patents filed in the USPTO decreased dramatically in 2003 and 2004, but increased again in the last two years of the study.

In 2009 we recorded the greatest deviation in numbers of agbiotech patents between the EPO and USPTO. The difference is even greater if we take into account cultivars. This suggests that R&D investments are mainly directed toward the US market, where regulations on cultivation and marketing of agbiotech products are more permissive. Hence, producers of agricultural biotechnologies tend to apply for patents in those countries where there is a real possibility of exploitation, with a preference for markets in which final products embodying innovations have potential access. The number of cultivars patents has been progressively increasing in the last four years.

In order to better understand the core of R&D in each patent office, we divided patents into subcategories and provide their distribution in Figure 2. In order to conduct a proper comparison between EPO and USPTO, we excluded cultivars. Subcategories 'genes & enzymes,' followed by 'bioprocesses/metabolic pathways,' 'nutrition components,' 'genetic transformation,' and 'stress disease resistance' are the most represented, accounting for more than 70% in both systems. This evi-

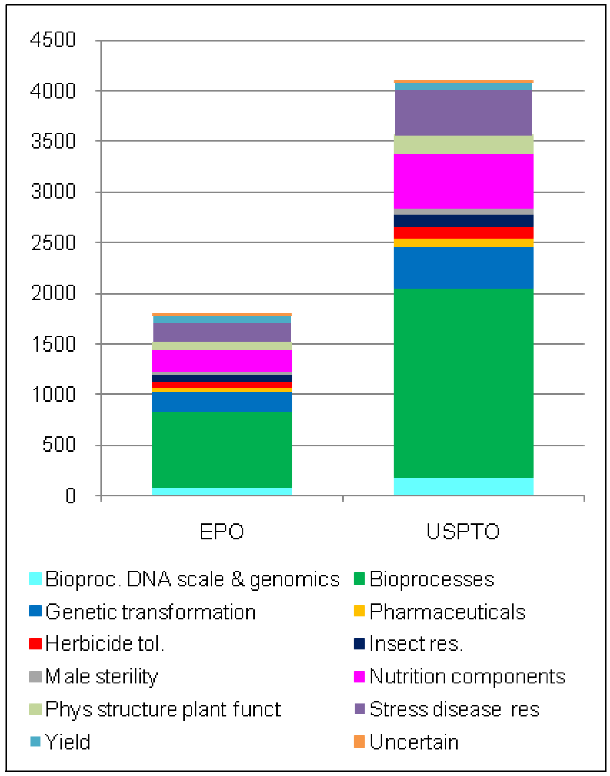

Figure 2. Patent distribution by office and subcategories, 2002-2009.

Source: Authors' calculations based on ep.espacenet.com data.

dence suggests that developers of new agricultural biotechnologies in the two patent systems assign the largest shares of R&D expenditure in the same research fields. This can be due to the high concentration of the private sector, which is mainly represented by a few multinational firms.

It emerges from the number of total patents that the USPTO is the major collector of agbiotech patents—greater by a factor of 2.3 with respect to the EPO. This is not surprising given that in the United States agricultural biotechnologies are an input to the agricultural sector (i.e., GM crops), and that products obtained with them are easily marketed.

Despite the difference in numbers, the two patent systems developed similar innovations. This is mainly due to the activity of multinational firms at the global level, which affects both agricultural factor markets and biotechnology development as a consequence. However, it is important to better address the role of each sector to disentangle the stock of knowledge between the public and private sectors.

Table 2. IP portfolio of single inventors by cluster of genetic trait technology.

Category	Public	BASF	Bayer	DAS[1]	DuPont	Monsanto	Syngenta	Other private	Total
Bioproc. DNA scale & genomics	**5.2**	**3.9**	**4.5**	**2.1**	**5.1**	**3.1**	**2.6**	**4.1**	**4.4**
Bio proc DNA scale	4.6	3.9	1.9	2.1	4.0	2.6	2.6	3.3	3.6
Genomics	0.6	0.0	2.6	0.0	1.1	0.5	0.0	0.8	0.7
Bioprocesses	**45.6**	**43.0**	**36.2**	**35.1**	**57.5**	**43.1**	**31.9**	**44.6**	**45.1**
Genes & enzymes	23.6	26.6	20.4	11.7	36.9	21.2	12.1	23.8	24.5
Promoters	7.7	3.6	3.2	5.3	9.3	8.7	8.2	6.5	7.1
Others	14.3	12.8	12.6	18.1	11.3	13.2	11.6	14.3	13.5
Genetic transformation	**10.5**	**6.0**	**12.9**	**11.7**	**6.0**	**11.6**	**9.5**	**12.8**	**10.4**
Pharmaceuticals	**2.7**	**0.0**	**0.6**	**9.6**	**0.0**	**0.3**	**0.0**	**3.9**	**2.1**
Plant technology	**36.1**	**47.1**	**45.6**	**41.5**	**31.4**	**41.9**	**56.0**	**34.6**	**38.1**
Herbicide res	1.5	3.4	9.1	4.3	2.6	2.6	11.2	1.9	2.9
Insect res	1.1	2.4	5.5	16.0	5.0	7.5	12.1	1.3	3.5
Male sterility	1.5	0.2	3.6	0.0	1.0	0.7	2.2	1.3	1.3
Nutrit components	11.6	9.2	19.7	13.8	10.8	16.8	10.8	14.1	13.0
Phys struct plant funct	6.2	0.7	4.9	2.1	3.4	2.1	7.3	3.5	4.2
Stress disease res	12.5	18.1	2.9	5.3	7.4	7.5	12.5	10.0	10.4
Uncertain	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.3	0.2
Yield	1.6	13.0	0.0	0.0	1.0	4.4	0.0	2.1	2.6
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
N° patents	*1,668*	*414*	*309*	*94*	*701*	*585*	*232*	*1,357*	*5,360*
CR4 sub category	61.9	70.5	65.7	55.3	68.3	62.7	48.3	65.1	61.3
HI sub category	0.129	0.153	0.131	0.122	0.185	0.127	0.105	0.133	0.128

¹ Dow Agro Science

Source: Elaboration on ep.espacenet.com data.

Public vs. Private: Who Plays the Game?

In order to display the different contributions to research from public and private actors, we provide a more detailed analysis on the differences between patent categories and subcategories and typology of applicants.

First, we calculate the HI considering major firms, the whole public sector, and other residual private organizations as an aggregate. A preliminary result shows a low degree of concentration, suggesting that each actor contributes to grant patents in each category (Table 2). The pharmaceutical category is an exception, with an HI of 0.4 due to the important contribution of the public sector and other private firms.

It is important to emphasize the contribution of public research—both in terms of basic research and research on plant developmental processes (such as abiotic resistance), which is useful in specific agricultural landscapes. The role of multinationals appears rather homogeneous among the different categories. This is in contrast with the analysis of the cultivars category, where almost 80% of patents can be attributed to three of the six major multinational firms (Monsanto, DuPont, and Syngenta).

Second, we investigate the portfolio compositions of major firms, other private firms, and public organizations. We calculated the CR4 index for different applicants and combined this information with the HI. Results for BASF, DuPont, Bayer, and Monsanto show that in spite of well-diversified portfolios, the core business is represented by the first four subcategories (Table 2). This result is affected by the absence of cultivars, as already mentioned, which represents a strategic category for three of the six multinational firms considered. The composition of the plant technology category exhibits a partial shift from the first wave of innovations—mainly herbicide and insect resistance—to a new one—namely nutritional components.

Both public sector and the other private applicants show a high level of diversification. In particular, public research is geared toward basic research as well as innovations to solve ecosystem problems related to biotic and abiotic stresses (e.g., virus resistance and drought tolerance).

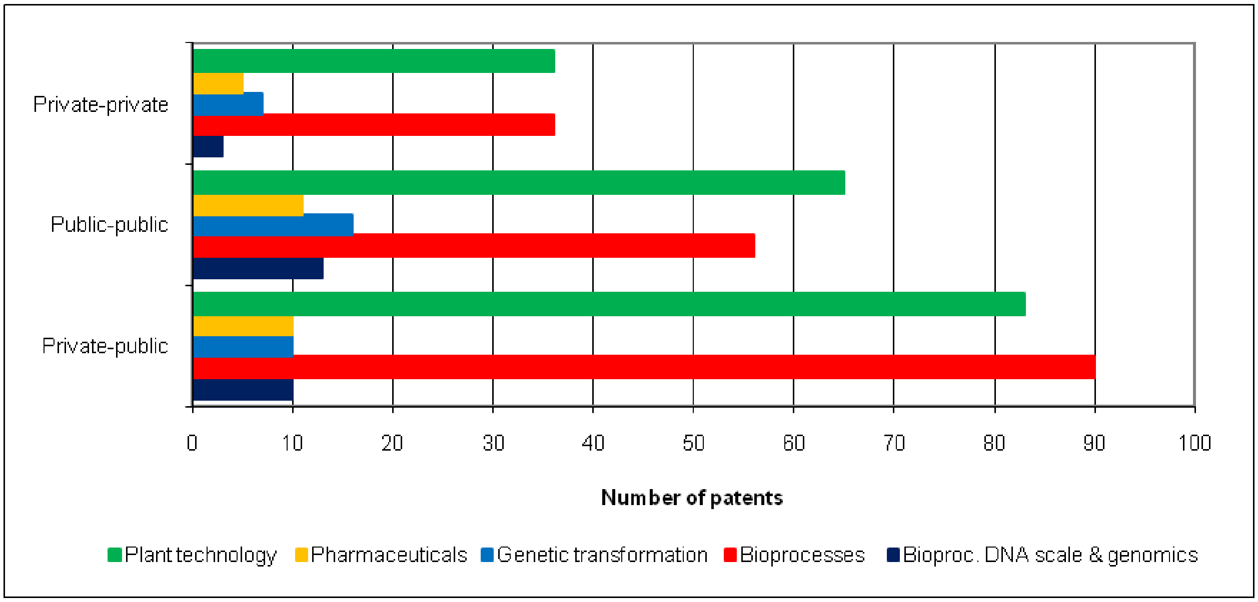

Figure 3. Patent distribution by collaborations, 2002-2009.
Source: Author's calculations based on ep.espacenet.com data.

In line with the period of time analyzed by Graff et al. (2003), we find a relatively small number of agbiotech patents jointly assigned to more than one organization. During the 2002-2009 period, almost 7.7% of patents come from synergies of some combination: 3.5% private/public, 2.7% public/public, and only 1.5% private/private. We observed that collaborations mainly appear in the research field of 'bioprocesses' (Figure 3), and more specifically within that field, the 'genes & enzymes' subcategory.

Collaborations are primarily focused on the development of basic research; public/public collaborations are geared toward 'stress disease resistance' and 'nutrient components,' which suggest an interest in improving agricultural development and increasing food security in poor countries with drought and soil salinity problems. In contrast, private/private collaborations are clearly market-oriented. Indeed, the largest number of patents is related to herbicide resistance, belonging to the 'plant technology' category.

Where is Public Research Competitive?

In this section we focus on the role of public research in agbiotech patent granting by investigating the main technological areas in which the public sector has a specialization and the public institutions (i.e., universities, governmental institutes, public/public collaborations, non-profit organizations, and other public research institutes) have a major role. We conduct this analysis by differentiating the patents filed in the EPO from those filed in the USPTO. Furthermore, we investigate the public sector at the country level.

The public sector holds a restrained but significant role in both patent systems. Its activity is almost absent (1.8%) in cultivars patents, but it accounts for 23.8% in the other categories as an aggregate in the EPO and 30.3% in the USPTO.

The public sector is characterized by a strong fragmentation. We counted 369 public applicants, but only 21 of them account for more than 1% of the granted patents. Within these 21 public institutions, 10 come from the United States; four each come from Japan and the EU; and Australia, Canada, and Taiwan each have one. Similar to Graff et al. (2003), we find a major role played by American universities. The University of California in particular accounts for 5.8% of patents granted to universities by the USPTO, a very high contribution within the public sector considering the number of institutions in the United States.

Table 3 presents the different public actors in each category. We found that in the EPO, the largest number of agbiotech patents is filed by universities and research institutes; in the USPTO, universities file more than 82% of patents, but the role of research institutions is almost non-existent. In comparing the two systems, we observed that the interest of public actors in both the European Union and the United States is focused on the same research fields. Public/public collaborations play a significant role in the European patent system but not in

Table 3. Public domestic actors: EPO vs. USPTO, 2002-2009.

EU in EP	Bioproc. DNA scale & genomics	Bioprocesses	Genetic transformation	Pharmaceuticals	Plant technology	Total	%
Collaboration	4	7	3	1	7	22	13.8
Research instit.	2	24	4	1	27	58	36.5
Government	0	3	0	0	2	5	3.1
No-profit	1	3	0	0	3	7	4.4
University	6	39	5	3	14	67	42.1
Total	13	76	12	5	53	159	100.0
%	8.2	47.8	7.5	3.1	33.3	100.0	
US in USPTO	**Bioproc. DNA scale & genomics**	**Bioprocesses**	**Genetic transformation**	**Pharmaceuticals**	**Plant technology**	**Total**	**%**
Collaboration	0	11	2	3	15	31	4.6
Research instit.	0	0	0	0	2	2	0.3
Government	0	3	1	0	10	14	2.1
No-profit	2	27	9	9	24	71	10.5
University	28	235	62	12	218	555	82.5
Total	30	276	74	24	269	673	100.0
%	4.5	41.0	11.0	3.6	40.0	100.0	

Source: Based on ep.espacenet.com data.

the American one, where universities and non-profit organizations account for more than 90% of the public sector.

The country-level analysis shows a significant difference between the two patent systems (Table 4). In particular, applicants from non-European countries in the EPO account for more than 68%, while in the USPTO this number is less than 50%. At the same time, the number of patents filed from European applicants in the USPTO is greater than in EPO. This suggests that European research centers—both public and private—have more interest in obtaining IP protection than US research centers, probably because the more permissive US regulation on biotechnology allows the exploitation of this innovation.

These results are supported by the high difference in terms of patent numbers granted by the USPTO and EPO. All stakeholders from different countries, including Europeans, have patented more in the United States than in Europe (4,103 vs. 1,779). This may be indicative of a lower attractiveness of the European patent system, affected by less supportive policies of agricultural biotechnologies (especially for final products).

Table 4. Foreign actors and public research: EPO vs. USPTO, 2002-2009.

	European Patent Office			
	Total		**Public**	
	N°	**%**	**N°**	**%**
US	628	35.3	133	7.5
Japan	144	8.1	71	4.0
Switzerland	90	5.1	2	0.1
Australia	65	3.7	41	2.3
Canada	46	2.6	29	1.6
Others	245	13.8	65	3.7
EU in EPO	561	31.5	159	8.9
Total	1,779	100.0	500	28.1
	US Patent and Trademark Office			
	Total		**Public**	
	N°	**%**	**N°**	**%**
EU	746	18.2	163	4.0
Japan	270	6.6	163	4.0
Switzerland	129	3.1	-	0.0
Canada	117	2.9	85	2.1
Australia	116	2.8	85	2.1
Others	396	9.7	160	3.9
US in USPTO	2,329	56.8	673	16.4
Total	4,103	100.0	1,329	32.4

Source: Authors' calculations on ep.espacenet.com data.

Table 5. Specialization (SRTA index) of public research by actors, 2002-2009.

	USPTO	EPO	US	EU	Japan	Australia	Canada
Bioproc. DNA scale & genomics	0.06	0.20	0.02	0.30	0.15	0.19	0.23
Bioprocesses	-0.01	0.01	-0.03	0.04	0.06	-0.06	-0.04
Genetic transformation	-0.01	0.04	0.04	-0.17	-0.15	-0.09	-0.09
Pharmaceuticals	-0.06	0.14	0.12	-0.05	-0.09	-0.59	-1.00
Plant technology	-0.01	-0.07	-0.01	-0.07	-0.07	0.07	0.06
Herbicide tolerance	-0.01	0.10	0.19	-0.63	-1.00	0.08	0.59
Insect resistance	0.10	-0.40	-0.07	-0.16	-1.00	0.58	-0.19
Male sterility	-0.10	0.22	-0.17	0.18	-0.20	-0.42	0.15
Nutrition/composition	0.01	-0.05	-0.02	0.08	-0.03	0.25	0.21
Structure/plant function	0.02	-0.10	0.05	-0.22	0.01	-0.10	-0.13
Stress/disease resistance	0.02	-0.10	0.03	-0.22	-0.04	-0.06	-0.09
Yield	-0.06	0.21	-0.31	0.33	0.29	-0.28	-0.24

Source: Authors' calculations on ep.espacenet.com data.

Furthermore, during the 2002-2009 period, US public actors' share in the USPTO was 16.4%, while the European share in the EPO was only 8.9%. This probably means that a greater development of public research in the United States could attract additional funding for the overall research.

Using the SRTA index, we show that in the EPO, total public patents have a high rate of specialization in the following categories: 'bioprocesses DNA scale,' 'pharmaceutical,' 'male sterility,' and 'yield' (see Table 5). Public research in the USPTO shows no specialization. At the country level, we saw that US public research is more specialized in 'genomics,' 'pharmaceuticals,' and 'herbicide resistance,' while the European public sector is specialized in basic research ('bioprocesses DNA scale') and shows no specialization in 'genomics' and in those categories characterized by a greater possibility of practical applications (applied research), with the exceptions of the 'male sterility' and 'yield' categories.

The available data for Japan, Canada, and Australia shows different degrees of specialization, but for a better analysis of these countries we need to investigate their domestic patent systems.

Summary and Conclusions

We analyzed agbiotech patents granted at the European Patent Office and at the US Patent and Trademark Office for the period of 2002-2009. We have shown that the public sector plays an important role in basic research on agbiotech both in Europe and the United States, and it represents an important source of intellectual property.

We then showed that a larger number of patents are filed at the USPTO than at the EPO, and that the number of agbiotech patents has been increasing in the USPTO in the last two years and has been decreasing in the EPO for the duration of the entire study period. We further showed that the subcategories 'genes & enzymes,' 'bioprocesses/metabolic pathways,' 'nutrition components,' 'genetic transformation,' and 'stress disease resistance' account for more than 70% of patents at both the USPTO and EPO.

Second, we investigated differences between the public and private sectors and found that the latter—and, in particular, six large multinationals—own the majority of the IP. This suggests a great economic interest in agricultural innovations, but it also indicates a partial shift from the first wave of innovations (herbicide and insect resistance) to a new one (nutritional components). We also observe a diversification in the innovation typology: the private sector is much more market-oriented, while the public sector is mainly focused on plant developmental processes useful in specific agricultural landscapes (for example, developing plants with abiotic resistance).

Third, we conducted an analysis of patents at the country level and showed that European research centers, both public and private, have more interest in obtaining IP protection in the United States. This may be explained by the fact that more permissive US regulation on biotechnology allows a better exploitation of the innovations embodied in final products.

Finally, using a specialization index, we investigated the role of the public sector and we found that in the EPO the public sector shows a specialization in the categories 'bioprocesses DNA scale,' 'pharmaceutical,' 'male sterility,' and 'yield.' The public research in the USPTO shows no specialization. It is important to highlight that the number of patents filed at the EPO has never grown at the same rate as those filed at the USPTO.

Our results give a basis for considering broader questions of science policy in agriculture, public-sector IP policies, and the design of more effective IP management strategies in order to maximize the exploitation of patented technologies in this rapidly innovating industry.

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See next page for Appendix

Appendix. Full explanation of technological categories.

Categories	ECLA code	Keywords
Bioprocesses DNA scale	c12n15/82a8	activ* tagg*, DNA, loc*, nucleic acid, polynuc*, receptor, recombin*, RNA, transcript*, translat*
Genomics	c12n15/82a10; c12n15/82a12	centromer*, analy* & segreg* or sequen*, chromos*, gen* & analy* or expres*, genom*, homolo*, identif* sequen*, microarr*, plastid*, proteom*, transpos*
Promoters	c12n15/82b	chimeri*, promot*
Genes and enzymes	c12n15/82b	enhanc* expres*, enzym*, gen* & expres* or silen* or targ*, knockout, suppres*
Others	c12n15/82b; c12n15/ 82c8h	abscis*, auxin, brassinost*, cytok*, ethil*, gibberel*, growth reg*, hormon*, met* path*, pept*
Genetic transformation	c12n15/82a4; c12n15/ 82a6; c12n15/82a8	agrobact*, amplif*, beta-gluc*, biosensor, bombardment, caroteno*, cell different*, clone method, culture proc*, diagnostic, embryo, electropor*, fluoresc*, gen* & clon* or engin* or mani* or meth* or modi* or transf*, germplasm, in vitro, mark* & excis* or microsat* or select*, marker, method, microinj*, mut* & assay* or insert* or screen*, mutag*, PEG, propag*, protopl*, restrict fragm* polym*,single nucleot* polym*, transform protoplast, transformat*, whisker
Pharmaceuticals	c12n15/82/c4d	plant & antibod* or choler* or coag* or coelia* or health or huma* or immun* or mammal* or pap protein or pharm* or somatot* or therapeut* or vaccin*
Cultivars	a01h5	cultiva*, even*, hybri*, inbre*, line, name*, variet*
Herbicide resistance	c12n15/82c8b4	epsp, glufo*, glipho*, herbicid*, imida*, sulfon*, weed*
Insect resistance	c12n15/82c8b6	aphy*, arthrop*, bacill*, bt, coleopt*, cry, insec*, lepidopt*, pestic*
Male sterility	c12n15/82c8d	apomixis, fertil*, incompat*, parthenocarp*, reproduct*, steril*
Nutrition components	c12n15/82/c4d	acid content*, amino acid comp*, beta-carot*, caroten*, cellulo*, fat & comp* or cont* or modif*, fiber & alter* or improv*, fructan, fruit qual*, improv* qual*, lignin, lipid modif*, modif* polysacch*, nutri* & charact* or enhanc* or qualit* or valu*, oil comp*, pigment*, protein & conten* or componen*, starch, vitamin
Physical structure & plant function	c12n15/82c8a	dormancy, dwarf, dwf, embryogen*, enhance root, fitness, flo* & dev* or tim*, longev*, organogen*, phenotyp*, plant & architect* or morpho*, plant or seed or fruit & size, root & alter* or architect*, seed shatt*, seedless, senesc*, stabil*, structur*, vernal*
Stress disease resistance	c12n15/82c8b2; c12n15/82c8b6	abiotic stress, abiotic-res*, alumin*, antifreez*, antimicrob*, bacter*, blight, botrytis, chilling, cold, diseas*, drought, freez* tol*, fung*, harmful organ, heat, hypox*, low temp*, metal*, mildew, nemat*, pathoge*, phytopht*, salinity, salt, stress, thermal, viral, virus
Yield	c12n15/82c8a	biomass, changed growth, enhanc* & agronom* or growth, high* plant, improv* & growth or plant, increas*, modif* growth, plant & enhanc* or growth or improvem*, yield