The amplified effect of market size on innovation: A comparative analysis of pea and wheat seed value chains in France

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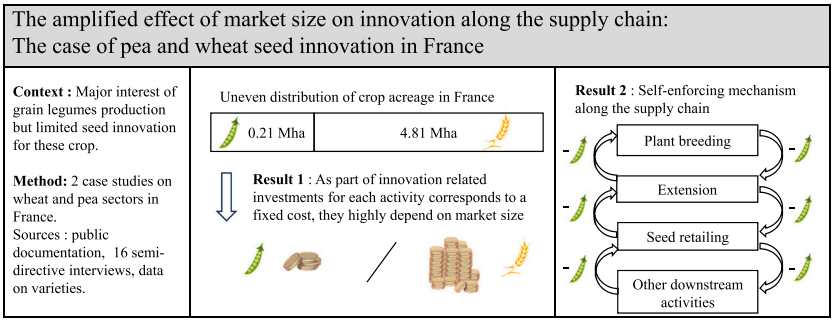
HIGHLIGHTS

- Seed innovation involves investments by multiple actors performing complementary activities
- Pea and wheat value chains differ mainly according to market size
- Most innovation-related activities represent a fixed cost
- Investments in innovation activities are positively related to market size.
- The low level of investment by actors in complementary activities self-reinforces the effect of market size on innovation.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Despite their interest for agro-ecological transition, grain legumes remain poorly cultivated in France. One reason is the low availability of seed innovations for farmers which, to a large extend, is related to the low incentives to innovate for these crops which represent a small acreage.

OBJECTIVE: In this article, we analyze the link between market size and the efforts made to create, diffuse and value innovation. We compare two value chains related to two field crops in France that mainly differ in terms of market size, namely, pea and wheat. Our analysis focuses more specifically on the seed-related innovations created in the upstream part of these value chains. In both of these cases, innovation relies on multiple complementary activities carried out by different actors, including the creation of the innovation, the production and diffusion of technical knowledge, the production and distribution of the innovation, and its valorization by downstream users.

METHODS: The two case studies on the pea and wheat sectors were conducted using a qualitative approach based on public documentation, 16 semistructured interviews with various actors in the innovation system of the two value chains and data on commercialized pea and wheat varieties.

RESULTS AND CONCLUSION: We show that the level of investment in each of these activities is highly related to market size. This result is first explained by the fact that part (if not all) of the cost of these activities is fixed; that is, these activity costs do not depend on the diffusion of innovation. This result is also explained by the complementarity of these activities, which makes the investment in one activity less beneficial if the investment

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in complementary activities is low. As a consequence, the effect of market size on innovation is self-reinforcing in those cases where innovation relies on different activities managed by different actors.
SIGNIFICANCE: In agricultural sectors, where there is a need for innovations in both large and small markets, this result calls for an evolution of innovation funding mechanisms to attenuate the impact of market size.

1. Introduction

Diversity is the first of ten elements of agroecology as defined by FAO (FAO, 2018), who recognize in its report that "*Diversification is key to agroecological transitions*" and that "*agroecological systems are highly diverse*". Diversification includes crop rotations, multiple cropping or intercropping, and aims to improve productivity, stability and ecosystem services (Hufnagel et al., 2020). Grain legumes production is a major lever for diversification, increasing temporal diversity (FAO, 2018; Watson et al., 2017) and contributing to ecosystem services (Watson et al., 2017; Cusworth et al., 2021). The capacity of grain legumes to fix atmospheric nitrogen makes their cultivation far less demanding for synthetic fertilizers, thus reducing their impact on greenhouse gas emissions. Their introduction in the rotation improves the nutrient status and soil structure, which also reduces fertilization needs for the following crop. In addition, they act as a "break-crop", breaking the cycle of weeds, pests and disease (Kirkegaard et al., 2008), with a potential impact on the reduction of pesticide use.

In France, increasing the surface of grain legumes is a major challenge. In addition to the environmental benefits mentioned above, this would help to reduce the national dependency on plant protein imports. These crops represent a good source of non-animal protein for food and a better-quality source of protein for animal feed. Recently, (dec. 2021), the French government launched the "Plan Proteines"[1] (200 M€) with the objective of increasing the surface area of legumes (grain and forage) by 40% within three years and 100% by 2030, which would result in 2 Mha. However, major subsidies have already targeted legume crops over the last two decades without exerting a significant effect on legume acreage.

The difficulty of increasing the surface area of legumes in French agriculture has already been analyzed in the literature. In general, these analyses underscore the fact that increasing legume surface area is not only a matter of crop substitution at the farm level but also requires a wider change at the whole value chain level. Among these analyses, Magrini et al. (2016) show that legume crops are marginalized in French agriculture, as a result of a lock-in situation. This lock-in results from the coevolution of agricultural practices (with an increasing reliance on fertilizers and pesticides), public policies and market incentives. The key mechanism of this evolution is related to the increasing returns to adoption in the food system, which favor cereal crops over legumes. The increased adoption of cereals has led to a significant improvement of their economic and technical performance, re-inforcing the incentives to adopt these crops at the expense of legumes. The search for economies of scales upstream and downstream of agricultural production has encouraged the actors of the sector to invest more on complementary technologies for cereal crops, reinforcing the comparative advantage of cereals (creation of improved cereals varieties, development of chemical pesticides adapted to cereal crops, investment in storage and processing equipment by actors of the agri-food sector…). Such a lock-in situation is not specific to the French context, having already been documented in the agricultural literature in other countries (Cowan and Gunby, 1996; Vanloqueren and Baret, 2008).

In this article, we specifically analyze the case of innovation on seeds, which is one of the important levers to increase grain legumes adoption and thus to the agro-ecological transition. Developing breeding activities for legumes would lead to the availability of new high-performance varieties. This would increase the profitability of these crops and encourage farmers to adopt them and diversify their rotations. This incentive is highlighted by Watson et al. (2017), who argue that the choice of farmers to grow more legumes depends, among others, on "*technical improvements of grain legume production such as breeding of new varieties*". Advances in breeding should increase tolerance to biotic and abiotic stresses, improving yield and yield stability. The authors present public-sector investment in legume breeding in Canada as a success example that has led to improvements in yield, quality and resistance. Such improvements in the performance of legume varieties reduces the comparative advantage of cereal over grain legumes production and makes these crops more attractive to farmers. Cusworth et al. (2021) give another example of the impact of new varieties development on the adoption level of a crop, drawing on the experience of the company Soya UK who developed soybean varieties more suited to UK climate. The central role of breeding is also mentioned by Chable et al. (2020) in the case of organic agriculture.

In France, and most of the European countries, these breeding activities are mainly carried out by private companies. The seed sector is research intensive, with generally between 10% and 20% of its sales revenue being reinvested in breeding (Fuglie and Toole, 2014; Jorasch, 2020). In this article, we analyze the drivers of the creation and diffusion of such new varieties with a focus on the role of market size. Our analysis covers the entire value chain from variety creation to crop production, as well as its downstream transformation. These results are established in the French context by comparing two cases, namely, wheat, which is the most widely cultivated crop (4.82 Mha), and pea, which is a rather minor crop (0.21 Mha). Considering two crops which mainly differ by their market size allows us to analyze the impact of this parameter for each of the actors of the value chain (breeders, technical institutes, seed dealers, farmers, elevators and food processing industries).

This article makes a contribution to two different streams of the literature. The first contribution is related to the literature showing that market size is one major driver of innovation. In this literature, the effect of market size is analyzed at the level of the actors involved in the creation of the innovation. Here, we show that this impact can be seen at different levels of the value chain, including extension, agricultural input retailing, production activities and processing. We also show that this effect is self-enforcing under a smaller market size: the incentive to innovate at one level of the value chain further decreases because the other levels of the value chain, both upstream and downstream, also have a smaller incentive to innovate. The second contribution of this article concerns the debate on the transition pathways toward agro-ecological food systems. Most of the literature on transition analyzes the specificity of the initiatives that foster this transition and how these initiatives articulate with each other (see, for example, Gaitán-Cremaschi et al., 2019). Our analysis complements this literature by focusing on the economic factors that could either constrain or favor transition. On the one hand, the comparative analysis of the current situation between pea and wheat highlights the effect of market size as one barrier to transition. On the other hand, in the conclusion, we discuss alternative economic mechanisms that could moderate this market size constraint. Such alternatives complement the toolbox that has been elaborated in the transition studies literature.

The different fields of the relevant literature are summarized in the first section. In the second section, we present the methodology used for the two case studies and provide some general background information on the seed and agricultural value chains. The third section establishes

[1] http://www.proteinesfrance.fr/fr/plan-proteines-quelle-strategie-pour-developper-la-filiere-en-france

the two results summarized above. At last, in the conclusion we consider alternatives that could mitigate the impact of market size as observed here.

2. Related literature

Market size and, more generally, demand are major drivers of industry innovation. Cohen (2010) shows that demand is one of the key determinants for the differences in the level of research and innovation among sectors. However, we are interested here in the differences observed within a given sector, as our analysis is limited to the agricultural sector. Such an analysis of the differences in the levels of innovation within a single sector has already been carried out in the pharmaceutical sector. Based on US data, Acemoglu and Linn (2004) show that more innovations are created for drug categories with a large market size. The key argument behind this dynamic is that R&D that leads to a new drug represents a fixed cost that is independent of the number of units sold. As a consequence, pharmaceutical companies have higher incentives to invest in R&D for those drugs that represent large markets because they can more easily recover the fixed cost of R&D through sales in these markets. R&D investments are therefore expected to be larger for larger markets, leading to more innovation. The authors show that in the US context, a 1% increase in potential market size leads to a 4% increase in the entry of new nongeneric drugs and a 4–6% increase in the entry of new molecular entities. Dubois et al. (2015) show similar results, but they consider the worldwide potential market rather than only that of the US market for the different product categories. Based on their estimates, one new chemical entity requires an additional revenue of approximately $2.5 billion.

More closely related to our application, Heisey et al. (2002) show that seed breeders have more incentives to enter a market if they perceive that that market has a large potential size. This effect is even more important in early development stages if marketing new varieties to farmers implies fixed costs. In this case, seed companies have more incentives to invest when the average farm size is large. This feature is observed in the French context by Charlot et al. (2015) and in the UE context by Deconinck (2019). In both cases, the authors analyze the link between market size and innovation, which is measured by the number of new varieties registered. Charlot et al. (2015) show that in France, the market size for different field crops, as measured by the total acreage at the French level, has a positive and significant effect on the number of new seed varieties developed. Deconinck (2019) shows that in the UE, a 1% increase in the size of the seed market results in a 0.4–0.5% increase in the number of new varieties. Market size is usually defined as total sales. This measure is indeed used by Deconinck (2019). However, measuring sales requires data on both quantities and prices. As these data are not always easily accessible, Charlot et al. (2015) use two proxies for each crop: the total area on which certified seed is sold as a proxy for quantity, and the fact that seed is hybrid as a proxy for price. Having hybrid seed prevents farmers from saving their own seed, which generally leads to higher seed prices.[2] In this paper, we compare two non-hybrid crops, for which the proportion of farmer-saved seed is equivalent. As a consequence, total crop area is a good indicator of market size.

None of the studies mentioned above account for the fact that different levels of the value chain are involved in the commercialization of innovation. Our article complements these analyses by showing how different actors of the value chain contribute to innovation and the impact of market size on these contributions. To reach this objective, we take a case study approach to have a rather detailed comprehension of the factors that contribute to innovation, and we collect data to document these factors in the specific cases studied.

Our analysis is also related to the literature on technological lock-in (Arthur, 1994) and, more particularly, its applications to agriculture. Following the initial work of Cowan and Gunby (1996) and Vanloqueren and Baret (2008), several studies have shown that a transition toward less intensive cropping systems using, for example, less pesticides, is difficult due to the existence of self-reinforcing mechanisms. More closely related to our work, Magrini et al. (2016) show that these mechanisms explain why grain legumes are marginal in French agriculture, despite the clear and recognized interest in these crops. In a similar vein, Meynard et al. (2018) analyze the barriers to crop diversification. They show that the low development of minor crops is explained by a sociotechnical lock-in around major crops that has self-reinforcing mechanisms. This lock-in arises from the fact that major crops are well known, improved seeds and inputs are available, their products are available for food processes and they comply with quality standards. Finally, stakeholders all along the value chain are involved in networks and conditioned to work together. Our article complements these analyses by specifically focusing on the seed-related businesses surrounding pea and wheat, which enables us to show the impact of market size on the strategy of the actors within these two value chains. More broadly, our analysis creates a link between the standard economic literature regarding the impact of market size on innovation (as summarized above) and the literature on technological lock-in. Even if the aim of the literature on the impact of market size is not to analyze lock-in situations, self-reinforcing mechanisms are acknowledged in this literature because market size is endogenous: a small market leads to less innovation compared to a large market, and this has a negative effect on market size. In addition to this dynamic, we show that market size affects the strategy of different actors along the value chain, leading to an additional self-reinforcing mechanism that is related to the interactions among these actors.

Showing that market size contributes to the lock-in opens a new perspective on levers that could favor the transition toward diversified agriculture. Magrini et al. (2018) underline that to break out of lock-in requires several changes both upstream and downstream of the value chain, with the support of public institutions. Meynard et al. (2018) show that, for some minor crops, value chains with strong added value and coordination among stakeholders can be viewed as innovation niches that could favor the transition. Beyond innovation niches, they identify three conditions that should be combined to consolidate value chains: adaptation of standards and official quality signs; coordination between stakeholders; and combination of genetic, agronomic, technological, and organizational innovations. More broadly, the literature on agricultural transition has underlined the characteristics of food systems favoring agricultural transition (Gaitán-Cremaschi et al., 2019); some general functions of this system (Vermunt et al., 2022); more specific factors such as inter-organizational collaboration (Cholez et al., 2023) or the necessity to couple innovations made at different levels of the value chain (Meynard et al., 2017). These results are consistent with the multi-level perspective framework proposed by Geels (2002, 2019) where innovation niches are central during the first phase of the transition while subsequent phases require hybridization with the dominant system. All along these different phases, the small market size of emerging value chains unfavors the transition. There is thus a strong interest in analyzing alternative economic mechanisms that could break the negative impact of market size. This point will be discussed in the conclusion of this article. If we could establish economic mechanisms limiting the negative impact of market size on emerging niches, it would enrich the different conditions mentioned above that favor the agricultural transition.

[2] In the econometric analyses, defining market size by total sales (or proxies of total sales) presents a problem because this explanatory variable is endogenous: a larger market leads to more innovation, and more innovation contributes to market extension. This problem is controlled in Acemoglu and Linn (2004) and Dubois et al. (2015) by using an indicator related to population characteristics, which are expected to be rather exogenous. Charlot et al. (2015) control this problem by using a lag with panel data.

3. Methodology and background information

To analyze the link between market size and the efforts made to create, diffuse and value innovation, we compare two value chains related to two field crops in France, namely, pea and wheat. Our analysis focuses more specifically on the seed-related innovations created in the upstream part of this value chain. This type of innovation, generally referred to as *"varieties"*, corresponds to a type of product innovation that can improve productivity at the farm level. The innovative process we analyze extends from the creation of new varieties through their diffusion to farmers and on to their downstream valorization in the value chain.

The sociotechnical contexts of wheat and pea share several similarities that make the comparison accurate. The organization of the value chains for these two crops is identical, with many actors working with both pea and wheat. As explained in more detail later, seeds are inbred lines for both of these species, making their breeding activities rather similar. As the margin on seed prices is equivalent for both types of crop, market size is mainly related to the total surface of each crop in France, which is 24 times larger for wheat compared to pea. Hence, the comparison of these two cases is appropriate to test our hypothesis regarding the effect of market size on the innovation efforts of actors.

Little data exist on the efforts made by pea and wheat actors to create, diffuse and value new varieties. For instance, the research investments per crop, the catalogs of seed dealers and the premium paid to farmers for a given variety are hardly, if at all, accessible. This lack of data encourages a case study approach based on qualitative data.

In the first subsection, we detail the data collection methodology used in this article. In the second subsection, we present data on wheat and pea production in France and describe the organization and activities of the actors along the two value chains, focusing on their role in the innovative process.

3.1. Data collection

The two case studies on the pea and wheat sectors were conducted using a qualitative approach based on bibliographic resources (websites of the actors of pea and wheat sectors, technical reports, seed dealers' catalogs, articles from agricultural press, etc.), semistructured interviews with stakeholders of the two value chains and data on commercialized pea and wheat varieties.

We interviewed 16 actors involved in the creation, diffusion and valorization of pea and wheat varieties between July and October 2019 (see Table 1 for details on the number of interviews per actor category). Except in the case of technical institutes, all of the interviewed actors are involved in both pea and wheat. Interviews were conducted by phone or videoconference using an interview guideline that included questions about their activities, the efforts made for each species (resource allocation) and the drivers behind this allocation, the number of pea and wheat varieties managed, and their relations with other actors along the value chain (see the interview guide for seed dealers in Appendix B). Each interview was recorded only after obtaining the interviewee's consent, and a detailed report of the interview was subsequently sent to the interviewee for validation.

We completed the information gathered via the interviews with data from GNIS (seed and plant interprofessional organization) and the professional journal "Semences et Progrès". This last source provides lists of commercialized varieties with their year of registration and their sales representative. From these data, we were able to estimate the volume of certified seed sales in France during the period of 1968 to 2019 for wheat and 1984 to 2019 for pea. We also compiled the life cycle during which the varieties were commercialized and the number of varieties commercialized from 1990 to 2019. Finally, all data related to surfaces, yield and use of crop production were obtained from the French Ministry of Agriculture (FranceAgriMer) and correspond to the average data collected over the 5 years between 2018 and 2022.[3] Some more specific data (e.g., proportion of spring compared with that of winter pea) are obtained from national technical institutes, specifically Arvalis for wheat and Terre Innnovia for pea.

Table 1
Number of interviews per actor category.

Actor category	Number of interviewed actors
Breeders	5
Seed dealers	8
Technical institutes	2
Interprofessional organizations	2

3.2. Background information

Between 2018 and 2022, the soft wheat area in France averaged 4.82 Mha (comprising 99% winter wheat and only 1% spring wheat) and that cultivated with pea averaged 0.21 Mha (comprising 80% spring pea and 20% winter pea). Both crops are mainly cultivated in the northern part of France (see Fig. 1). The clear contrast between the two crops in terms of cultivated areas, which represents the market size of the seed supply, justifies the selection of these two cases as the research target used to analyze the link between investment and market size.

Table 2 describes the agricultural value chain, giving more details on the upstream part due to our focus on upstream innovation. Except for some particularities that will be discussed later, this general structure is quite common to all agricultural crops.

The creation of a new variety is handled by private actors, known as breeders, whose objective is to obtain improved products for various traits such as yield, pest resistance and technological quality (e.g., protein content). The commercialization of these products is framed by two regulation standards defined at the European level: DUS and VCU. DUS requires that products are distinct, uniform and stable. The DUS standard requires seed variety to be stable and homogenous over time. As a consequence, any genetic improvement has to be embedded in a new variety. DUS also enables breeders to obtain a plant breeder's right, which is the *sui generis* form of intellectual property right commonly used in the seed sector. The VCU (Value for Cultivation and Use) standard corresponds to an evaluation of the new varieties performance, which should be better than those of the most currently sold.[4] Once a new variety passes the DUS and VCU tests, it is registered in the official catalog.

The breeding activity is based on consecutive cycles that last from 5 to 10 years for both pea and wheat. New varieties can be released at the end of each cycle. Wheat breeding in France is performed by nine different companies,[5] seven of which[6] also breed pea.[7] Some breeders are multinational groups, and others are national firms. New varieties are registered each year by breeders. The number of varieties commercialized in France since the mid-2000s is between 50 and 100 for pea and above 300 for wheat. There is a high level of turnover among varieties,

[3] The year indicated here corresponds to the harvest year. For almost all wheat and winter pea, the crop is sown during autumn of the previous year.

[4] VCU testing is specific to field crops and some forest tree species. This is a requirement in Europe and certain other countries, but not others, such as the US.

[5] Agri Obtentions, Caussade Semences (now Lidea), Florimond Desprez, KWS Momont, Lemaire Deffontaines, Limagrain, RAGT, Secobra, Unisigma.

[6] Agri Obtentions, Florimond Desprez, KWS Momont, Lemaire Deffontaines, Limagrain, RAGT, Unisigma.

[7] A survey made by the GNIS shows that, in 2016, private breeders invested 55.5 M€ in France for small grain cereal and legumes in 2016 (GNIS 2016). Small grain cereals and legumes include wheat and peas. In France the other crops in this category with significant areas (more than 0.1Mha) are winter and spring barley (1.8 Mha), durum wheat (0.3 Mha) and Soybean (0.2Mha) (source: FranceAgriMer, 2020).

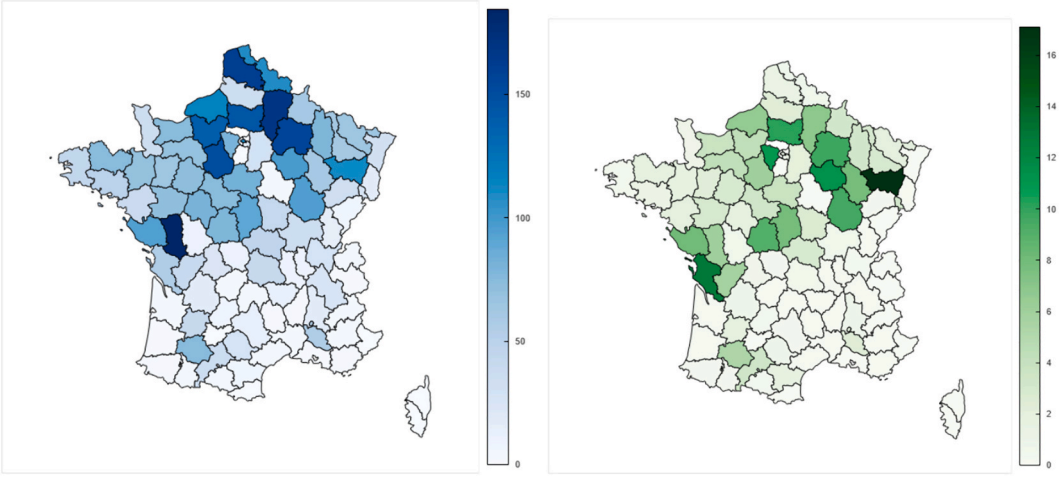

Fig. 1. Distribution of soft wheat (left panel) and pea (right panel) areas (source Agreste 2020).

Table 2
The actors and activities of the pea and wheat value chains.

Actor	Role in the innovative process	Activities
Breeders	Creating innovation	- Creating new varieties embedding genetic gain - Registration of new varieties in the seed catalog (DUS and VCU standards).
Technical institutes and seed dealers	Production and diffusion of technical knowledge regarding the performance of the innovations	- Evaluating new varieties after registration. - Diffusing knowledge concerning the performance of new varieties under different climatic and growing conditions
Seed dealers	Diffusing the innovation	- Referencing the new varieties in their catalogs - Seed multiplication and processing - Certifying seed quality
Farmers	Adopting the innovation	- Purchasing certified seeds or producing farm-saved seeds - Producing crops from certified or farm-saved seeds
Downstream actors: Cooperatives, Grain elevators, Food and feed industries	Valorizing the innovation	- Processing food and feed from agricultural productions and marketing the end-products - Valorizing specific qualities in dedicated outlets

and the life cycle of one variety generally lasts between 5 and 10 years.

The performance and ranking of new varieties can vary depending on the location and year. VCU testing enables a first screening of the variety, but additional evaluation is needed for farmers to obtain accurate information on the performance of varieties in their specific production context. This additional evaluation of new varieties is handled by technical institutes and seed dealers, who implement field trials in various locations and environments to obtain data on yield, pest resistance and quality. Seed dealers use this information to determine the list of referenced varieties offered in their catalog. This postregistration evaluation is also used by seed dealers and technical institutes who advise farmers on their varietal choice. The data produced are disseminated to farmers in professional journals, on seed dealers' and technical institutes' websites, and through field visits organized for farmers. The technical institutes dealing with wheat and pea are different (Arvalis for wheat and Terres Inovia for pea). Seed dealers are numerous and mainly act as cooperatives or private elevators operating at a regional level for both the distribution of agricultural inputs and the collection of harvested agricultural production.

Seed production is conducted by seed dealers who use basic seeds produced by breeders and contract with farmers for their multiplication. The seeds thus produced are then processed, treated and packaged in seed production units. After production, seeds are certified according to their purity, germination ability and sanitary handling conditions. For 80% of the certified seed stock produced in France, the activity of seed production is vertically integrated with seed dealing (short circuit). Alternatively, for the other 20%, seed dealers have no production capacity and must purchase seeds from another vertically integrated seed dealer (long circuit). Seed dealers pay royalties to breeders on the sales of certified seeds. In 2022–2023, the amounts of these royalties were 8.86€/quintal for wheat and 10.95€/quintal for pea (source SICASOV).

Pea and wheat are self-pollinating crops, which constrains breeders to create seeds that are inbred lines. For this type of crop, farmers can easily produce their own seed from the grain harvested the previous season.[8] The performance of such farmer-saved seed is close to that of certified seed, so farmers can save money by using saved seed compared to purchasing certified seed. This practice covers approximately 50% of the pea- and wheat-producing area in France. The self-production of farmer-saved seed is allowed for pea and wheat varieties under the plant breeders' right. However, farmers may have to pay a royalty for this type of seed. For wheat in France, an end-point royalty (called a CRIV) of 0.9 €/ton is taken on the collected cereal, which represents 6.3 €/ha if we consider the average yield of wheat in France over the last few years.[9] Eighty-five percent of the CRIV is redistributed to breeders according to the market shares of their wheat varieties. The CRIV is not implemented for pea essentially because of the high level of self-consumption in the farm for animal feeding purpose (28% for pea rather than 8% for wheat).

Even if a contribution is collected on farmer saved seed for some

[8] This strategy is not relevant with hybrid seed because farmers then experience a yield loss if they use farmer saved seed. Hybrid seeds are generally used for open-pollinated crops such as corn, sunflower or rapeseed. Hybrid seeds are created and produced for wheat in France, but they have only covered 30,000 ha in average during the past few years (0.6% of the French area for wheat). There is no hybrid seed for pea.

[9] A discount of 5 €/quintal of purchased certified seed is given to farmers, to keep them from paying royalties twice. This discount approximatively corresponds to 6.3 €/ha according to the wheat sowing density in France.

crops, such as wheat, self-pollinating crops are not very beneficial for breeders and seed dealers. Indeed, the market power for increasing royalties on certified seed is very limited because farmers can easily switch to farmer-saved seed when a supplier decides to increase the price of certified seeds. Because of this important common feature, most of the difference between pea and wheat in terms of the dynamics of seed innovation relates to the difference in market size between these two crops.

Agricultural production is performed by farmers who choose the best varieties to use according to their production context, which includes soil and climate conditions, pest pressure, targeted outlets, etc. They then implement crop management practices according to their field conditions and the varieties they have chosen. The level of pesticide use and the related expenses are similar between pea and wheat, with a treatment frequency index of 4.6 for pea and 5.1 for wheat. The value of the production is higher for wheat than for pea because the average yield is approximatively twice for wheat (7.2 t/ha instead of 3.4 t/ha) and sales per ha are 70% higher for wheat (1075€/ha instead of 638€/ha). Investments have been made during the last decade to develop winter pea with the expectation of obtaining a higher yield from production with a longer production cycle. However, winter pea represents only 20% of the french pea area. One major advantage of pea is that it does not require fertilization, which leads to important cost savings. However, despite lower expenses for pea, this crop is less beneficial for farmers than wheat. Apart from the revenues directly generated by pea production, growing pea has a beneficial impact for the following crop: it facilitates its no-till installation, promotes disease and weeds regulation and increases soil fertility, thus decreasing nitrogen needs. The technical institute Terres Inovia calculated that cultivating pea before wheat increases the yield for wheat from 0.6 to 1.2 t/ha compared to wheat following another cereal. Rapeseed after peas produces between 0.05 and 0.3 t/ha more than rapeseed after straw. These results are consistent with the ones highlighted by Watson et al. (2017) in their meta-analysis: pea as a pre-crop always has a positive effect on the yield of the subsequent crop, whatever the fertilization rate and the country considered.

Most pea and wheat production is processed outside of the farm by downstream actors. This first includes the grain elevator activity, which consists of collecting the agricultural harvests and sorting and marketing them in different markets. The food and feed industry then processes agricultural production into feed and food products and values the specific qualities in specific outlets. In the case of wheat, half of the production (35 Mt) is exported, while the rest is used for several outlets, including milling (2.76 Mt), starch (2.70 Mt), biscuits (1.17 Mt), animal feed (4.84 Mt), ethanol (1.59 Mt) and self-consumption on the farm (2.88 Mt). These outlets require different levels of qualities which lead to differentiation among varieties, namely, bread wheat, strong wheat, feed wheat, biscuit wheat, and starch wheat. In the case of pea, 35% of the production (0.7 Mt) is exported, the rest being used for human food (0.14 Mt), animal feed (0.09 Mt) or self-consumption on the farm (0.18 Mt). The principal distinction is made between green peas, which are used as split peas for human food, and yellow peas, which can be used for human food or animal feed. However, segmentation is currently increasing with the development of new uses, such as the industrial use of pea proteins for human food and pea starch.

4. Results

In the first subsection, we consider the activities performed by the actors along the value chain, taken independently of each other. The interdependency between these activities is analyzed in the second subsection.

4.1. The efforts made by actors at different levels of the value chain depend on the market size of the crop

As explained in the background subsection, seed innovation relies on various complementary activities that are related to the creation of new varieties, the evaluation of their performance, the seed production, their adoption by farmers and the downstream activities for the processing and commercialization of agricultural products. For each category of actors involved in the innovation process, we analyze the sources of costs and the returns on their activity. Based on interview data, we then compare the effort taken toward the creation, evaluation, diffusion, production and processing of both pea and wheat varieties. The key result indicates that market size is a major diver of research investment not only in research activity but also in other complementary activities.

For breeders, the research investments needed to create new varieties cover the labor and equipment costs to make the crosses, field testing of progenies and genetic analysis. The general organization of the breeding programs between pea and wheat is very similar because the objective in both cases is to create new inbred lines. These costs are all independent of the number of seed units sold, so they represent a fixed cost. The benefit of this activity depends on the quantities of certified seed sold and, to a lesser extent, on the quantity of farm-saved seed used. Breeders' revenue then depends on the cultivated area with the crop. Based on the royalty levels presented in the background subsection, we estimate a total revenue on certified and farm-saved seed of 43 M€ for wheat and only 1.9 M€ for pea (see Appendix A for more details).[10] This difference explains why breeders have a much higher incentive to invest in wheat than in pea. Information on the distribution per crop of the research investment made by all breeders in France is very difficult to obtain. However, interviews with experts reveal that the level of research investment is very different between wheat and pea and that these levels reflect the order of magnitude of the revenues obtained from royalties.

Demand is heterogeneous across the seed market. Seed varieties are grown in different environments (including distinct soil, climatic conditions, pest pressure, and agricultural practices), leading the needs of farmers to be heterogeneous with respect to seed varieties. As a consequence, higher research investment leads not only to higher innovation levels but also to a larger number of varieties. This result is consistent with the literature. For example, using a model that includes product differentiation and endogenous investment in research, Dubois et al. (2015) show that the number of products increases with the level of differentiation (i.e., the per unit transport cost in their framework). In the case of pea, 60 to 70 varieties are commercialized, and approximately 10 new varieties are released each year. In the case of wheat, 400 varieties are commercialized. The number of new varieties released annually is highly variable across years but is on average approximately six to seven times higher than the number of new pea varieties. The breeders interviewed explained that the low returns on pea make it difficult to fund the research programs needed to create new varieties. One breeder argued that he had to cease activities involving spring pea because the small cultivated area with this subspecies leads to an insufficient return on investment.

For technical institutes and seed dealers, the efforts made to evaluate the performance of the new varieties consist of implementing trials in multiple environments, measuring yields and disease resistance and conveying performance information to farmers. The cost related to this activity includes land costs, agricultural and measurement equipment, inputs (water, fertilizers, phytosanitary products), labor costs, and costs linked to communication tools (websites, reports, professional

[10] As explained above, we use total crop area as a proxy for market size. If, alternatively, we use the total amount of royalties collected, we obtain a very close ratio: the total area is 24.1 times larger for wheat compared to pea, and the total amount of royalties is 22.6 times larger for wheat compared to pea.

magazines, field visits, etc.). This cost is fixed in the sense that, for a given crop and given experimentation network, the cost is the same for any new variety evaluated (regardless of its possible diffusion level). For seed dealers, the returns on investments are made by the margin obtained through the sale of certified seed. Technical institutes are mainly funded by a fee collected on the cultivated area of the species they work on. As a consequence, the gross revenue for seed dealers as well as the budget for technical institutes depends on the number of hectares cultivated with the relevant species. Seed dealers' incentive to expend effort in variety testing is thus expected to be higher for wheat than for pea. This effort can be measured by the number of new varieties tested, the number of trial devices implemented and the number of characteristics evaluated for each new variety.

One interviewed seed dealer reported that he tests approximately 80 wheat varieties each year but only 20 pea varieties. Another indicates that he tests 30 to 40 wheat varieties and 10 pea varieties annually. Other interviewees explain that they do not implement trials each year on pea, while they systematically test wheat varieties. Moreover, wheat varieties are evaluated two years prior to official registration in official catalogs, whereas pea varieties are seldom evaluated prior to registration. Field evaluation by technical institutes also varies between the two species. The field trial network implemented by Arvalis for wheat consists of 70 to 80 trials, in which 25 to 30 new wheat varieties are tested yearly. The technical institute involved for pea, Terres Inovia, implements a network of 25 trials for winter pea for the evaluation of approximately 10 new varieties and 50 trials on spring pea for 12 to 14 new varieties evaluated yearly. Moreover, the postregistration evaluation for wheat benefits from the availability of the results of trials conducted prior to the registration, which is not the case for pea.

The evaluation intensity also depends on the characteristics (or traits) that are evaluated for each new variety. Numerous traits are evaluated in the case of wheat, including yield, specific weight, earliness (stem elongation and heading stages), ear characteristics, resistance to a wide set of diseases and pests, protein content, and multiple quality criteria (baking strength, quality for bread, starch or cookie making, etc.). In the case of pea, the most important evaluation criterion is yield, and additional criteria include stem strength, protein content, thousand kernel weight, seed size, cold resistance (for winter peas), earliness and resistance to certain diseases. All interviewees recognized that wheat varieties are evaluated for a much wider range of traits than pea. The interviews also show that technical institutes and seed dealers expend more effort promoting new varieties. The information released for wheat variety performance is much more detailed and denser than that for pea, whatever the information channel (technical advice, marketing efforts, description of varieties performance and consideration of farmer feedback). For instance, one of the interviewed seed dealers explained that each year, they publish a new catalog describing wheat varieties, while the catalog for pea varieties is updated less frequently.

For seed dealers, producing a new variety first requires multiplying the variety to obtain a sufficient quantity of seeds and, second, processing and certifying those seeds in seed production plants. Multiplication is achieved through a contract with farmers, and the cost here is mostly proportional to the number of seed units produced. The processing, conducted by the seed dealer, includes seed sorting, possibly dressing with pesticide and applying several controls related to certification. Processing multiple varieties requires specific cleaning operations after each variety and additional capacities for separate storage. For a given total volume of seed produced, adding new varieties to the production chain without removing the varieties already in the catalog implies a stronger product segmentation, which leads to higher production costs. In other words, there is a fixed cost for processing a variety. There is thus a minimum volume needed to cover this cost, and seed dealers will not commercialize a new variety if the expected sales fall below this level. This minimum volume is easier to reach for a crop that is produced more often and with larger quantities in a zone where the dealer is active. Hence, the fixed costs for processing a new variety are more easily covered for wheat than for pea.

In addition, seed dealers sell not only seeds but also complementary products associated with pea and wheat agricultural production, such as phytosanitary products and fertilizers. Even if these other products are linked to different markets, they contribute to the attractiveness of the different crops for a seed dealer. The number of phytosanitary treatments is equivalent between the two crops, but pea does not require fertilizers. Hence, the sale of wheat provides an additional side benefit for seed dealers. However, this dynamic was neither acknowledged nor contradicted by the interviews with seed dealers.

These interviews actually show that the number of commercialized varieties is 3 to 10 times higher for wheat than for pea. Moreover, the turnover for pea varieties is lower than that for wheat varieties, and pea varieties remain longer in the seed dealer catalogs. In addition, the interviewees explained that seed dealers use information on farmer needs to decide whether to reference a new variety in their catalog. Because their actual exchanges with farmers about pea varieties are scarce, seed dealers have little information on farmers' needs regarding this crop and thus reference fewer new varieties in their catalogs.

Concerning farmers, we can consider their time investment needed to gather information on varieties, choose which variety to sow and acquire technical knowledge on crop management as fixed costs. Their returns are made on the sales of their agricultural productions, and they are thus dependent on the cultivated area and the benefit related to each crop. Some interviewees reported that farmers value variety performance in wheat as much as in pea. However, others claim that farmers are more sensitive to the performance of wheat varieties than to the performance of pea varieties for several reasons, as follows: (i) wheat is generally one of the main crops in farmers' fields, while pea remains as a secondary crop; (ii) farmers are less demanding and show less technical hindsight for pea – which represents a lesser portion of their revenues – than for wheat; and (iii) farmers use several wheat varieties on their farms and therefore have more information with which to compare them, whereas they generally use only a single pea variety. Farmers thus seem to be more concerned about varietal choice for wheat than for pea. In the case of pea, they somehow delegate this choice to the advisers from technical institutes, extension services and cooperatives.

In the downstream part of the value chain, a portion of the efforts spent by elevators and food-processing industries to value the new varieties also represents fixed costs in both time and money. These fixed costs are related to the search and development of new outlets, the adaptation of the production chain and the increase in storage capacities. The returns are made on the sales of processed products, thus they depend on the volumes sold. The sales outlets are numerous for wheat (animal feed, milling, export, starch production, etc.), requiring varieties with specific technological characteristics that have been stored in different silos by the elevator. For pea, the range of outlets is much more limited. A distinction is mainly made between green peas (for the production of split peas) and yellow peas (for either human food or animal feed). Nevertheless, segmentation tends to develop with the industrial valorization of pea proteins for human food and pea starch as a texturizing agent for the food industry. One interviewee mentioned a contractual arrangement between an elevator and a downstream agrifood actor that corresponds to this type of channel. However, such initiatives are rather rare and breeders indicated that the specific characteristics of seeds for such value-added outlets (types of proteins required, for example) are still insufficiently defined.

4.2. Self-enforcing effect related to the interdependency along the value chain

Our first result demonstrated that actors along the value chain have more incentives to invest in crops that represent a large market size. Large acreages indeed enable them to cover more easily the fixed cost of their own activities. They therefore invest less in crops representing small acreage, such as pea. This situation is reinforced by the

interdependency among actors along the value chain.

All the activities handled by the different actors of the value chain are closely linked. As these activities are not vertically integrated, the incentives for one actor depend on the efforts made by other actors. If even a single actor fails to make sufficient effort, it could compromise the entire chain of varietal creation and distribution and, in turn, disincentivize the actors at other levels of the chain from making efforts. For each type of actor, we detail the actions necessary to avoid affecting the incentives of other actors.

Breeders create new varieties with valuable performance and technical characteristics for farmers and food/feed industries. If these new varieties are not superior to the existing ones, seed dealers do not have incentives to reference or produce them, technical institutes do not have incentives to evaluate their performance, and farmers do not have incentives to adopt these new varieties. The interviewees indicated that, in the case of pea, breeding has not resulted in significant genetic progress over the past 20 years. As an illustration, the spring pea variety Kayanne (registered in 2008) has remained in the postregistration trial network as a control variety for more than 10 years. In wheat, genetic progress is higher, and the new varieties are better adapted to farmers' productivity conditions. The higher research investment made by breeders also enables better differentiation of varieties with respect to their final use downstream of the food value chain. For instance, important investments are made for developing bread-making varieties. Seed dealers and farmers then have more incentive to reference and adopt the new – efficient and outlet adapted– wheat varieties than new pea varieties.

Technical institutes and seed dealers provide technical data on varieties' performance and characteristics, as evaluated in variety trials. Farmers do not adopt new varieties without having such information. Moreover, if farmers have too little information to differentiate high-performing varieties in their region from low-performing ones, breeders will have a lower incentive to invest in research. Any new variety with good performance prospects in a given region would be less likely to be identified and adopted by the farmers in that region. The sales volumes for that variety would then remain low, disincentivizing breeders from undertaking efforts for creating a new variety and seed dealers for producing it. As previously stated, the trial network is much denser and the evaluation criteria are much more numerous for wheat than for pea. The information released on the performance of new varieties is much more detailed and accurate across the different production regions for wheat than for pea. Interviews also reveal that the efforts undertaken for marketing and the time dedicated for technical advice – for example, through technical field visits – are less important for pea than for wheat. Only basic information, mainly regarding yield performance, is provided to farmers about pea varieties. Farmers are thus less sensitive to the quality of new pea varieties and have fewer incentives to adopt them.

Seed dealers produce the new varieties and reference them in their catalogs to make them available for farmers. The interviewees indicated that the number of available varieties and variety turnover favor the diffusion of varieties. Referencing new varieties of a given species less frequently disincentivizes breeders from investing in research, as they will not obtain returns on these investments due to market access for the new varieties being more difficult. In the case of pea, the low renewal rate of the varieties in seed dealers catalogs would indeed disincentivize breeders from creating new ones. Conversely, the interviews reveal that wheat seed dealers have high expectations in terms of new varieties. For example, one of the cooperatives interviewed expects to renew at least two varieties per year. These expectations encourage breeders to offer numerous new varieties.

Farmers adopt varieties that correspond to their production context (climate, pest pressure, crop management, etc.) and to their targeted outlet. If they do not consider new varieties, breeders and seed dealers have no incentives to offer new high-performance varieties, and technical institutes have no incentives to provide them with data on the performance of these new varieties in their production context. According to interviewees, the low economic profitability of pea crops, the high yield variability from one year to another and the existence of technical deadlocks when dealing with certain pests limits the farmer's interest in this crop and hinders the diffusion of varieties for the corresponding species. This situation disincentivizes breeders and seed dealers to create and produce new pea varieties.

Food and feed industries value, for certain outlets, specific qualities that depend on the varieties. If these actors do not specify their needs in terms of expected varietal characteristics and offer a quality premium to farmers who supply them with agricultural productions from such varieties, then the farmers' incentives to adopt these varieties are reduced and other actors' incentives to create, produce and evaluate new varieties for these specific outlets are limited. In the case of wheat, millers evaluate new varieties based on their baking ability and define two restrictive lists of varieties. The "varieties recommended by millers" (VRM) are those varieties that can be used in their pure form (i.e., not mixed with others) to produce high-quality bread or cookies. The "wheat for French mill" varieties (BPMF) can be used in mixtures by the bread or cookie-making industry. Such varieties enable a better valorization of agricultural production, which is passed on to farmers who grow these varieties for a premium price. This valuation increases the interest of farmers in baking wheat varieties and, as a consequence, the interest of breeders, technical institutes and seed dealers in creating, evaluating and producing baking wheat varieties. In the case of pea, the emerging new markets for human food could lead to a valorization of pea starch and pea protein. The increasing demand for plant proteins as an alternative to animal proteins is increasing the interest of the industry in pea protein. Nevertheless, our interviews reveal that the expected types of proteins are not clearly defined and that no bonus payment exists for farmers who deliver high protein peas. The quality criteria for pea are therefore not valued by the market, which does not encourage the creation, distribution and adoption of pea varieties with high protein content.

The interdependency mechanism for seeds that we illustrated here is amplified by an interdependency with complementary inputs. The interviewees referenced the case of pesticide use. Market approval for active ingredients and pesticide products are regularly re-evaluated, and their number has been decreasing over the last decades. Market approval represents a fixed cost, and pesticide companies often select the largest markets to apply for or renew approval. As a consequence, farmers access to pesticides to control pests in crops that represent small markets is made more difficult. This property interacts with the activity along the value chain. With lower levels of pest protection, pea production is riskier, and on average, productivity decreases. As a consequence, this decreases the interest in pea production among farmers and contributes to the low acreage for this crop. The expected return on investment in pea R&D made by seed companies and seed dealers is thus reduced. Hence, the interdependency with complementary inputs such as pesticides amplifies the effects related to the interdependencies within the value chain.

The opposite effect could also occur; the absence of pesticide solutions for some pest problems could be seen as an opportunity to create varieties that can resist this pest problem. However, the interviewees never mentioned this effect. This can be explained by the time delay in identifying sources of resistance for the pest problem and then the introduction of this resistance into new seed varieties. Second, the limited market size for pea also decreases the expected return from such investment.

5. Conclusion

Based on two case studies in agriculture, this article provides new evidence pertaining to the impact of market size on innovation. Innovation generally relies on complementary efforts made by several actors who are vertically related: research investment to create innovation, extension activities, innovation retailing and production. Sustaining

such innovation entails specific costs for these different actors, and part of these costs is fixed. Because of that, the effect of market size on the incentives to innovate is observed not only at the innovator level (as recognized in the literature) but also at different levels along the value chain. In addition, because of the complementarity among the activities along the value chain, we identify a self-enforcing mechanism: a low effort to sustain innovation at one level of the value chain decreases the incentive to innovate at the other levels, both upstream and downstream. This self-enforcing mechanism can contribute to some technological lock-in situations, as observed in agriculture as well as in other economic sectors.

In this article, we focus on the impact of market size on the various complementary activities of the value chain. Over either the medium or long run, this effect is amplified by the endogeneity of market structure. For instance, in the two cases studied here, due to less innovation and fewer extension activities for pea than for wheat, farmers have an interest in replacing pea with wheat in their land allocation. As a consequence, the market size for pea is expected to decrease to the benefit of more productive crops such as wheat. This effect is related both to the performance and the range of seed varieties. A larger number of varieties and more differentiation among these varieties enables these varieties to better match the needs at the different levels of the value chain. Farmers should more easily find varieties that are adapted to the specific needs of their farm, and downstream actors should more easily identify production that fits with the outlets that they target. Conversely, with a narrow range of products, actors are constrained to use more generic products that can hardly match their specific needs. For these different reasons, a large number of more differentiated seed products leads to an increase in market size. The positive effect of innovation on market size combined with the positive reverse effect of market size on innovation is one additional self-enforcing mechanism that can also contribute to the creation of a lock-in situation.

These results call for remedies designed to overcome such lock-in situations. These remedies have been widely analyzed in the transition studies literature. More closely related to this paper, Meynard et al. (2018) discuss this issue for the crop production case. Public support for innovation favoring the transition is one important lever but, as exemplified by the legume case in France (Magrini et al., 2016), the effect is limited if it does not compensate for the inequality of innovation investments by private actors.

There is thus an interest to analyze whether alternative incentive systems driving private research could decrease the inequalities of investment among markets of different sizes. The impact of market size we observe in this article is linked to the fact that innovation-related investments are fixed cost, and that the reward from innovation is related to the sale of the innovation (improved variety). As a consequence, a given genetic improvement embedded in a new seed variety will lead to larger seed sales for crops that correspond to large markets. However, research could be funded alternatively than from the sale of the innovation, and this could lead to different economic properties. Wright (1983) is among the first to compare theoretically the impact of patents, prizes and research contracts on innovation incentives (see Clancy and Moschini, 2017 for a recent review). These systems are also widely implemented, but not necessarily in the agricultural sector. Research contracts are frequently used in agricultural research (Fuglie and Toole, 2014). Prize or contests have been used by public agencies as well as private companies (Liotard and Revest, 2018; Kireyev, 2020). Other mechanisms such as crowdfunding are widely used in other sectors such as medicine (Aleksina et al., 2019; Bassani et al., 2019; Sauermann et al., 2019). In agriculture, levy-funding of research by farmers shares some similarities with crowdfunding and has been applied successfully to pulse crops in Canada (Carew et al., 2013). In all these alternative examples, rewards from research are not related to the sale of the innovation, so that we could expect a lower impact of market size on innovation incentives. However, the literature on these alternative mechanisms is still limited and more comparative analysis should be developed. In particular, one question that has not been addressed in these comparisons is whether these different research funding mechanisms can moderate the impact of market size on innovation.

We focus here on financial incentives driving the efforts of each actor for innovation. Considering the increase of pea acreage as a sustainable transition, non-financial incentives could also play a role, but these incentives were generally not mentioned in the interviews. Some breeders and cooperatives mentioned that pea acreage could increase in the following years in relation to agro-ecological transition and to the increasing interest for plant-based proteins for food and for organic products. In this context, maintaining a selection program and/or a trial network for pea could be viewed as an option value strategy to avoid losing knowledge and skills on this species. Even if non-financial incentives should be recognized and were probably overlocked in this article, empirical evidence on the difficulty to increase pea production areas shows that such incentives have been too limited for the time being to compensate for the negative effect of small market size.

The analysis presented here is based on two cases, but we think the results can be extended to other commodity crops, with the necessity to adapt the definition of market size. Extending the results to other agricultural productions should be carried out with caution because value chains may be very different. At last, it should be observed that the effect of market size analyzed here is probably overstated because of different research histories for these two crops.[11] In France, plant breeding for wheat started in the second half of the XIXth century, while breeding for protein pea started in the 1970's. Hence the higher cumulated research investment on wheat is related not only to the higher investment per year during the last decades, but also to the longer history of selection for this crop. This history explains the differences in the value chains observed for wheat and pea, with much more outlets for wheat. Complementary historical research would be very interesting to better understand the current differences between these two crops.

CRediT authorship contribution statement

Aline Fugeray-Scarbel: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Stéphane Lemarié:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

Stephane Lemarie reports financial support was provided by French National Research Agency. Aline Fugeray-Scarbel reports a relationship with ICF International Inc. that includes: consulting or advisory. Stephane Lemarie reports a relationship with ICF International Inc. that includes: consulting or advisory. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data on commercialized varieties will be made available on request; the authors do not have permission to share transcriptions and reports of the interviews.

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Appendix A. Estimation of revenue on certified and farm-saved seed for wheat and peas

The revenues for breeders come both from the royalties on the certified seeds they sell and, for wheat, from the CRIV collected on farm-saved seeds. These revenues can be estimated by taking into account the following parameters: the total acreage for the crop (Acr), the percentage of certified seeds used (%CS), the sowing density (SD), the amount of royalties (Roy) per quintile of certified seed used, the amount of CRIV per ton collected (CRIV), the percentage of CRIV returned to breeders (%CRIV) and the average yield (Y).

We can then compile:

- the total royalties collected on certified seeds sold (TOT_{ROY}) = Acr x SD x %CS x Roy.
- the total CRIV collected on farm-saved seeds (TOT_{CRIV}) = Acr x Y x (1 - %CS) x CRIV x % CRIV.

The parameter values are presented in the table below. Given these values, we estimate a total revenue of 43 M€ for wheat breeding (27,65 M€ from royalties and 15,3 M€ from CRIV) and 1,89 M€ for pea, coming exclusively from royalties.

These estimates rely on the assumption that all farmers buying certified seed and benefiting from the discount equivalent to CRIV effectively pay the CRIV on their production. This assumption leads to neglecting the revenue loss related to farmers who self-use their production and use certified seed (mainly livestock farmers). Indeed, these farmers do not pay the CRIV but rather receive a discount when they buy certified seeds.

Parameters	Winter wheat	Spring pea	Winter pea
Acreage in millions hectares (Acr)	5	0.150	0.05
Percentage of certified seeds use (%CS)	50%	50%	50%
Sowing density in ql/ha (SD)	1,4	2	1,75
Amount of royalties in €/ql (ROY)	7.9	9.77	9.77
Amount of CRIV in €/ton collected (CRIV)	0.9€	–	–
Percentage of CRIV returned to breeders (%CRIV)	85%		
Average yield in ton/ha (Y)	8		

Appendix B. Interview guide for seed dealers

B.1. Point 1. Organization's activities

- Presentation of the interviewee
- Presentation of the organization:
  - o Different areas of activity (agro-supply, processing, collection of the agricultural production…)
  - o Activities within the seed industry (seed multiplication and/or seed sales…)
  - o Number of members, member of a cooperative union
- Species handled (distribution of sales by species)
- Area of activity (collection zone, sales sites) and main competitors in your area?

B.2. Point 2: Varieties offered

- How many soft wheat (winter and spring) and pea (winter and spring) varieties are in your catalog?
- On average, how many new wheat and pea varieties do you add to your catalog each year? How many do you remove?
- On average, how long do wheat and pea varieties remain in your catalog?
- What factors might explain these differences between wheat and pea varieties?
- Can you provide us with your catalog of varieties?

B.3. Point 3. Design of the catalog

- How do you segment your wheat and pea varieties? (targeted market, geographical area, season, use…)
- What main criteria do you take into account to integrate a new variety in your catalog (yield, disease resistance…)? and to remove it?
  - o How do you obtain information on these criteria you use to select the varieties (breeder trials or your own trials)?
  - o Do you have the same level of information on the varieties of the 2 species?
- What variety trials do you set up to establish your catalog?
  - o Total number of plots per species
  - o Distribution of your R&D budget among species
- What information do you have on farmers' needs (preferred varieties)?
  What is your positioning strategy on the French seed market? (Differences with competitors, important criteria…)

B.4. Point 4: Seed production - contracts for seed multiplication

- How are seed production contracts drawn up with breeders?

o How many breeders do you have contracts, with for wheat and for pea?
- What elements are discussed/negotiated in the relationship between breeders and seed multipliers/distributors (type and volume of seed supplied, exclusivity, return of unsold stock, length of commitment)? Do these elements differ between peas and wheat?
- Do the varieties offered by breeders meet your expectations?
- Are production costs (seed sorting, cleaning, etc.) of the same order of magnitude for pea and wheat?
- What proportion of the amount of seeds you produce is sold in the long/short circuit?

B.5. Point 5: Distribution

- Are marketing efforts of the same magnitude for the 2 species?
- Are sales of associated products (crop protection products, fertilizers, seed treatments) of the same order of magnitude for these 2 species?
- In what geographical area are your varieties (pea and wheat) distributed?
- Have you ever encountered difficulties in marketing certain varieties? What could be the reasons?

B.6. Point 6: Relations with farmers

- Do you forecast farmers' demand to determine which varieties to produce and in what quantity?
- In your opinion, are farmers equally sensitive to the performance of wheat and pea varieties?
- Is genetic progress on these 2 species in line with farmers' needs?
- Does the information available on new varieties enable you to provide the same level of advice for the 2 species?

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