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The Economic Impact of Plant Breeder's Rights in Australia

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EXECUTIVE SUMMARY

This report was commissioned by IP Australia, with the goal of providing a better understanding of the users of Australia's Plant Breeder's Rights (PBR) system and the economic impact of PBR.

Over 10,000 plant variety rights have been registered in Australia since the inception of the system in 1988.

55 per cent of all PBR applications are made by firms or individuals with an address outside of Australia. The share of applications from abroad has grown over the past 10 years. Among foreign applicants, the leading source countries are USA, Netherlands, and Germany.

Using confidential tax records in the Australian Bureau of Statistics' (ABS) Business Longitudinal Analysis Data Environment (BLADE), we identify 265 unique PBR owning ABNs (60 per cent of Australian PBR owning firms). The collective turnover of the Australian firms over 5 years to 2020 was $13 billion, with 78,000 full-people equivalent people employed. Not all the economic activity attributable to firms that apply for PBRs are directly related to the breeding and distribution of new plant varieties.

To better understand economic end-use of PBR registered cultivars, we mapped the PBR register to the ABS Value of Agricultural Commodity Produced (ABS VACP). The largest sectors by end-use include wheat ($4.9 billion), barley ($3.0 billion) and forage crops ($2.8 billion). Our data show that the number of PBR applications and the overall gross value in a sector are not well correlated. Several large sectors account for few PBR applications while other PBR intensive sectors are associated with relatively low gross output value.

PBR usage is not well correlated with applications for plant-related patents in International Patent Classification subclass AH01(IPC AH01) at the firm level. Most Australian firms which apply for PBR do not apply for plant-related patents, with the exception among breeders of key broadacre staples and government and university research entities. Similarly, most Australian firms which apply for plant related patents do not apply for PBR. Over 90 per cent of relevant patent applications are from abroad, far more than in the case of PBR.

In the final section of this report, we estimate the overall economic impact of PBR.

PBR are likely to have the largest impact where:

- Output is high
- Yield growth is high
- Alternate appropriation mechanisms are most limited (e.g., open-pollinated cultivars dominate)

These factors point to broadacre crops including wheat, barley, and canola. Evidence regarding other crops is discussed in the Propagation and Ease of Appropriation section.

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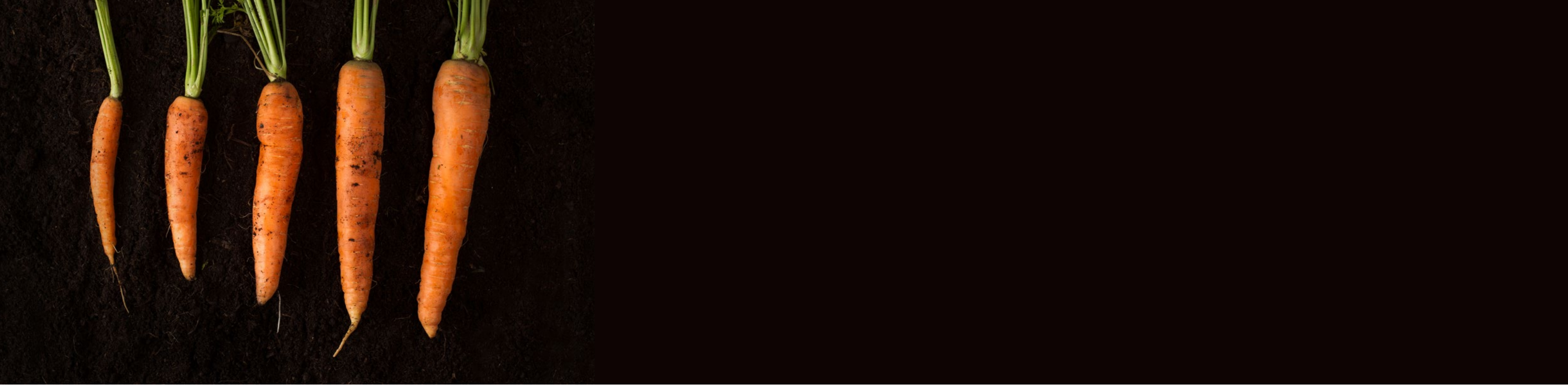
CONTENTS



INTRODUCTION

This report was commissioned by IP Australia to inform a better understanding of users of Australia's Plant Breeder's Rights (PBR) system, and of the economic impact of PBR.

It includes:

i. A detailed description of plant breeding sector (users of the PBR system);

ii. A measure of the economic activity of PBR applicant firms;

iii. A discussion of alternate mechanisms of appropriation (e.g. patents); and

iv. An estimate of the economic impact of new cultivars on downstream sectors.

New plant varieties contribute to productivity growth in a wide range of Australian agricultural industries including horticulture, and nurseries. New and improved plant varieties require investment. The purpose of PBR is to encourage private investment in breeding and commercialising new and improved plant varieties.

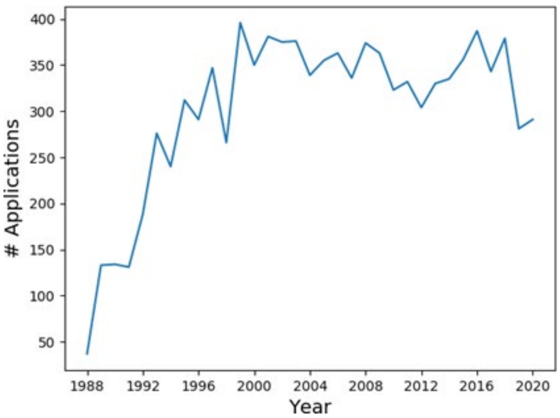
In the absence of PBR, markets are likely to underinvest in new plant varieties because breeders cannot recoup their investment in new varieties which can be propagated and distributed without users remunerating the breeder. In principle, owners of PBR receive a commercial monopoly for a finite period which enhances their ability to ensure users pay royalties on varieties cultivated.[1]

The economic impact of the PBR system comprises both the value captured by PBR holders themselves, and importantly the value that their new cultivars generate when used in downstream sectors.

Australia first introduced intellectual property protection for plant varieties in 1987.[2] Major reform required to meet Australia's obligations under the International Convention for the Protection of New Varieties of Plants (UPOV) 1991 Act led to the Australian Plant Breeder's Rights Act (The Act) in 1994. Since the first applications in 1988, more than 10,000 PBR applications have been filed.

Figure 1 presents a count of total PBR applications filed by year up to 2020. This figure shows an enthusiastic take-up of PBR protections following the inception of the scheme, followed by steady, continuous use in subsequent decades.

Figure 1: Number of PBR applications. 1988 to 2020, IP Australia



Source: PBR register. Note: since data was obtained prior to 2021 year-end, 2021 application count has been omitted from Figure 1 as incomplete. However, 2021 applications are included in subsequent analyses.

[1] Prior to the introduction of Plant Breeder's Rights, variety improvement in key open pollinated broadacre crops such as wheat was largely undertaken by government (see Thomson 2015). An advantage of user financed innovation is that it underpins an incentive for innovators (breeders) to target consumer needs and the use of efficient research and breeding practices.

[2] The 1987 Act afforded relatively weak protection in the case of open pollinated crops, in that it did not protect saved seed or crops grown from saved seed.

PROFILE OF PBR APPLICANT POPULATION

Applications for PBR protection have been made both by individuals and by organisations including companies, universities, and government research institutions. Approximately three quarters of the 10,000 PBR applications made to date have come from organisations, with the remainder made by individuals.

Over half (55 per cent) of all applications are made by firms or individuals with an address outside of Australia. Addresses reveal they include a mix of both Australian and foreign entities. Of organisation applicants, 43 per cent have an address in Australia, while the corresponding number for individuals is only a little higher, at 49 per cent. The breakdown of PBR between individuals and organisations and between Australian and overseas addresses is depicted in Table 1.

An Australian address is by no means a perfect indicator that the company is Australian owned, nor whether breeding work was completed in Australia. The Australian address listed on a PBR application may be that of a subsidiary that is partly or entirely foreign-owned.

Indeed, several breeding companies have significant foreign ownership. Conversely, Australian-headquartered firms may choose to register varieties to foreign subsidiaries.

In many industries, plant variety improvement is a highly internationalised endeavour. Germplasm is commonly shared across international boundaries both from international multi- lateral breeding organisations;[3] between public research institutes; or within the auspices of multinational firms. In most agricultural contexts, foreign-sourced varieties expressing desirable traits require additional breeding to be adapted to the target Australian agricultural environmental conditions. Cultivars used in agriculture therefore often reflect the result of local breeding efforts to improve or build on germplasm sourced from abroad. Horticultural and ornamental plant species may not require such local breeding or local adaptation. PBR creates an incentive both to invest in domestically-bred cultivars and encourages international transfer of varieties and germplasm by private firms – downstream industries in Australia benefit from both.

Table 1: PBR Applications by Domestic vs Foreign. 1988 to 2020, IP Australia

	Domestic #	Foreign #	Total #
Individual	1,207	1,270	2,477
Organisation	3,283	4,297	7,580
Total	4,490	5,567	10,057

Source: IPGOD database party_type and country_code.

[3] E.g. International Maize and Wheat Improvement Centre (CIMMYT) and the International Rice Research Institutes (IRRI).

Top Plant Breeder's Rights Applicants

To identify and describe firms who were most engaged with the PBR system, we undertook a harmonisation process with organisations listed on all PBR applications made to IP Australia. Then where possible, we linked these to the Australian Business Register (ABR) to retrieve the industry and Australian Business Number (ABN), as well as other economic indicators. To do this, we built on and extended the Intellectual Property Government Open Database (IPGOD), a dataset produced by IP Australia linking PBR (and other intellectual property registrations) to ABNs. Over all time, IPGOD identifies 299 unique ABNs attributable to 2,541 applications. Our analysis, outlined below, resulted in 50 per cent more PBR applicants and 40 per cent more PBR applications linked to unique ABNs than are included in IPGOD.

We harmonised and disambiguated all organisation names in the PBR register using established CTI codebases (see Appendix A).[4] We then linked all organisation names to the ABR using text similarity scoring combined with detailed manual checking. This process resulted in identifying an additional 140 ABNs with registered PBRs (over and above the 299 already included in IPGOD), bringing the total number of known ABNs with PBRs to 439 PBR registering firms. This represents an increase of almost half as many ABNs again as were previously known. Our resulting dataset links 3,494 PBR applications by those 439 unique ABNs, reflecting an additional 953 applications over and above those already linked in IPGOD. This covers almost 90 per cent of all applications with an address in Australia.

Once we account for duplicates we also identified 1,075 unique organisations with an address outside of Australia. The clarifications made should be treated with caution due to greater potential for unresolved name variations in the absence of unique known ABN. The top PBR applicants – whether Australian or international – are shown in Table 2. It reveals that the Australian Grains Research and Development Corporation (GRDC) is the top applicant; followed by US firm Zaiger's Inc Genetics, and by the NSW Department of Primary Industries.

We highlight that many of Australia's most prolific applicants (over all time) are government departments, or public bodies such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO). To a considerable degree, this is likely to reflect the historical prominence in Australia of government-led broadacre breeding programs. The data depicted here aggregate over time and therefore do not fully describe the nuances of a shifting balance of PBR applicants between the public and private sectors. Relatedly, research-intensive public bodies such as GRDC, CSIRO and government departments are often listed as PBR co-applicants, alongside other organisations. This may indicate where they have played a role as a funder or partner, rather than undertaking plant breeding activities themselves. A full analysis of the balance between the public and the private in PBR applications – and of the relationships and collaborations between them – await future research.

Table 2: Top 15 PBR applicants. 1988 to 2020, IP Australia

Name	Applications	ABN-matched	Country
GRDC	371	Y	AU
Zaigers Inc Genetics	230	N	US
NSW Department of Primary Industries	158	Y	AU
Nunhems BV	147	N	NL
QLD DAF	146	Y	AU
Nuflora International Pty Ltd	127	Y	AU
CSIRO	127	Y	AU
Suntory Flowers Limited	113	N	JP
Driscolls Inc	111	N	US
Ball Horticultural Company	110	N	US
Van Zanten Plants BV	109	Y	NL
Sugar Research Australia Limited	105	Y	AU
Western Australian Agriculture Authority	105	Y	AU
Rijk Zwaan Zaadteelt En Zaadhandel BV	103	Y	NL
W Kordes Sohne Rosenschulen Gmbh & Co Kg	92	N	DE

Source: IPGOD database country_code. Note: Data includes all applications, over all time, and is not restricted to active or granted PBR. All care was taken to harmonise unique organisations, however it is not possible to rule out the possibility that some name variations or alternative names listed on applications lead to incorrectly attributed PBRs.

[4] No harmonisation or disambiguation of individual applicants was attempted.

Applicants Outside Australia

Table 3 presents application counts by country where at least 10 PBR applications are recorded (based on applicant address). This table reveals that the United States is the most frequent international user of the system, whereas the Netherlands is the second most significant. From 2010 to 2020, the share of total applications from the Netherlands and the United States increased from 13 to 18 per cent, and from 7 to 17 per cent. At the same time, the share of PBR applications from Australian organisations fell from 53 to 41 per cent. We return to analysis of the contribution of foreign and domestic applicants (see below for a breakdown of the end-use sectors where key international PBR users are most active).

Table 3: PBR application counts for Australia and key foreign countries. 1988-2020, IP Australia

Country	Total	Organisational Applications	Individual
Australia	4,490	3,283	1,207
United States	1,682	1,428	254
Netherlands	1,060	950	110
Germany	634	360	274
New Zealand	515	388	127
Great Britain	329	233	96
France	276	177	99
Japan	275	227	48
Denmark	168	135	33
South Africa	117	54	63
Italy	77	32	45
Israel	76	70	6
Spain	59	32	27
Switzerland	42	41	1
Canada	32	24	8
Belgium	29	14	15
Ireland	28	16	12
Bulgaria	21	21	-
Austria	16	14	2
Czechia	15	15	-
Chile	10	1	9

Source: IPGOD database country_code and party_type categorisations.

Location of Domestic PBR Applicants

Information about the applicant's main business location is available for domestic PBR applicants matched in the ABR. Using ABR state and postcode data, Table 4 and Figure 2 present an overview of the geographical distribution of PBR applicants within Australia.

Table 4: Total PBR applications by Australian state. ABN-matched applicants, 1988-2020, IP Australia

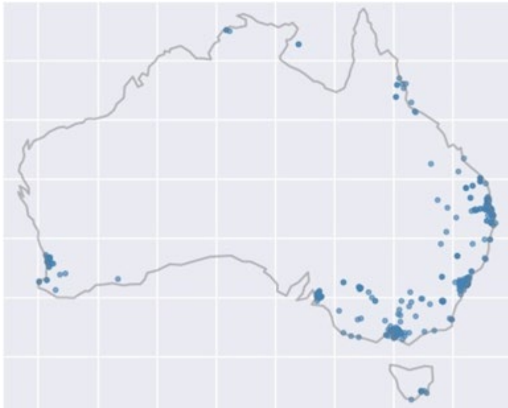
State	Total
NSW	952
ACT	608
VIC	520
QLD	456
WA	322
SA	203
TAS	39
NT	26

Source: IPGOD database country_code and party_type categorisations.

These breakdowns show that NSW accounts for almost twice as many PBR applications as Victoria, despite typically closer parity between the two states on other economic measures. Also noteworthy is the relatively high representation of the ACT based organisations.

Figure 2 displays the location of PBR applications. This illustrates that key agricultural regions are well represented; and although a clear concentration in the cities is evident, there is some evidence that PBR-applicant firms appear less concentrated in the capital cities than the population. Although not unexpected, given the regional distribution of Australia's agricultural and horticultural sectors, these observations tend to suggest that PBR has a role to play in supporting regional economies.

Figure 2: Postcode of main business location for ABN-matched PBR applicants. 1988-2020, IP Australia



Source: ABR database Mn_Bus_Pc; postcode geocoding

Industry of ABN-Matched PBR Applicants

Table 5 presents the top 10 most prominent industry classifications for Australia's PBR applicants. These industry classifications come from the ABR and cover all firms linked to PBR applications. Inspection of these industries – recorded here at the 1-digit ANZSIC division level – reflects a broad cross-section of the agricultural and horticultural industries, along with the research and development sector and government.

Table 5: Top-10 ANZSIC divisions by number of PBR applications. ABN-matched applicants, 1988- 2020, IP Australia

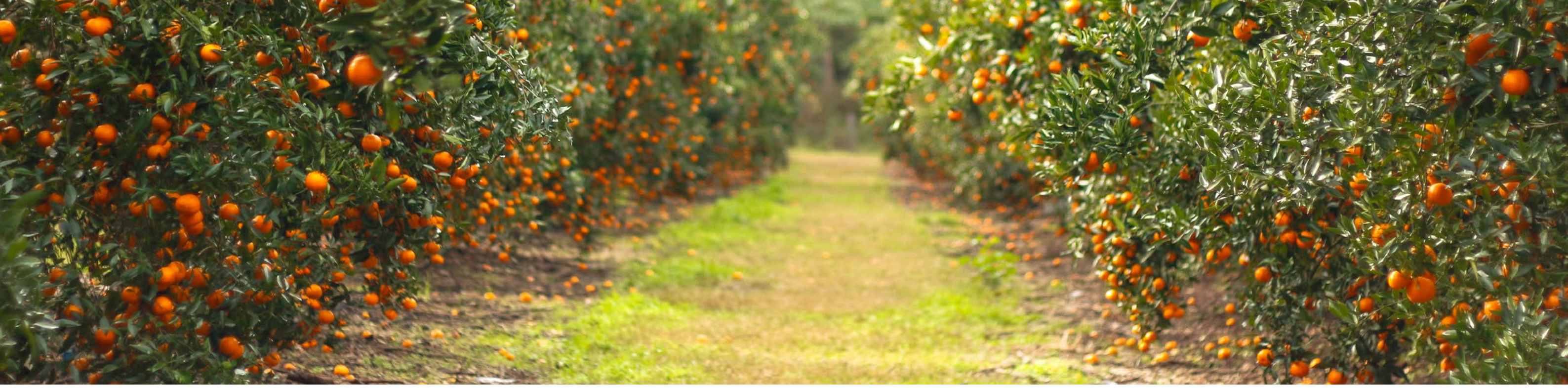
ANZSIC Division	PBR Applications #	PBR Applicants #
Agriculture, Forestry and Fishing	667	136
Professional, Scientific and Technical Services	626	48
Wholesale Trade	457	69
Other Services	396	9
Public Administration and Safety	332	12
Rental, Hiring and Real Estate Services	294	21
Education and Training	99	12
Financial and Insurance Services	85	35
Retail Trade	67	29
Manufacturing	44	13

Source: ABR database Mn_Indy_Clsn; ABS ANZSIC concordance tables

We note that several industry divisions are represented here which might not intuitively be expected. We have undertaken additional data quality assurance for these instances to confirm PBR-ABN linking and industry classification. These industry classifications may represent situations such as:

- Firms with more than one industry of operation (e.g., "Seed Technology & Marketing Pty Ltd" record their industry as "Advertising Services", in division "Professional, Scientific and Technical Services"). This is a significant part of their business; but they are also a respected seed business focusing on commercialisation.
- Firms who have categorised themselves in an unexpected industry (e.g., the "Western Australian Agriculture Authority" uses industry code "Non-Financial Intangible Assets (Except Copyrights) Leasing", which falls into the division of "Rental, Hiring and Real Estate Services").

We argue that due to the prevalence of considerations such as these, decomposition by industry of the applying firm is of limited analytic value. When used, ABR industry information should always be interpreted with care. We undertook a mapping to end-use sectors, outlined below, which provide more informative categories.



ECONOMIC ACTIVITY ATTRIBUTABLE TO APPLICANTS

The aggregate economic activity attributable to Australian PBR applicants were estimated using data in ABS Business Longitudinal Analysis Data Environment (BLADE). BLADE is a comprehensive census of balance sheet information on all firms in Australia. These include three administrative databases from the Australian Taxation Office covering the universe of Australian businesses since 2001-2019 — The Australian Business Activity Statement (BAS), Business Income Tax records (BIT) and the Pay-as-You-Go records (PAYG).

To identify firms which have registered PBRs we use Intellectual Property Longitudinal Research Data (IPLORD). IPLORD, produced by IP Australia, provides summary measures of each business's PBR applications (as well as other forms of registered IP). Note that these data are incomplete: IPLORD in BLADE include 265 unique ABNs with 1,409 PBR applications – this is considerably fewer than the 439 unique ABNs with 3,494 identified by CTI as part of this project. This difference primarily reflects incompleteness in the matches identified in IPLORD. A more comprehensive picture of the economic activity attributable to PBR owning firms would require linking the new CTI data to BLADE.

To estimate economic activity attributable to PBR owning firms, we identify all ABNs in BLADE with both financial data and at least one PBR application.[5] 265 ABNs account for a total of 1,409 PBR applications (as of 2018). This accounts for only 48 per cent of the 2,915 applications by Australian organisations up until 2018. Not all of the economic activity attributable to firms that apply for PBRs is directly related to the breeding and distribution of new plant varieties. For example, well known biscuit manufacturer Arnott's co-own three wheat PBR with Allied Pinnacle Australia.[6]

With these caveats in mind, Table 6 presents average annual economic activity for those PBR registering firms which averaged over 5 years to 2020. This data shows that PBR registering firms have a total annual turnover of almost $13 billion and total employment of approximately 78,000 full-time equivalent jobs. Since there are many firms which register PBR that are not linked in the ABS BLADE, these aggregates can be considered a lower bound. For example, this data only include 25 firms R&D expenditure[7] which is a small fraction of the 439 ABNs identified in section 1 of this report.

Table 6: Key metrics of economic activity PBR registering firms (average annual, 2016-2020)

Measure	Number of firms with data	Average	Aggregate
Legally enforceable Plant Breeder's Rights	235	5	1,085
R&D Investment ($1000s)	25	2,054	51,350
Turnover ($m)	160	80	12,816
Annual Capital Investment ($m)	160	10	1,578
Total Assets ($m)	235	3	742
Employment (FTE)	112	699	78,316

Source: BLADE Notes: Averages are across all years reported and across firms. BLADE variables and source tables are: Turnover (turnover, BAS), number of PBR (pbr_filed, IPLORD), R&D expenditure (c_label_d, BIT), employment (fte, PAYG) assets, Capital expenditure (capex, BAS). All units in real 2020 dollars (price index from ABS 6427.0 division A). Firms with enforceable PBR for which economic aggregates are taken are fewer than 265 reflecting firm entry and exit to BLADE as well as PBR non- renewals.

[5] Identified using the variable: pbr_first_gained_le_status_fy
[6] Though we have no way of knowing whether Arnott's are included in these aggregates reported in Table 6 because individual firms cannot be identified in BLADE.
[7] R&D investment data comes from claims for the R&D Tax Incentive. This data is preferred to the ABS Business Expenditure on R&D Survey because it has vastly better coverage (fewer missing observations). Plant breeding would not necessarily qualify for the R&D tax incentive (nor be counted under BERD) as this would depend on the extent that the outcome of selective breeding involves appreciable risk, inter alia.

PBR APPLICATIONS BY END-USE

To better understand economic end-use of PBR registered cultivars, we created a concordance between variety's scientific name (genus and species), and the commodity sector in which those plants are *primarily* used. The concordance maps to end-use were consistent with the agricultural commodity classifications as the Australian Bureau of Statistics (ABS) Value of Agricultural Commodities Produced (VACP) (ABS 2021).

To place PBR species into these commodity classifications, each plant's scientific and common names were considered by our team, alongside plant type lookup tables provided by IP Australia. This was in addition to other suitable reference sources wherever possible, generation a suggested categorisation. Classification to a single primary use comes with some caveats especially in the case of species with multiple potential uses. An example is barley, which may be grown for malting, animal fodder, or human consumption. The concordance table developed for this analysis which maps genus-species to economic end-use, is included as an attachment to this report and is subject to revision based on feedback from IP Australia, and other relevant stakeholders.

Table 7 provides a summary of the number of PBR applications, PBR applicants, and VACP estimated gross value[8] (2019-20 financial year) for each end-use category. Total applications comprises all applications, including foreign, domestic, individual, or organisational; so some categories record zero ABN-matched firms despite non-zero application counts.

Table 7: Stock of Total PBR Applications 1988 to 2020 (IP Australia) by end-use sector; with FY 2019 to 2020 gross commodity value (ABS VACP).

VACP Category	Detailed VACP Category	Total Applications #	ABN-matched Applicants #	2020 Production ($M)
Broadacre crops	Cereal crops - Wheat for grain	322	24	4,948
	Cereal crops - Barley for grain	113	18	3,006
	Non-cereal crops - Oilseeds - Canola	168	16	1,371
	Non-cereal crops - Sugar cane	134	5	1,253
	Non-cereal crops - Pulses and legumes - Other pulses (b)	34	4	870
	Cereal crops - Oats for grain	93	14	425
	Non-cereal crops - Cotton lint	110	3	252
	All other crops n.e.c.	72	12	197
	Non-cereal crops - Pulses and legumes - Chickpeas	35	10	179
	Cereal crops - All other cereals for grain or seed (a)	51	15	40
	Cereal crops - Rice for grain	14	5	39
	Non-cereal crops - Oilseeds - Other	8	2	26

[8] We note that the VACP gross "Production" values listed here represent prices as "realised at the point(s) of valuation where ownership of the commodity is relinquished by the agricultural industry" (ABS, 2021). This "farm gate" price provides a consistent comparison measure across commodities; however, for sectors such as ornamentals, it may not capture the ultimate retail value of e.g., nursery plants as sold to the consumer.

VACP Category	Detailed VACP Category	Total Applications #	ABN-matched Applicants #	2020 Production ($M)
Fruit and nuts	Grapes - Total	162	13	1,510
	Nuts - Almonds	15	1	784
	Plantation fruit - Bananas	8	2	647
	Orchard fruit - Apples	196	18	543
	Orchard fruit - Oranges	35	8	517
	Berry fruit - Strawberries	244	5	387
	Berry fruit - All other berries	250	6	370
	Orchard fruit - All other orchard fruit	210	8	329
	Orchard fruit - Avocados	21	6	328
	Orchard fruit - Mandarins	69	10	268
	Nuts - Macadamias	8	1	266
	Orchard fruit - Cherries	113	4	204
	Orchard fruit - Mangoes	41	10	172
	Orchard fruit - Nectarines	155	2	121
	Other fruit - All other fruit	122	22	119
	Nuts - All other nuts	8	0	87
	Orchard fruit - Peaches	234	12	71
	Pears (including Nashi)	36	4	68
	Plantation fruit - Pineapples	3	1	68
	Orchard fruit - Olives	13	3	61
Nurseries, cut flowers, cultivated turf	Nurseries	5,332	235	1,268
	Cultivated turf	154	34	218
Vegetables	All other vegetables n.e.c.	143	17	1,119
	Potatoes	352	8	652
	Tomatoes	46	1	480
	Carrots	9	0	254
	Lettuces	240	3	220
	Onions	15	1	177
	Beans (including french and runner)	74	13	158
	Sweet corn	4	0	146
	Broccoli	2	0	125
	Capsicum (excluding chillies)	19	1	116
	Pumpkins	10	3	86
Forage Crops	Forage crops	273	45	2,980

Source: Authors' calculations based on CTI genus-species-end-use concordance; ABS VACP (2019-2020) Table 1; value of forage crops Australian Seed Federation (2022).

Forage crops are a key input to improved pastures which underpin Australia's dairy, wool and meat and livestock industries, which collectively represented more than $32.4 billion of output in 2019-2020 (ABS 2021). However, forage crops are unusual in the sense that their economic impact derives significantly from their on-farm usage as an input to the livestock industry, rather than as a traded commodity. The value of forage crops is not captured in ABS VACP commodities tables. The Australian Seed Federation 2022 estimates that in 2021, $2.98 billion in farm-gate value from the major livestock industries can be attributed to annual pasture seed.

Table 7 reveals that the number of PBR applications and the overall gross value in a sector are not well correlated. Although some valuable sectors, such as wheat cropping, are comparably prominent in PBR applications, this is far from a general rule. Some highly prolific sectors for PBR (e.g. peaches) are associated with relatively lower gross output value, while some larger sectors (e.g. almonds) account for fewer PBR applications.

Table 8 shows the breakdown between domestic and foreign applications, summarised to major VACP categories. Table 9 shows the breakdown for Australian applicants by state.

Table 8: Key end-use sectors by applicant address. 1988-2020, IP Australia

End-Use	Foreign %	Domestic Applications %	Total #
Fruit and nuts	70	30	1,943
Nurseries, cut flowers or cultivated turf	56	44	5,486
Broadacre crops	17	83	1,154
Vegetables	82	18	914

Source: CTI end-use concordance table; IPGOD database country_code

Table 9: Percentage distribution of PBR end-use sectors by State and Territory. ABN-matched organisations, 1988-2020, IP Australia

	Percentage (%)								
End-Use Sector	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	Australia
Nurseries, cut flowers or cultivated turf	4	46	1	14	2	1	24	9	100
Vegetables	43	26	0	4	9	4	15	8	100
Fruit and nuts	20	33	3	16	4	1	17	15	100
Broadacre crops	37	18	0	24	10	1	10	12	100

Source: CTI end-use concordance table with ABR database Mn_Bus_Stt

COMPLEMENTARY APPROPRIATION MECHANISMS

Private business invests in breeding and commercialising improved varieties only to the extent that their expected return (seed sales and royalties) provide a commercial rate of return. Plant Breeder's Rights contribute to cultivar owners' ability to generate revenue from their registered varieties, by helping them prevent unauthorised, uncompensated use.

Commercial strategies to appropriate returns to innovation often involve multiple complementary legal, technological and commercial mechanisms. In the case of new plant varieties, legal instruments including PBR, patents and contracts as well as biological attributes and the commercial context affect the ease of unauthorised propagation. For example in the case of open pollinated wheat, the traded commodity (grain) is also propagative material making it difficult to prevent unauthorized propagation and use without IP rights enforcement. In contrast, a hybrid corn or canola is the product of two different parent lines so saved seed does not maintain desired agronomic attributes. In the case of hybrid varieties propagation requires access to the parental lines which are secret and not dispersed in normal commercial use. For this reason, commercial breeding in corn predated the introduction of plant variety patents (e.g. Grilliches 1957). Many fruit trees are clonally propagated, meaning propagating material is dispersed across growers, but not downstream users of agricultural output, such as fruit consumers. Contracts with individual breeders may be more useful in this case than in the case of open pollinated wheat.

A comprehensive review and quantification of the role of PBR in appropriating returns to each specific variety or even across all end-use is beyond the scope of this report. Instead, in this section we aim to describe the distribution of some observable factors which can affect breeders' ability to appropriate returns on their varieties. We focus on the extent of relevant patenting, and mode of propagation.

Plant Related Patenting

Beside PBR, one Australian IP protection of particular relevance to plant breeders is the patent. Patents are another form of intellectual property protection potentially relevant to plant breeding.[9] In practice, conventionally bred varieties are not patented in Australia, presumably because they do not meet the novelty and non-obviousness requirements. Genetically modified varieties, however, have been patented.

Aside from varieties themselves a range of related technologies involved in plant breeding and the development of transgenic varieties are patentable. Patents can play a role across pre- breeding activities and other upstream genetic science, which can be used by in variety improvement. Pre-breeding activities include identifying genetic markers associated with specific phenotypic traits (qualitative trait loci, or QTLs). QTLs are typically not patented. Genes are patentable in some circumstances. Innovations relating to genes, gene regulators, and transformation methods are all potentially subject to patent.

[9] Trademarks are another relevant protection. However, analysis of trademarking is out of scope of this report. Future work on trademarking in plant breeding would be valuable.

The extent that the breeding industry applies for patents is an indicator of the degree to which patents provide a complementary appropriation mechanism for PBR. To assess the extent to which industry uses these plant patents, we first aim to identify the corpus of relevant patent applications. We focus on patents designated under International Patent Classification (IPC) subclass A01H ('*New plants or processes for obtaining them; plant reproduction by tissue culture techniques*').[10] We refer to these as "plant-related patents". This subclass comprises "all aspects related to new plants", (WIPO 2021) including processes for modifying genotypes and phenotypes, and reproduction by tissue culture techniques. The subclass includes:

- the plant variety;
- any part of the plant (including harvested material, genes, proteins, other molecules);
- use of the plant variety or its part(s);
- methods of breeding plants using the protected variety and resulting progeny; and
- products derived from the plant.

Administrative data reveal 4,931 patents are recorded under the A01H subclass, which we will refer to below as "plant-related patents" (A01H). The breakdown of these patents by represented IPC main group code is given in Table 10. From our reading, it appears that few of these patents cover varieties specifically – but more commonly relate to specific genetic or biological processes or elements associated with that species.

Table 10 and underlying data show that patents pertaining to angiosperms generally, to genotype modification, and to angiosperm seed were most common in this subclass. Most other classification groups and subgroups were quite sparsely represented.

Table 10: Breakdown of patents within IPC subclass A01H, by IPC main group code. 1960 to 2020, IP Australia

IPC Main Group Code	Main Group Description	Applications #
A01H 5/00	Flowering plants, i.e. angiosperms	3,871
A01H 1/00	Processes for modifying genotypes	1,514
A01H 4/00	Plant reproduction by tissue culture techniques	530
A01H 3/00	Processes for modifying phenotypes	162
A01H 15/00	Fungi; Lichens	46
A01H 17/00	Symbiotic or parasitic combinations including one or more new plants, e.g. mycorrhiza	44
A01H 7/00	Gymnosperms, e.g. conifers	41
A01H 13/00	Algae	33
A01H 6/00	Angiosperms, i.e. flowering plants, characterised by their botanic taxonomy[11]	29
A01H 11/00	Bryophytes, e.g. mosses, liverworts	24
A01H 9/00	Pteridophytes, e.g. ferns, club-mosses, horse-tails	20

Source: IPGOD patent-classification table, classification and application_number fields

Patenting Behaviour with Time

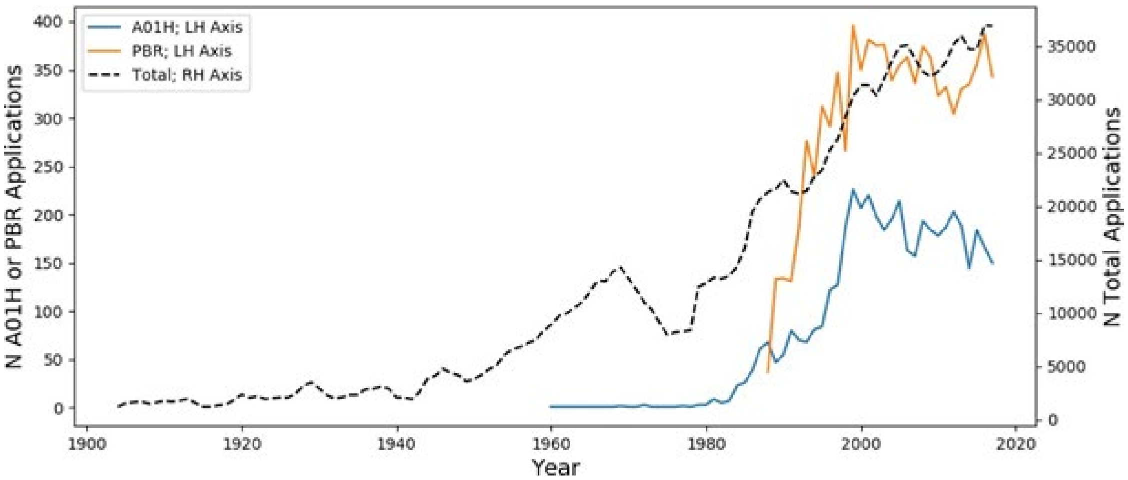
Figure 3 shows trend in applications for patents in class A01H by filing date. This figure shows that use of plant related patents began in Australia in 1960 and rose rapidly from around 1980 towards the turn of the century, where they appear to have plateaued, and perhaps subsequently undergone a gradual decrease. Comparing this to the time distribution of *all* patent applications, as at right, shows that the usage trends in A01H are not merely a reflection of general trends in patent usage: rising much more rapidly, and peaking somewhat earlier than the overall patent corpora.

Trends in A01H are reasonably similar to trends in PBR applications, albeit at an overall lower level. PBR applications also rose rapidly to a peak in around 2000 and have held fairly steady since. However as Figures 1 and 3 show, PBR applications tend to number between 300-400 per year; approximately double the 150-200 A01H patent applications.

[10] We also assessed the closely related IPC subclass A01G ('*Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or seaweed; forestry; watering*', however this subclass appears to cover techniques and apparatuses of plant production generally (i.e., downstream industries from breeding). Some A01H patents (especially in main groups A01H 1/00 – A01H 4/00 may also pertain to the protection of techniques, rather than of plant varieties *per se*. However, being more closely aligned with plant breeding, these A01H patents have been retained in the following analysis.

[11] A01H 5/00 codes apply to angiosperms classified according to their plant parts, whereas A01H 6/00 codes apply to angiosperms classified according to their botanical taxonomy (WIPO, 2021)

Figure 3: Comparative time distribution of patent applications in A01H; PBR applications; and total Australian patent applications. Patents 1901 to 2020; PBR 1988 to 2020; IP Australia



Source: IPGOD earliest_filed_date; PBR register application_number

Who uses Patent Protection?

A total of 1,538 parties are responsible for these patents.[12] Of these 83 per cent are organisations, and 17 per cent are individuals. Table 11 describes the distribution of patent applicants by entity type. More than 90 per cent of plant-related patents are owned by foreign entities,[13] which is significantly higher than the share of PBR applications attributed to foreign entities (55 per cent). Table 12 gives an analogous breakdown for application counts, and reveals a similar dominance of organisational and foreign applicants.

Table 11: A01H patent applicant count by type. 1960 to 2020, IP Australia

	Domestic #	Foreign #	Total #
Individual	21	214	235
Organisation	116	1,058	1,174
Total	137	1,272	1,409

Source: IPGOD party_type, party_id, country_code, application_number

Table 12: A01H patent application count by type of applicant. 1960 to 2020, IP Australia

	Domestic #	Foreign #	Total #
Individual	40	137	177
Organisation	388	4,504	4,892
Total	428	4,641	5,069

Source: IPGOD party_type, country_code, application_number

[12] That is, are associated with the patent in the role of 'applicant' or 'patentee'. Other possible roles, such as 'agent', 'opponent', etc have not been included in this analysis.
[13] As noted previously domestic/foreign classification is based on the address provided by the applicant, which is subject to a number of caveats. We caution against over-interpretation of these breakdowns. We further note that more than one applicant may be recorded per application.

Of the 116 organisations that applied for plant related patents (A01H) that also have an Australian address, 98 were matched to their ABNs.[14] These firms account for 359 of the 388 total A01H patent applications from Australian firms.

Few Australian firms which apply for PBR also apply for patents. Earlier in the report, we observed 439 Australian firms which have applied for PBR, which is considerably greater than the 98 Australian firms holding A01H patents. Only 34 firms were identified which have applied for both PBR and plant related patents. That is, only 8 per cent of PBR applicants also take out patent protection.

Table 13 illustrates the PBR and patent (A01H) count for those companies which have applied for both.

Only a small number of organisations have more than 10 patent applications. Only three organisations have both patent and PBR application counts in the dozens. These three are significant breeding and R&D institutions: CSIRO, GRDC, and Agriculture Victoria. Smaller organisations including private companies, appear relatively unlikely to use both PBR and patents in large numbers, but seem to make more use of PBR. No organisation uses patents more than they use PBR.

Among those firms applying for both, those firms which are most intensive users of PBR are least intensive users of patents (and vice versa). The overall pattern suggests that PBR and plant related patents are generally used by different firms.

Table 13: Count of A01H patent applications vs count of PBR applications for firms using both. 1960 to 2020, IP Australia

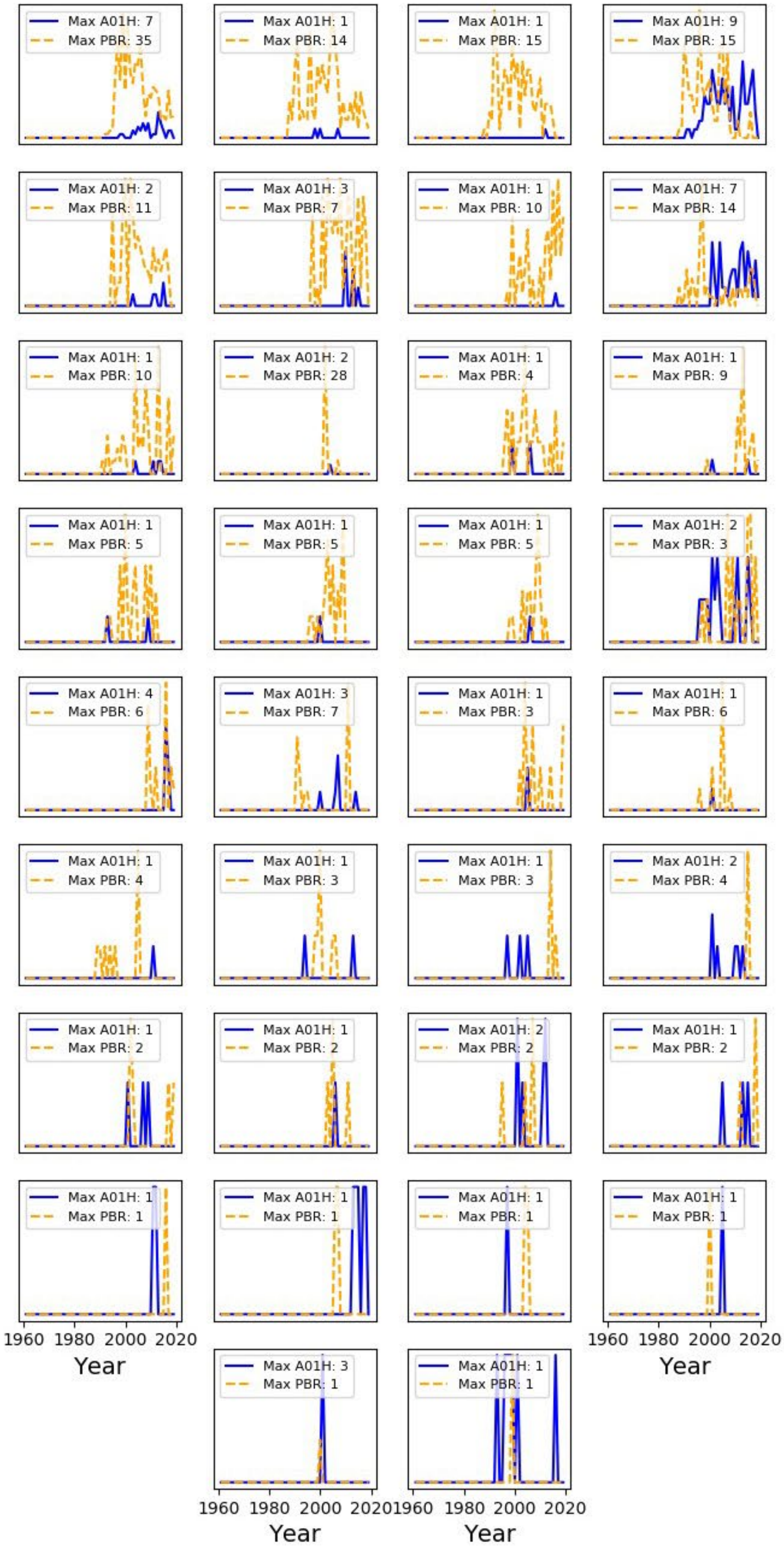
Applicant	A01H Patent Applications #	PBR Applications #
Grains Research and Development Corporation	41	371
NSW Department of Primary Industries	3	158
QLD Department of Agriculture and Fisheries	1	146
CSIRO	109	127
Sugar Research Australia Limited (SRA)	5	105
Ozbreed Pty Ltd	6	79
The Paradise Seed Company Pty. Limited	1	76
Agriculture Victoria Services Pty Ltd	66	61
Bonza Botanicals Pty Limited	4	60
Phytonova Pty Ltd	2	34
Rural Industries Research & Development Corporation	2	27
SARDI	2	26
Pacific Seeds Pty Ltd AKA Advanta Seeds Pty Ltd	2	25
Australian Wool Innovation Limited	1	22
University of Tasmania	1	18
The University of Queensland	16	17
Cotton Seed Distributors Ltd	6	17
Adelaide Research & Innovation Pty Ltd	6	15
Pristine Forage Technologies Pty Ltd	1	11
VIC Department of Natural Resources and Environment	1	10
QLD Department of Employment Economic Development and Innovation	1	9
The University of Western Australia	2	7
Meat & Livestock Australia Limited	3	6
Queensland University of Technology	6	5
The University of Adelaide	3	5
Syngenta Seeds B.V.	1	4
Bses Limited	6	4
Springbrook Nominees Pty Ltd	3	3
QLD Department of Agriculture Fisheries and Forestry[15]	2	2
Nuseed Pty Ltd	6	2
The Cooperative Research Centre For Tropical Plant Pathology	1	2
Belair Technology Pty Ltd	1	1
Dairy Research and Development Corporation	3	1
The University of Melbourne	7	1

Source: IPGOD party_name and application_number; CTI ABN-matched and disambiguated PBR register

[14] 91 have an ABN recorded in IPGOD, and through additional disambiguation and matching the authors identify a further 7 unique ABNs

[15] Historically distinct from "QLD Department of Agriculture and Fisheries", also listed.

Figure 4: Historical applications for PBR and for A01H patents, by firm. 1960 to 2020, IP Australia



Patenting and End-Use Sectors

Table 14 shows the share of PBR which are accounted for by organisations which also apply for plant related patents (A01H), by broad end-use category for Australian applicants. This shows that most PBR in broadacre are applied for by firms which also apply for a patent.[16]

Plant related patents do not appear to be highly correlated with the use of PBR. Over 90 per cent of relevant patent applications are from abroad, in contrast to a little over half in the case of PBR.

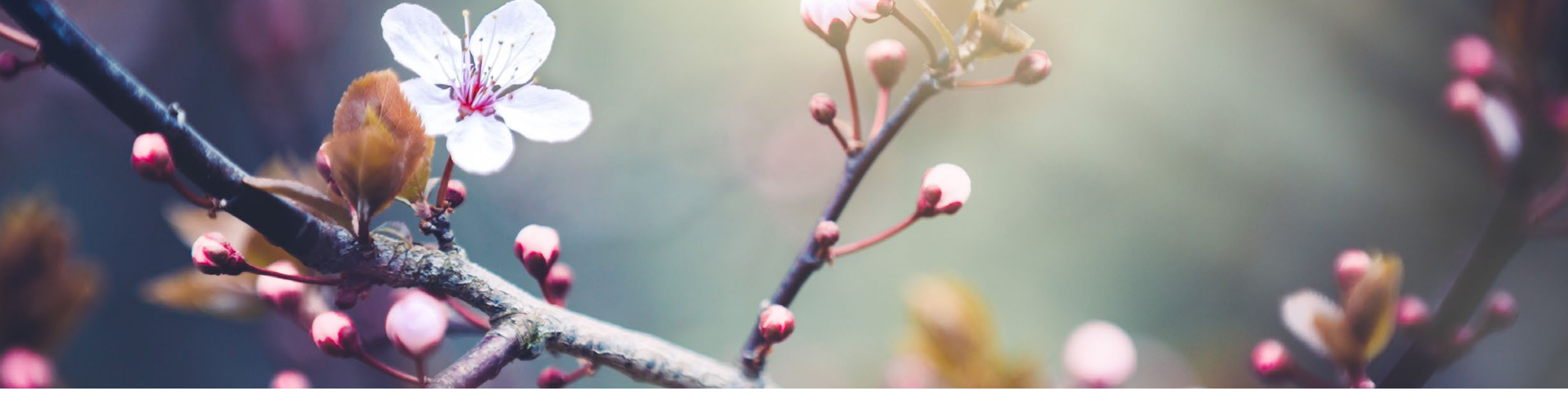
Most Australian firms which apply for plant-related patents do not apply for PBR. Our comparison of the pattern of applications for plant-related patents and PBR indicate that, among Australian firms, the two are not highly correlated. Conversely most Australian firms who apply for PBR do not apply for plant-related patents, with the exception among breeders of key broadacre staples and government and university research entities.

Table 14: PBR application counts by broad VACP category – comparison of contribution from all applicants vs contribution from patenting applicants. 1988 to 2020, IP Australia

VACP Category	Total PBR applications #	PBR applications from firms which patent #	PBR applications from firms which patent %
Broadacre crops	1,159	556	47.97
Forage crops	514	165	32.10
Vegetables	959	105	10.95
Fruit and nuts	1,899	140	7.37
Nurseries, cut flowers or cultivated turf	5,502	290	5.27

Source: CTI end-use concordance table; IPGOD & PBR register disambiguated ABNs

[16] Note that it is not readily possible to identify end-use of relevant varieties from patents alone, since the genus and species is not systematically recorded for plant related patents.



PROPAGATION AND EASE OF APPROPRIATION

Biological attributes relating to conventional commercial propagation of various cultivars influence how costly it is to prevent unauthorised use and therefore breeders' ability to appropriate returns on their varieties. In this section we aim to describe the distribution of prevalent commercial propagation methods by end-use. We distinguish first between whether propagation is typically clonal or via seed. If propagation is typically via seed, whether saved seeds express the relevant attributes of the parent lines. Historical evidence suggests that PBR play a different role in each case, which is consistent with a view that the role of PBR in enabling breeders to prevent unauthorised use and collect revenue varies between these categories.

Among varieties grown from seed, we specifically distinguish between hybrid and open-pollinated varieties. A hybrid cultivar is the product of two *different* parent lines,[17] so saved seed does not maintain desired agronomic attributes. Unauthorised use of hybrid seed is more difficult than in the case of non-hybrids. It is generally considered that this biological appropriation mechanism supported the establishment of commercial breeding of hybrid corn prior to the introduction of plant patents (Berlan and Lewontin 1986; Kutka 2011).

Sexually propagated crops which are not hybrids are referred to as open pollinated varieties, and these can be grown from saved seed.[18] Many key stable crops such as wheat and barley are open pollinated. In the absence of legal recourse, it is difficult to prevent unauthorised use (resowing, on selling etc) of open pollinated varieties. Arguably, PBR are the most important for appropriation in the case of open pollinated crops. Prior to the introduction of PBR, variety improvement relied on government investment.

Many ornamentals and a majority of fruits are typically clonally propagated – i.e. propagated from plant tissue taken from the parent plant, such as a cutting. In principle for clonally propagated plants a one-time purchaser of a new variety can thereafter propagate that variety freely, without profit to the original breeder. However unlike the case of open pollinated sexually reproduced varieties, agricultural products (e.g. an apple grown from a clonally propagated apple tree) are not, of themselves, propagating material of the protected cultivar.[19] This implies that propagating material is in general restricted to growers only, and not extended to consumers. Appropriability in the case of clonally propagated species is therefore likely to fall between open-pollinated and hybrid seed propagated varieties.[20]

We have estimated the share of PBRs in each of these three categories. To do so, a literature search was performed to establish the usual methods of commercial propagation in each end-use sector.[21] For each end-use sector[22], we have sought in Table 15 to give a (necessarily general) assessment of what the *most common commercial* method of propagation is for plants in that category.

Wheat for example, has historically been almost exclusively open pollinated, due to the difficulty of creating hybrid strains. We therefore categorise wheat's 'typical (commercial) propagation' as being 'open pollinated'. Similarly tomato farming at a commercial level is dominated by hybrids, and has been categorised as such in Table 15; however, there is also enthusiasm, especially among smaller growers, for so-called "heirloom", or open-pollinated, varieties. Despite such nuances, we believe Table 15 provides a fair summary of the most typical commercial propagation method by end-use sector.

[17] The progeny of these different parents (F1) has a known phenotype but unstable genotype due to heterozygosity, hence the subsequent generations will exhibit random diversity (i.e., they do not breed 'true to type').
[18] The terms "open-pollinated," "self-pollinating," and "inbred" are sometimes used interchangeably. Such seed are both inbred and self-pollinating. Self-pollinating means the flowers can pollinate themselves. Inbred (or homozygous) means the progeny (F1) is bred from parents carrying the same alleles (i.e., genetically the same) for physiological attributes of interest.
[19] Varieties of these species are typically heterozygous so seed progeny do not breed true-to-type
[20] Of course, there is likely to be variation in the ease of appropriation across different clonally propagated species and sectors
[21] The authors gratefully acknowledge Andrew Hallinan, PBR data steward, for useful discussions on the methodology and results of this search
[22] Excluding nonspecific sectors such as "Broadacre crops - All other crops n.e.c.", for which a specific assessment may not be possible or appropriate

Table 15: Category of typical propagation method by end-use sector. 1988-2020; CTI, IP Australia

VACP Detailed Category	Typical Propagation	Applications #
Broadacre crops - Cereal crops - Barley for grain	Open Pollinated	110
Broadacre crops - Cereal crops - Oats for grain	Open Pollinated	89
Broadacre crops - Cereal crops - Rice for grain	Open Pollinated	15
Broadacre crops - Cereal crops - Wheat for grain	Open Pollinated	322
Broadacre crops - Non-cereal crops - Cotton lint	Open Pollinated	110
Broadacre crops - Non-cereal crops - Oilseeds - Canola	Open Pollinated	168
Broadacre crops - Non-cereal crops - Pulses and legumes - Chickpeas	Open Pollinated	35
Broadacre crops - Non-cereal crops - Sugar cane	Hybrid	134
Forage crops	Variable	514
Fruit and nuts - Berry fruit - Strawberries	Clonal	246
Fruit and nuts - Grapes - Total	Clonal	157
Fruit and nuts - Nuts - Almonds	Clonal	15
Fruit and nuts - Nuts - Macadamias	Clonal	8
Fruit and nuts - Orchard fruit - Apples	Clonal	195
Fruit and nuts - Orchard fruit - Avocados	Clonal	21
Fruit and nuts - Orchard fruit - Cherries	Clonal	115
Fruit and nuts - Orchard fruit - Mandarins	Clonal	69
Fruit and nuts - Orchard fruit - Mangoes	Clonal	40
Fruit and nuts - Orchard fruit - Nectarines	Clonal	156
Fruit and nuts - Orchard fruit - Olives	Clonal	13
Fruit and nuts - Orchard fruit - Oranges	Clonal	35
Fruit and nuts - Orchard fruit - Peaches	Clonal	234
Fruit and nuts - Orchard fruit - Pears (including Nashi)	Clonal	36
Fruit and nuts - Plantation fruit - Bananas	Clonal (Triploid)	8
Fruit and nuts - Plantation fruit - Pineapples	Clonal	3
Fungi	N/A	19
Nurseries, cut flowers or cultivated turf - Cultivated turf	Clonal	154
Nurseries, cut flowers or cultivated turf - Nurseries	Clonal	5,368
Timber	Variable	5
Vegetables - Beans (including french and runner)	Open Pollinated	74
Vegetables - Broccoli	Hybrid	2
Vegetables - Capsicum (excluding chillies)	Hybrid	19
Vegetables - Carrots	Hybrid	9
Vegetables - Lettuces	Open Pollinated	241
Vegetables - Melons	Hybrid	46
Vegetables - Onions	Hybrid	15
Vegetables - Potatoes	Clonal	351
Vegetables - Pumpkins	Variable	10
Vegetables - Sweet corn	Hybrid	4
Vegetables - Tomatoes	Hybrid	46

Summarising Table 15, 8,037 PBR applications are in end-use sectors where plants are more likely to be open pollinated (N=1,164 applications) or clonally propagated (N=7,224 applications). Only 275 (3 per cent) PBR applications are in end-use sectors where plants are more likely to be hybrid – although, of course, some PBR applications in traditionally open-pollinated end-use sectors are likely to describe new hybrid cultivars introduced to those sectors.

Some of the remaining share of PBR applications (N=880 applications) are in non-specific sectors for which no categorisation has been attempted (e.g. "Vegetables - All other vegetables n.e.c."); or in fungi, for which none of these categories apply. It is worth mentioning the forage crops and timber sectors in particular, which have been categorised as having "variable" typical propagation (N=529 applications total). Forage crops for example, include a wide range of true-to-seed pasture grasses and grains, but also include subsectors which are hybrid-dominated, such as forage sorghums and hybrid ryegrasses. We have not attempted to apply a single categorisation to these highly diverse sectors.

ECONOMIC IMPACT OF NEW VARIETIES

In this section we provide estimates of the economic value attributable to plant breeding across a range of end-use sectors. The logic of our evaluation approach involves breaking down the economic contribution of PBR into three stages of the value chain:

1. The role of PBR in the provision of new varieties
2. the growth rate of commodity output that is attributable to new varieties; and
3. the overall value of each commodity produced in Australia.

The economic value of output in each end-use sector (3) is taken from the ABS's Value of Agricultural Commodities Produced (VACP) database, as described in the PBR Applications by End-Use section of this report. We estimate the contribution of new cultivars to annual growth in output (2) by taking a share of observed long term average yield growth, where the share comes from existing literature described below.

To measure average recent yield growth[23], we obtain yield data by sector for Australia for the years 1961-2020 from the Food and Agriculture Organisation of the United Nations (FAOSTAT).[24] We calculate the average yield growth per annum by fitting a linear model to the data. This assumes arithmetic growth, consistent with evidence for most field crops (Duvick 2004; Grassini *et al* 2013).[25] These data are depicted for each sector in Appendix Figure A1. Recent growth in percentage terms is derived by dividing arithmetic growth rate by average yield over the most recent five year period.

We find that average growth in yield in three sectors has been negative. These are excluded from the analysis, since new varieties cannot reduce value of sector output.[26] We also omit from analysis any end-use sectors for which suitable yield data is not available in FAOSTAT, or for which productivity is not well summarised by yield (e.g. nurseries).

In practice new cultivars are one of several factors contributing to yield growth. Trends in yields over time reflect the combined effect of changes in land use, new agronomic practices, capital equipment, fertilizer and pesticide use, *inter alia*. To estimate the component of growth attributable to new varieties we refer to existing literature, which commonly places the contribution of new varieties to overall yield growth at around 50 per cent of the total yield growth per annum (Cardwell 1982; Duvick 2004; Fischer & Edmeades 2010; Berzsenyi 2018; Kumar *et al* 2019).[27]

We note that existing evidence is not evenly focused across end-use sectors, with most studies being focused on field crops. However estimates outside field crops appear broadly consistent. For example, Walker *et al* (2003) report values between 17 per cent and 89 per cent for potatoes in limited tests, while Grandillo *et al* (1999) report values between 19 per cent and 67 per cent for tomatoes. We therefore assume approximately half of observed yield increases can be attributed to new cultivars.

[23] Yield growth provides a suitable metric of sector output for most agricultural commodities. For some sectors, however, the trade-off between output quantity and output quality may play a more important role than is typical: wine grape growing is one such example. Although it is beyond the scope of this research to incorporate sector-specific modelling of this trade-off, we encourage the reader to bear such considerations in mind while interpreting Table 16.

[24] Initially, it was planned to source yield increase estimates from the literature independently by end sector. However, published estimates were absent for some sectors, and highly variable for others. Moreover, it quickly became apparent that FAOSTAT was the most widely cited source of yield data, establishing this as a suitable source for our research.

[25] Although some projections assume yield increases can compound to produce exponential yield growth, exponential growth has historically occurred over short time periods only, rather than in the long term (Grassini *et al*, 2004).

[26] Note this does not allow for the possibility that fall in yield would be greater in the absence of variety improvement.

[27] Some authors put this figure even higher. A contribution of up to 90 per cent of yield increase for field crops is attributed to breeding alone by Fischer & Edmeades (2010) and the British Society of Plant Breeders (2008). Further, Edmeades & Tollenaar (1990) and Fischer & Edmeades (2010) suggest that the proportion of yield growth due to genetic improvement has increased in recent decades, as gains from management improvements plateau.

Table 16: Estimated economic impact of new cultivars by end-use sector in Australia. Yield growth calculated 1961-2020 (FAOSTAT); gross value 2019-2020 FY (ABS VACP)

VACP Category	Historic Aus. yield growth (% p.a.)	VACP gross value (2019 - 2020; $M)	Approx. contribution from new cultivars ($M p.a.)
Broadacre crops - Cereal crops - Barley for grain	0.92	3,006	13.76
Broadacre crops - Cereal crops - Oats for grain	0.88	425	1.87
Broadacre crops - Cereal crops - Rice for grain	0.71	39	0.14
Broadacre crops - Cereal crops - Wheat for grain	1.43	4,948	35.33
Broadacre crops - Non-cereal crops - Oilseeds - Canola	0.87	1,371	5.94
Broadacre crops - Non-cereal crops - Pulses - Chickpeas	0.38	179	0.34
Broadacre crops - Non-cereal crops - Sugar cane	0.16	1,253	0.99
Vegetables - Beans (including french and runner)	0.35	158	0.27
Vegetables - Carrots	1.02	254	1.29
Vegetables - Lettuces	0.78	220	0.86
Vegetables - Melons	1.42	177	1.26
Vegetables - Onions	1.32	177	1.17
Vegetables - Potatoes	1.19	652	3.87
Vegetables - Pumpkins	1.05	86	0.45
Vegetables - Tomatoes	1.24	480	2.99
Fruit and nuts - Berry fruit - Strawberries	1.44	387	2.78
Fruit and nuts - Grapes - Total	-0.02	1,510	-
Fruit and nuts - Nuts - Almonds	1.96	784	7.67
Fruit and nuts - Orchard fruit - Apples	0.28	543	0.77
Fruit and nuts - Orchard fruit - Avocados	0.89	328	1.45
Fruit and nuts - Orchard fruit - Cherries	0.19	204	0.19
Fruit and nuts - Orchard fruit - Olives	0.67	61	0.20
Fruit and nuts - Orchard fruit - Oranges	0.61	517	1.58
Fruit and nuts - Orchard fruit - Peaches plus Fruit and nuts - Orchard fruit - Nectarines	-1.50	192	-
Fruit and nuts - Orchard fruit - Pears (including Nashi)	-0.16	68	-
Fruit and nuts - Plantation fruit - Bananas	0.89	647	2.89
Fruit and nuts - Plantation fruit - Pineapples	0.94	68	0.32

Source: long-term yield growth calculated by CTI from FAOSTAT yield; gross values (2019-2020 FY) from VACP

Table 16 depicts our estimates of the *additional* annual agricultural output attributable to variety improvement by sector. These figures indicate that – across those sectors for which data was available – cumulative output increases due to yield increases total around $180 million each year.

Assuming 50 per cent of this growth in yield is attributable to the development and commercialisation of new cultivars, we estimate that *each year* new cultivars expand agricultural output by something in the order of $90 million.

The end-use where new cultivars are likely having the largest impact include those with the largest value of output and those which are achieving the highest yield gain. Among those end-use for which both these data are available these data suggest broadacre staples (including wheat, barley canola) are among the commodities with the greatest value of increased yield to which new cultivars contribute. All of these are predominantly open pollinated and therefore the most reliant on PBR to encourage private breeding. Among fruits and nuts, almonds and strawberries exhibit both larger output and yield increase, both are clonally propagated. Among vegetables, for which both data are available, the commodities with the highest value of increased yield are potatoes (clonal) and tomatoes (often hybrid).

The economic contribution of new varieties does not end after one year. The additional value is generated by that variety in each year it is sown and potentially beyond to the extent the variety improvement is cumulative.

In the long view of history, much of the agricultural sector today would not be possible were it not for historic investment in improved cultivars.

The net present value of economic activity attributable to a new cultivar therefore reflects the additional output it generates in the first year it is sown, plus the additional output generated in each year thereafter. The net present value of new cultivars each year reflect the discounted stream of value attributable and can be calculated by the formula:

$$\lim_{n \to \infty} \sum_{t=1}^{n} R\left(\frac{1-\delta}{1+\pi}\right)^{n} = \frac{R}{1-\frac{1-\delta}{1+\pi}}$$

Where depreciation is denoted by δ and discounting is denoted by π. As is always the case with these types of net present value calculations, the final estimate is enormously sensitive to the choice of discount rate and deprecation rate applied. We therefore provide the discussion below to provide an indicative scale rather than a definitive estimate.

Depreciation of capital goods reflects the reduction of productive capacity over time. Depreciation of physical capital occurs because of physical wear and tear. Depreciation in the case of intangible assets such as plant varieties is more complex. The private value of new cultivars diminishes as they are superseded by improved varieties, but the public benefit (value contributed to the overall agricultural sector) depends on the degree to which existing varieties provide genetic input to future varieties.[28] Varieties do not depreciate in the manner that physical capital goods depreciate. Once this variety is superseded by another higher yielding variety, the private value is extinguished but the social value depends on the extent that breeding is cumulative. The evolution of new strains of pathogen (e.g. stem rust) may be seen as causing economic depreciation of social value of cultivars.

One way to provide an upper bound estimate of the rate of depreciation of new cultivars is to consider their effective economic life. Singe *et al* (2020) summarize the average varietal age among different crops across different crops and regions, which are found to vary from a low of wheat in the UK (3 years) to potato in the USA (40-50 years). Observing that the private depreciation rate is likely to be higher than the social depreciation rate, 5 per cent per annum might provide a reasonable benchmark. Though estimates would be improved if end-use specific estimates were available.

Accordingly we use a depreciation rate of 5 per cent and a societal time preference rate of 1 per cent. The net present value (NPV) of the additional economic output generated by new cultivars bred and commercialized each year is therefore given by:

$$\frac{\$90\text{m}}{0.06} = \$1.5 \text{ billion}$$

As noted this figure should be interpreted bearing in mind key caveats.

- Sensitivity to choice of time preference and deprecation rates and lack of clear guidance as to an appropriate value to use.
- Key sectors worth a total of 33 per cent of 2019-2020 agricultural output could not be included in this total. These were omitted because of the lack of readily available or suitable data on yield growth.
- Evidence on the contribution of new varieties to productivity appears limited. In practice this measure probably varies between end-use sector, however in the absence of more detailed data we apply a blanket 50 per cent across the board.
- The analysis does not consider the investment cost by breeders to generate these yield gains, so this should not be considered a rate of return.

[28] While individual varieties are not necessarily superseded by their own direct descendants, the population of frontier cultivars is largely developed from the germplasm of existing varieties.

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APPENDIX 1: DATA SOURCES AND LINKING

The analysis presented in this Report is based on analysis of four main sources:

1. The Plant Breeder’s Rights Register (PBR Register): an internal database maintained by IP Australia, which records information pertinent to all Australia’s PBR applications. The portions of this database provided to support this research include data tables recording the genus, species, and variety where supplied, of the cultivars for which a PBR protection has been sought.
2. The Australian Business Register (ABR): the official record of Australian business entities and their details. The ABR database used for this project incorporates both public and non-public ABR information, including business addresses, as at 2020.[29]
3. Intellectual Property Government Open Data (IPGOD): a publicly available data set, recording key information on Australia’s intellectual property applications and applicants, including Australian Business Numbers. This data set is released annually. Our analysis uses the 2020 IPGOD release, as available from data.gov.au.[30]
4. Business Longitudinal Analysis Data Environment (BLADE) provides a comprehensive census of balance sheet information on all firms in Australia. We link 4 administrative databases including IPLORD; The Australian Business Activity Statement (BAS), Business Income Tax records (BIT) and the Pay-as-You-Go records (PAYG).

The PBR Register and IPGOD are the two data sources from which this research has extracted PBR applications. However the overlap in applications between these two datasets is not exact. The PBR Register extract used for this research contains a small number of applications which - due to recency, or privacy considerations - are not contained in the IPGOD 2020 data release. Similarly IPGOD contains <50 applications which were not contained in our PBR register extract. To enable methodological consistency throughout our research, only those applications which appeared in both IPGOD and the PBR register have been considered in the analyses presented above. However with >10,000 applications under consideration and only 160 discarded, this does not affect confidence in the results above.

With this sample in place, a single piece of non-standard processing was performed: specific to the PBR register/IPGOD data format and to the case where a PBR application is submitted on behalf of multiple entities. In this case this text field recording applicant_name contains the names of all applying entities (e.g. it might record ‘Smith Nursery and Jones Investments’, or ‘NSW Department of Primary Industries; University of Sydney’). Such applications submitted on behalf of multiple entities were carefully identified, and each entity split to a separate record associated with the appropriate application number.

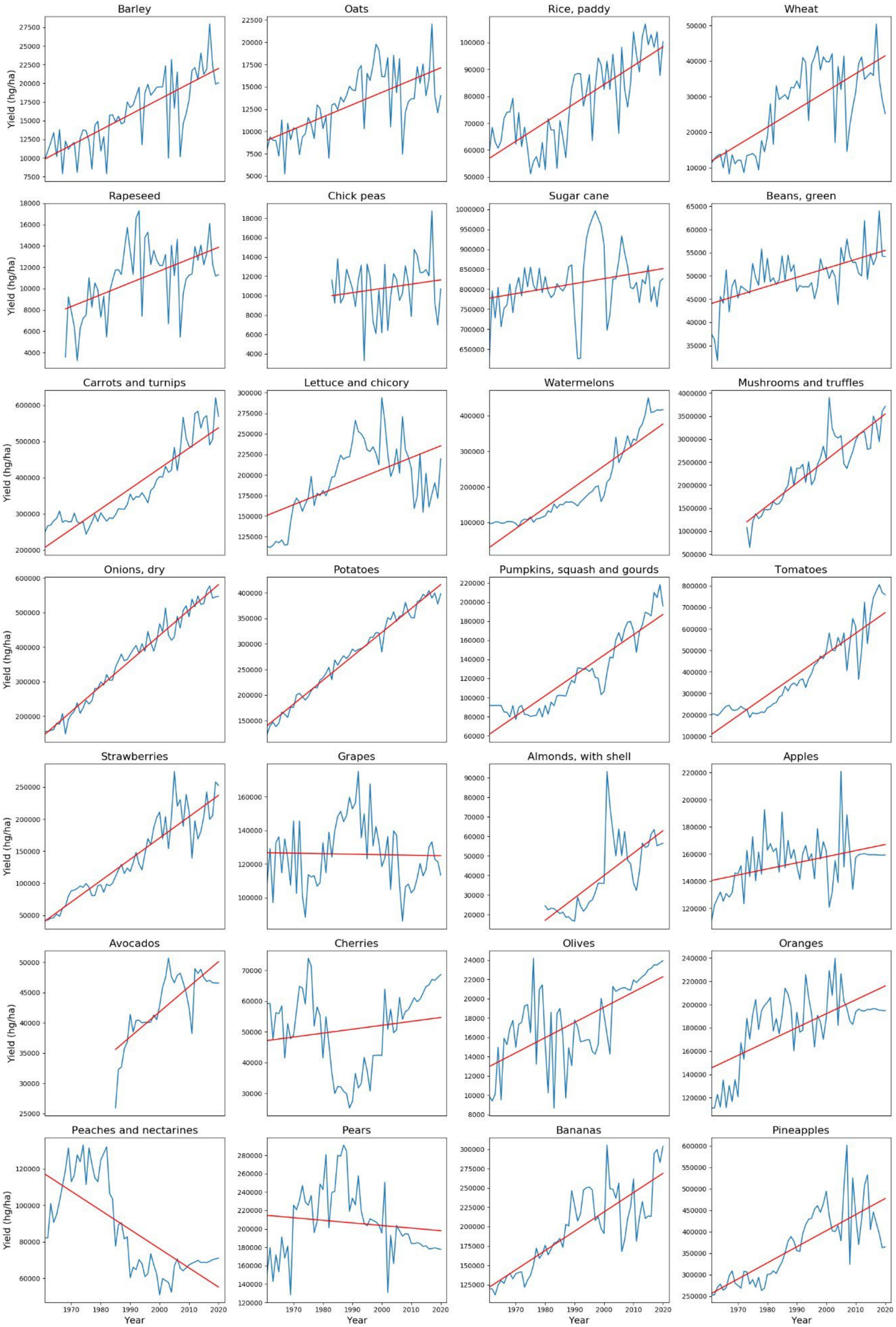
With this processing complete all organisational applicant entity names were harmonised and disambiguated using established CTI codebases. However as noted above, no harmonisation or disambiguation of individual applicants has been attempted. These approaches are significantly less reliable for individual names, as is ABN identification (e.g. there is likely only one instance of “Barossa Horticultural Services” in the ABR, but there may be dozens of listings under “P Smith”). For this reason, no counts of un-disambiguated individual “unique applicant names” have been presented in this report.

Once harmonisation was complete, organisational applicants with no ABN originally available in IPGOD were matched against the names of ABN holders in the ABR. Using this approach we were able to significantly increase the number of PBR applicant firms with a firm ABN identification – from the 299 known ABNs in our IPGOD sample, to a new total of 439 ABN-identified firms.

This represents an increase of almost half as many ABNs again as were previously known. Moreover almost 90 per cent of PBR applications from Australian firms are now associated with an appropriate ABN. In this we consider that the aim of identifying and disambiguating all firms with PBR registrations is well satisfied.

[29] The ABR is available at https://www.abr.gov.au/government-agencies/accessing-abr-data/abr-data- products-and-services/abr-explorer. Non-public data is available only to authorised agencies.
[30] IPGOD is available at https://data.gov.au/data/dataset/ipgod2020

Figure A1: FAOSTAT historical Australian yield data (hg/ha) for selected sectors (1961-2020), showing CTI linear fit



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