The Holstein cow as an institution of the agricultural modernisation project: commodity or common good?

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The Holstein cattle breed in the modernisation of agriculture: between common-pool resources and tradeable goods

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"Holstein" is the common name of the most familiar breed of black-and-white dairy cows that produce the milk found on our tables in the morning. The most widespread cattle breed on farms in the world and in our collective imagination, it is associated with the successes and the crises experienced by dairy farming and the milk industry in Europe. The Holstein is one of the breeds that has undergone the most selection, particularly with the development of the animal genetics industry in the 20th century, and still remains a pioneer breed for the dairy industry. Likewise, with the recent development of genomics in service of animal selection, it was the first dairy breed to benefit from this modern biotechnology that can "read" an individual's DNA and instantaneously identify sires or brood dams with high performance potential. This cow, the ultimate "machine cow" (Ruet, 2004), has become one of the symbols of the industrialisation of agriculture and the commodification of living organisms. The market for Holstein bull sperm, embryos and cattle for reproduction purposes is estimated at €335m in financial transactions between countries worldwide (2015, from a professional trade source). There are many specialised companies in this sector and the Holstein breed has gone global. This breed is used on French medium-sized pasture-based dairy farms just as well as on the giant dairy farms in California and elsewhere that house several thousand cows. Despite climates considered to be unfavourable for this ultramodern breed, emerging countries are also turning to the Holstein breed through the process of "holsteinisation", whereby Holstein genetics are spread around the world (Theunissen, 2012) and to other breeds, improving their milk production. Holstein cattle are associated with mass market dairy development.

However, although Holsteins are emblematic of the commodification of living organisms, the breed itself nevertheless is a common-pool resource, belonging as much to dairy farmers as to breeders, and nowadays to other stakeholders. There are currently no (exclusive) intellectual property rights on animal breeds and, as such, no limitations on the access to these animals, nor – for the time being at least – to the genetic products derived from them. Still today, in 2017, an animal breed is the common property of all the farmers that use it. Drawing on Hess and Ostrom (2003:121) who make the distinction between flow and resources in common-pool systems, whereby even if the resource units produced (flow) by the resource (here, the animal breed) are commodities (e.g. animals, embryos, semen), the actual "breed" is a common-pool resource, possibly threatened if its management is left entirely up to market mechanisms. For example, there is a risk of inbreeding or spread of genetic anomalies when the best individuals of an animal population are overused for reproduction purposes (deterioration of the resource)[1]. One study has shown that the number of ancestors that – alone – have contributed half the genes found in the Holstein population dropped by a factor of 3.5 between 1988 and 2003 (Mattalia *et al.*, 2006). In contrast, breeds with small population sizes are threatened by the non-use of the breed (extinction) or breeders who no longer contribute to the breeding programme (Labatut *et al.*, 2012).

The Holstein breed is a particularly relevant case study for analysing the paradox of management of a common-pool resource faced with growing commodification of the resource units

1 « The strong decrease in fertility of Holstein cattle, as well as the recent emergence of new hereditary diseases, is a sign that inbreeding is becoming a serious threat in the short term » (Taberlet et al., 2008).

produced from the resource. This issue is becoming more and more important in the context of the recent changes in the animal genetics market: growing globalisation, deregulation, withdrawal of government funding from genetic selection programmes (particularly in France where government funding was previously high), and emergence of new technologies that dramatically accelerate genetic progress (genomics, semen sexing, etc.).

Here, we will examine the evolution of the Holstein breed to explore various forms of industrialisation in agriculture. First, we will cover some of the steps in the genetic and marketing process that led to the biological and institutional creation of the Holstein breed and to the holsteinisation of French dairy cattle. Then, we will use the concept of "breeding regime" (Labatut *et al.*, 2011; Labatut *et al.*, 2013) to shed light on the evolution of the Holstein breed. A breeding regime is an institutional regime made up of political, scientific, technical, informational and organisational measures that determine the dynamics of an animal population and its genetic progress. We carry out this analysis in the particular case of France. We will show how holsteinisation in France is part of a dual cooperative-public breeding regime based on Fordist-type industrialisation, and we describe the measures implemented to manage the tension between common-pool resources and commodification dynamics. Finally, we outline the emergence of a new breeding regime, that of genomic selection spearheaded by the Holstein breed. This breeding regime relies on the segmented industrialisation of genetic resources rather than on Fordist industrialisation centred on the mass production of homogenous goods. This quality differentiation of the breed, based on the new breeding regime, anticipates a dairy mass market differentiation by quality standards. Differentiating in an opposite way, we see the reappearance of local breeds

From the (Holstein-)Friesian to the modern Holstein, an account of the construction of the breed

Although zootechnical studies have explored the genetic evolution of the Holstein and socio-economic studies have analysed the changes in the dairy market and industry, there are no studies that trace the genetic history of the breed in light of the history of the dairy industry. Although we do not claim to exhaustively bridge this gap, we attempt to identify the parallelism of both historical trajectories. In contrast to most French breeds, the Holstein, whose official name in France is "Prim'Holstein", is found in all the dairy regions of the country and is not specific to any one of them. As emphasized by Pellegrini (1999), the Holstein breed "no longer evokes the cow from the German region of the same name, but now refers to a high-performing dairy breed, selected in North America and now found worldwide through commercial distribution of semen." The breed has a long history of selection and crosses with various branches of black-pied cattle[2].

The history of the Prim'Holstein cannot be traced back to a single country. This breed was introduced in France from the Netherlands and was then crossed with various other types to provide "new blood", first from the Netherlands and then from the United States in 1965-1970. The change in the name of this breed in France reflects the various influences that have contributed to its construction: "*Hollandaise*" (Dutch), "*Française Frisonne Pie-Noire*" (French Black-Pied Friesian), "*Française Frisonne*" (French Friesian) and finally Prim'Holstein. But let's start from the beginning.
The so-called "black-pied" cattle found around the world seem to all come from the same region along the coast of the North Sea, an area covering the present-day Dutch provinces of Friesland and North

2 "Pied" is the term used to describe the coat of animals with large patches of two or more colours, one of which is usually white; also used to designate the animal itself. Usually used in conjunction with the other dominant, non-white, colour (e.g. black-pied, red-pied, etc.).

Holland (Netherlands), the Jutland peninsula (Denmark) and the German state of Schleswig-Holstein[3]. In the middle of the 19th century, exports rose and European buyers (England, Belgium, Prussia, etc.) "attached great importance to the characteristics and the purity of the breed, leading to the need for pedigree records" (Denis, 2010). Two herdbooks[4] were then created, one (NRS) for Dutch cattle in general, primarily dairy, and the other (FRS) specifically for Friesian cattle, relatively dual purpose[5]. It was only in 1905 that the Hollander-Friesian black-pied cow breed was officially defined as such in the Netherlands. Overseas, the breed was renowned for its dairy production and qualified as "Hollander" or "Friesian". The first exports to North America date back to 1852, giving rise to the North American branch of the breed that developed under the name of "Holstein-Friesian". Since that time, selection in North America has been carried out practically without any "new blood" brought in from other countries. The ensuing phase of unrestricted trade and genetic exchanges between countries was followed in 1905 by a phase during which North America closed its borders for animal health safety reasons. This breed, with its own herdbook and a dedicated association created in 1885 (Holstein-Friesian Association of America) was from the beginning selected based exclusively on dairy criteria (drinking milk, low in butterfat and protein) and for long body length.

In the mid-19th century, animals from the dairy branch of the Hollander-Friesian black-pied cattle from the Netherlands were not common in France. Imports only became significant in 1830-40 (in Normandy). This Dutch breed was tall, low in muscle mass, had pronounced hook bones and, above all, boasted high milk production (Spindler, 2002). The breed gradually spread throughout France, first under the name of "Hollander". It became established in "sustenance" farms, dairy farms located around large cities at the time, particularly Paris (Denis, 2010). There were some farms with Hollander cows in highly populated industrial areas such as northern France (Nord-Pas-De-Calais, Picardie), the Parisian region (Ile-de-France) and the Bordeaux area (Gironde). However, other attempts to introduce the breed in rural areas were not very successful, particularly due to the poor adaptation of Hollander cattle to the most common farming conditions at that time.

In the Netherlands, the control of dairy performance and the creation of bull stud farms occurred in the early 20th century. According to Flamant (2011), "the Dutch and the Danish played a pioneering role in this field in the early 20th century by systematically recording individual cow production and by controlling milk quality in herds to provide clear, accurate data that could be used by all dairy farmers, for example, for comparison in livestock competitions." France only followed this example after WWI (*Contrôle Laitier Beurrier*, dairy unions in eastern France (Vissac, 2002; Flamant, 2011)) In parallel, in the late 19th century and early 20th century, a veritable dairy industry began to develop owing to the progress in transportation means and storage techniques. Thus, with the development of the railroad and the generalisation of pasteurisation, the Paris milk distribution network spread out to nearly 300 km (Vatin, 1996).

The importance of the Dutch cows' population and the desire to improve the breed led breeders in northern France to create, in Lille in 1922, the genealogical pedigree for the Hollander breed created under the name of "*Herd-Book français de la race Hollandaise*". At that time the role of the herdbook was to record those animals that met a "breed standard" and establish their pedigree (recording of births and publication of directories). Between WWI and WWII, the population increased significantly, going from 200,000 cows in 1918 to 600,000 cows in 1938 (Denis, 2010). The population reached 840,000 head in 1943, representing only 5.2% of the entire French cattle

3 Source: Prim'Holstein France, http://primholstein.com/

4 Breed registries of the male and female parents of an animal and their pedigrees. This term can also designate the organisation that is mandated to maintain this registry.

5 Dual-purpose breeds provide good yields of both meat and milk.

population[6]. However, during WWI, the French population of the breed had been devastated, and new imports were brought from the Netherlands to rebuild the herds. The breed spread mainly in northern France, north-eastern France, the Parisian region and in the South-West. The demand for services of the breed association (who maintained the herdbook), now based in Cambrai (northern France), grew rapidly. Milk records became mandatory for members of the breed association as of 1948, marking the beginning of the relationship between objective, scientific measurements of performance and the pedigree records, the two pillars of genetic selection.

Until the end of WWII, the animals of the two main branches (American and European) had the same production and morphological characteristics. American breeders then began to intensify the selection of Holstein-Friesians according to dairy-production and udder-quality criteria, while in Europe, selection concentrated on the butterfat content[7]and conformation[8]. In the Netherlands, the Hollander-Friesian black-pied breed, originally renowned for its milk production, was steered from 1945 towards "a balanced dual-purpose model, primarily at the behest of FRS, that resulted in a smaller body frame and better muscle development" (Denis, 2010). In France, selection turned to a dual-purpose breed and the Hollander breed then changed its name to "French Black-Pied Friesian" (*Française-Frisonne Pie Noire*, FFPN) in 1952, following the FRS Friesian model, but the breed was still primarily known as a dairy cow. The population increased to 1,500,000 head. This trend was not copied in other countries; for example, the United Kingdom, Italy and the North Holland province in the Netherlands chose to maintain the predominantly dairy breed.

After WWII, the progression of the FFPN breed continued in France, partly encouraged by the growing consumption of dairy products, and specialisation in production. It is effectively during this period that dairy companies (cooperatives) began to invest heavily and companies such as Danone and Chambourcy launched the production of yogurt (Vatin, 1996). For Vatin, by the early 1960s, Paris had an "authentic dairy industry". However, the analysis of this evolution requires a look back at French agriculture after the end of WWII.

During the reconstruction period, agriculture in France was criticised for its low efficiency compared with agricultural systems in other countries, such as Denmark, the Netherlands or the United States (see article by Pierre Fromont in *Le Monde*, 28 May 1946). For Fromont, who had published a rural economy treatise, "the agricultural technical revolution is not just about replacing horses or oxen with a tractor; that is only one aspect – undoubtedly the most spectacular, but not the most important. The most important instrument in agricultural production is the living organism, plant or animal; (…) [they] are the real agricultural machine-tools" (Pierre Fromont, 28 May 1946, "*La révolution technique en agriculture et la politique" Le Monde*, cited in Cranney, 1996). This statement illustrates the appeal of industrial processes to improve the efficacy and the yield of the agricultural tools and techniques, and one in which living organisms are considered as machines. The American Holstein breed was to become the emblem of this logic, whose development is today criticised because the "price to pay" is the fragility of the breed, imposing changes in the tasks of the breeder, who must implement a multitude of animal health measures (Ruet, 2004: 66).

For Pierre Fromont in 1945, "as in the industrial sector, we have witnessed the ageing and planned for the renewal of our equipment and machine-tools, as in agriculture, it is important to consider the efficacy of our biological tools. However, it must be admitted that, overall, these tools have not benefitted from the same improvement efforts as exerted in many other countries. One must

6 Source: Prim'Holstein France

7 Fat content in milk, expressed in grams per kg of milk.

8 Physical appearance of a livestock animal, scored according to production type (dairy, beef or dual-purpose)

continuously address the issue of efficacy of the living machine-tool […]. The work towards constructing a breed has been carried out on a smaller scale in France than in Denmark, Great Britain and the United States. […] Thus, to take but just one example, the average annual production of a dairy cow is evaluated at 1800 litres in France and exceeds 3000 litres in Denmark" (ibid.). However, for Fromont, and where fate contradicts him, the solution does not lie in importation: "we must get to work immediately. Other than the fact that improvement of living organisms is a necessarily slow process, because the cycle must be completed and cannot be rushed, it is almost impossible to have recourse to the method that is used for our industrial machine-tools: imports from other countries" (ibid.). Thus, as Flamant (2011) explains, INRA researchers in the 1960s adjusted the Friesian cow breeding programme to meet the "actual situation of farms": "In the French context of small farms, the economic outcome obviously relies on the sale of milk, which provides for a monthly source of revenue, but also on the added value that meat provides […] they propose a bull breeding programme targeting the French ideal of the Dutch-origin Friesian breed, the *Française-Frisonne Pie Noire* with a goal of increasing herd milk production to gain competitiveness at a level similar to that of other European Community countries and nonetheless maintain the meat production qualities" (Flamant, 2011:2). However, the importation of Holstein genetics will play a major role in the development of the French cattle population.

In parallel, during the 1960-70s, a second dairy revolution (Vatin, 1996) was based on the development of intensive dairy farming, with the "creation of efficient stables, the increase in dairy cow milk yield, the intensification of the farm-factory through the introduction of refrigeration on farm premises and the payment for production according to milk quality" (Vatin, 1996). The economic context was favourable to dairy production, providing incentive for European farmers (and abroad – Harris and Kolver, 2001) to massively import Holstein bulls from the United States and Canada to improve the milk yield of their cows and thus augment their productivity. The holsteinisation process began in several European countries and in France under the influence of crosses carried out using North American Holstein strains. The dual-purpose FFPN became specialised in milk production and grew in size and in udder quality.

The first introductions of Holstein-Friesian cattle from North America occurred in 1965 and 1966 in the Isere department. In 1972, the FFPN breed was the leading French breed in terms of population with 6 million head of cattle, exceeding that of the Normande breed (5.7 million, at its peak). On the European scale, in the 1970s, eight national Friesian black-pied populations made up the large majority of the 23 million dairy cows in the EEC (Vissac, 2002:174) and were to constitute the "target for absorption by the American Holstein" (ibid.). In 1979, the breed became "French Friesian" (Française Frisonne (FF)) encompassing at that time all Hollander-type animals, Holsteins born in France and the Friesian-Holstein hybrids.

The holsteinisation process was both biological and institutional. It occurred on different time scales and with different dynamics in each European country. For example, Vissac (2002) indicates that British farmers only became interested in American Holsteins much later, and attributes their initial disinterest in the selection for individual milk production to their large herd sizes (the United Kingdom had chosen to breed for milk yield when imports of Dutch dairy cows began). Likewise, in the Netherlands, the massive infusion of the local population with American Holsteins occurred long after France began importing (Theunissen, 2012). Vissac (2002) suggests that the Netherlands were in a defensive position, being the cradle of the Holstein breed. The percentage of the North American Holstein strain in the French cattle population increased from 40% in 1970 to 78% in the 1990s (Boichard *et al.*, 1993;1996). Boichard *et al.* (1993) also indicate that the percentage of Holstein genes in the black-pied bulls used for artificial insemination (AI[9]) was low prior to 1970, greatly increasing

9 Formerly called artificial insemination, now called animal insemination.

thereafter. From the 1980s, the proportion of Holstein blood reached nearly 100% for bulls used for AI. Thus, the percentage of Holstein genes in females rose from 5% in 1970 to 83% in 1990, which was clearly greater than the upper estimation that had been predicted by statistical geneticists at INRA (Colleau and Tanguy, 1984) and attests to the sharp and unexpected rise in holsteinisation. By the time milk quotas were introduced, the absorption of the local population by the American branch was practically irreversible. Nevertheless, the increase in productivity was accompanied by other changes such as the increase in stature, a change in conformation, improvement in udder morphology and a decrease in female fertility. Moreover, the arrival of the Holstein in France did not take place as peacefully as it may seem. In rural areas, there were conflicts, sometimes vehement, between supporters and detractors. Duroselle (1980) notes that the Holstein was the "be-all and end-all of modern selection in terms of milk for its supporters" and "depicted as a calamity for its detractors".

Several years after the French Livestock Act (1966), the Union for the Selection and Promotion of the Holstein Breed (*Union pour la sélection et la Promotion de la Race*, UPRA) (French-Friesian at the time) was created in 1975 (as a non-profit organization). A collective organisation that determined the scope of the breed as a common-pool resource (Labatut, 2013), this breed association aimed to define the targets of a breeding programme and also provided services for breeders, maintained the herdbook for registered animals and ensured the promotion of the breed. Since 1989, the UPRA headquarters has been located in St. Sylvain d'Anjou (Maine et Loire), the epicentre of farms in western France in terms of density. In 1990, with the goal to "make better known the efforts with regard to breed genetics and the breed's considerable population size in France", the UPRA decided to "abandon the terms "French" and "Friesian" and chose a new name: Prim'Holstein."

The structure of the UPRA breed association was created as a hybrid structure, both a parliament for the breed and an organisation that provides advice and services to its members (farmers). This ambiguous mixture between sovereign functions and extension service functions "caused all the same a certain number of concerns […]" (Bieri, Director of PHF, 2014 interview). Following the 2006 Agricultural Guidance Law (*Loi d'Orientiation Agricole*, LOA), an amendment to the 1966 Livestock Act (2006), Prim'Holstein France (PHF) became on 1 July 2008 the French Prim'Holstein Breeders Association (*Association des Eleveurs de la race bovine Prim'Holstein*) whose main vocation was to offer "independent services and counsel for dairy farmers on breed genetics and the management of their herd" (PHF). The regulatory missions (maintenance of the herdbook, breed policy) were entrusted to a new organisation, a selection organisation "OS Prim'Holstein". This OS is the "breed parliament" with members from PHF representing the member farmers/breeders, selection companies and AI cooperatives representing the stakeholders in the creation and dissemination of genetic progress, and finally other partners (milk records operators, EDE[10] CNIEL[11]). In 2009, based on a decision by Ministry of Agriculture, a representative of the Red-pied breed (formerly called *Pie Rouge des Plaines*) was integrated as the fourth member of this OS because the breed harbours a large proportion (90 to 95%) of Holstein ("red") genes (Bieri, 2014). At the departmental and regional levels, breeder associations were created to carry out local promotional activities for the breed by organising, for example, livestock competitions. Although they are independent of PHF, PHF funds and provides technical support for the organisation of these activities. In 2014, PHF assembled roughly 6700 member farmers/breeders and various unions or departmental breed associations. In the past few years, the emphasis has been placed on functional criteria, i.e., reproduction and health, without neglecting the currently high performance level. The various components of the global merit index (called *index de synthèse global* in France, or ISU) that assigns a value to individual sires are the

10 Departmental Livestock Identification Agency

11 Centre National Interprofessionnel de l'Economie Laitière.

translation of the breeding strategy chosen jointly by the various members of the OS. Thus, during its last revision in 2012, the ISU weights were the following: milk production (35%), morphology (15%), fertility (22%), udder health (18%), lifespan (5%) and milking rate (5%).
In 2010, the breed represented more than 60% of all dairy cows in France, attesting to the strong development of this breed in the country and its hegemony over other dairy breeds. On 1 January 2013, the French Prim'Holstein population included 2,422,000 cows or 31% of all cows (dairy and suckling) in France (BDNI data, Idele data processing). Each year, more than 2,500,000 cows are inseminated with a pure Holstein breed (source: Prim'Holstein France). The average milk yield of Holstein cows in France is 9329 kg of milk in 355 days of production (2014 milk records data, raw values) with an average butterfat content of 39.1‰ and an average protein content of 31.9‰.

This genetic and socio-economic history of the holsteinisation of the French cattle population occurred in a Fordist system of animal selection that we detail below.

Holsteinisation in the dual cooperative-public selection regime: between common-pool resource and tradable goods

With the 1966 Livestock Act, the French government set up a national centralised selection programme for animal breeds, particularly for cattle, sheep and goat breeds based on an alliance between breeders, researchers (INRA geneticists) and government agencies. For Flamant (2011), the selection of animal breeds "whose genetic heritage is considered to be of public interest" justifies the "public investments all along the selection chain" (Flamant, 2011). The period from the 1960s until the early 2000s make up a "cooperative and public selection regime" (Labatut *et al*., 2013). The sharing of resources and the "collegial" management of the breed were at the heart of this regime, whose national genetic policy was heavily funded by the government, in an effort to prevent inbreeding and to ensure that genetic progress was accessible to all breeders across the nation. In the interest of the national economy and food security, genetic progress can be considered a common-pool resource (Allaire *et al*., 2018). To meet this goal, the law defined the roles of the various partners involved in the selection process. The National Commission for Genetic Improvement (*Commission Nationale d'Amélioration Génétique*, CNAG), whose members are agents from the Ministry of Agriculture, scientists and genetic selection stakeholders, supervised the activities related to the genetic selection policy (validation of UPRA certification, definition of selection targets, regulation of the sale of semen, etc.)
The government designated INRA and the Institut de l'Elevage to manage the national genetic databases, which are shared among all the breed stakeholders, and constitute a platform of public information. The assessment of sires and brood dams, the calculation of the genetic value of animals (indexes) was delegated to INRA (in addition to its research mission) and to the Institut de l'Elevage. In contrast to the plant selection system, where the targets and performance criteria for varieties are defined by the private companies that produce them, animal selection is carried out in a dual cooperative-public regime, where the selection targets for each breed, translated into genetic indexes that evaluate the genetic merit of each animal based on these targets, are defined collectively within the UPRAs. In this regime, as we have demonstrated elsewhere, "the private market, cooperative associations and public agencies are not opponents but are collaborative partners" (Labatut *et al*., 2013). The recognition of the public stakes on these common-pool resources was not actually established until after the implementation of market schemes that ensured the distribution of the benefits from genetic progress and the sustainability of the resource (Labatut *et al.*, 2013). Thus the 1966 Livestock Act regulated the semen market and AI market by limiting competition, particularly by establishing monopolies according to geographical zone (territories) for AI cooperatives. This territorial organisation of the semen market sought to ensure access to AI services as well as to genetic

~~progress~~ improvements at fair prices for all livestock farmers. AI cooperatives were thus vested with a public service mission for the transfer of genetic ~~progress~~improvements.

Recognisably, this breeding regime has "allowed [livestock farmers and cooperatives] to invest in long-term breeding programmes at no risk. Today, it is acknowledged that the implemented strategy, set up to foster cooperation, has paid off" (CSAGAD seminar, 18 October 2006). This breeding regime accompanied the development of the Holstein breed in France, a country characterised by small herds raised in many different kinds of production systems and local terroirs, features that differ considerably to the countries that have historically exported their Holstein genetic products. Although the French Holstein strain was little exported during the years that followed the 1966 Livestock Act, the French breed had sufficiently progressed to compete with North American genetics in France. Thus, this dual cooperative-public regime was the background for the development of Fordist-type industrialisation of cattle genetics. On the one hand, the selection industry relied on the interconnection between cooperatives and the "mass consumption" of genetic progress (common selection targets and thus a genetically uniform product offer, with dissemination of semen by IA services nationwide). On the other hand, collegial socio-economic associations were constituted to represent the stakeholders (UPRAs). As in the Fordist-monopolistic type of industrialisation identified by the theory of regulation (Boyer, 2002), the international trade and outlook of French genetics was poor and the State controlled the market (through the CNAG). In this breeding regime, the tasks of design and execution of breeding programmes were clearly divided between the public institutes that devised the breeding programmes and the genetic evaluation tools (indexes) and the farmer-owned cooperatives that implemented the programmes and marketed the semen evaluated by INRA and the Institut de l'Elevage.

In France, this form of industrialisation contributed to the development of a market for Holstein genetics as in other countries, while participating nonetheless in a certain degree of standardisation and therefore some degree of reduction in domestic biodiversity (i.e. less productive breeds were abandoned (Audiot, 1995)). Historically, France has enjoyed a large diversity of animal breeds that varies with the locality and traditional regional products. One of the stakes at hand was to avoid an unreserved influx of Holsteins into all the other French dairy breeds used in various economic sectors. Vissac called attention to the decrease in the number of breeds in the early 1970s: "the number of cattle breeds with more than 100,000 breeding females has dropped from 21 in 1945 to 7 in 1971" (Vissac in INRA, 2009:136). Compared with other countries, the French dual breeding regime has more recently nevertheless been recognised as acting in favour of diversity: "the French system is unanimously considered to be highly efficient because it allowed, although its initiators did not realise it, the preservation of our livestock animal and breed diversity. This is the strong point in French breeding, due to its history and geography. France is undoubtedly the country with the most breed diversity in the world. The cooperation between stakeholders in selection has fostered work in many species and breeds simultaneously" (Giroud, 2009). As we have noted elsewhere (Labatut *et al.*, 2013), this collegial system is linked to the role of the State and professionals from the agriculture sector in the implementation of selection policy. Thus, although the Holstein largely dominates the cattle population, other breeds remain nonetheless firmly rooted in economically important industries (Normande, Montbeliarde, French Brown, Simmental, Tarentaise, Abondance, Vosgienne, etc.). Some of them are even expanding in some historically Holstein areas, such as the Montbeliarde, due to its more robust features (Courdier *et al.*, 2012).

The genomics selection regime: a trend towards segmented industrialisation?

Since 2006, profound political and technological changes have radically disrupted the animal selection landscape and have led to the emergence of a new breeding regime (Labatut, 2013; Labatut *et al.*, 2013; Allaire *et al.*, 2016). In 2006, the 1996 Livestock Breeding Act was amended as part of the Agricultural Guidance Law (*Loi d'Orientation Agricole*, LOA) that reorganised the genetic selection infrastructure and the role of its stakeholders.

Several years prior, the territorial monopoly of selection cooperatives had been criticised by the French Competition Council (*Conseil de la concurrence*) which fined[12] the genetics sector for obstruction to fair competition following complaints filed by veterinarians and foreign private operators who wanted to set up business in France. Those involved in implementing the selection policy and the French government thus made a move to reorganise the genetics sector through the 2006 LOA, which abolished the territorial monopolies of AI cooperatives and thus encouraged the deregulation of the genetics market, but preserved the democratic access to genetic ~~progress~~ improvements by setting up a Universal Artificial Insemination Service (*Service Universel d'Insémination Artificielle*, SUIA). Each livestock farmer is now free to choose his/her own semen collection centre or semen store. The SUIA also issues calls for tender to ensure coverage in areas with low cattle farm density and the distribution of semen for breeds with smaller population sizes.

The government has decreased its funding of animal genetics activities partly because it has reached the goal set in 1966 (and due to a decrease in agriculture funding in the public budget): French genetics now enjoys the same reputation as its competitors. It now delegates the authority and the responsibility for managing the national selection system to a trade association made up of selection stakeholders (specialised organisations and livestock farmers), "Livestock Genetics France" (*France Génétique Elevage*, FGE). The responsibilities of the CNAG have been largely reduced and the management of the genetic selection industry is now mainly in the hands of trade professionals. In the 2006 LOA, selection cooperatives have become animal selection businesses (*Entreprises de selection*, ES) and UPRAs have become breeding organisations (*Organismes de selection*, *OS*), which theoretically are more inclusive with regard to livestock farmers that use the breeds selected and managed by the OS. In certain cases (e.g., the French Brown breed), stakeholders have joined forces to create combined selection organisation-businesses (OESs) that design and carry out the breeding programme. As noted previously (Labatut *et al*., 2013), a central aspect of this new organisation is that the State nevertheless maintains a monopoly on the production of "official" indexes mandated to public research and development (R&D) institutes (INRA, Institut de l'Elevage), and the management of the genetic databases remains in the public domain. However, in conjunction with new technologies (similar to those that occurred when AI was developed), other changes have rapidly taken place and will overwhelm this approach. Getting rid of the territorial monopoly helped accelerate the merging of operators and mergers among cooperatives. In 2015, there were three main animal selection businesses with a Holstein genetic selection programme in France: Evolution, Gènes Diffusion and Origenplus.

As of 2009, a radical technological change came onto the scene that restructured the organisation of the genetics sector: genomics. This innovation was first developed for the three main dairy breeds (Holstein, Montbeliarde, Normande) based on a new form of public-private partnership (set up in the early 2000s) compared with the previous modes of cooperation for innovation. It involves a consortium between public research and some partner genetic selection businesses. Genomics can assess almost instantaneously the genetic potential of an animal using a DNA chip, without the long

12 *Decision no. 04 D-49 of 28 October 2004 on the antitrust practices in the cattle artificial insemination sector*

steps of progeny testing (for which the value of a bull was only determined when a sufficient number of his daughters had been tested, i.e. after 4 or 5 years). We have described how genomic evaluation technology works in more detail in a previous publication (Labatut *et al.*, 2014). The issue here is to identify the various changes that shed light on this new breeding regime and the concomitant change in the genetics industrialisation trajectory.

The complex system of common-pool resources on which selection activities rely in agriculture has two components (Labatut *et al.*, 2013):

- Genetic resources: the genome of the breed population, taken in its entirety (thus difficult to separate and privatise);
- Information resources: the database used to design the selection programme, recording animal performances and genetic indexes. It can be managed by a breeder association or declared a public good (as is the case in France since the 1966 Livestock Act), or developed by private companies (most recent cases) (Labatut *et al.*, 2013).

The changes in the new regime operate on both of these components along with a transformation of knowledge systems due to new technologies (genotyping, sexing, OPU-IVF[13], etc.). The production, treatment and transfer of data (phenotypes and genotypes) has become a major strategic issue, differentiating among operators in a competitive environment. Genetic data that rely on monitoring a high (but limited) number of animals on farms to determine the genetic value of a sire with respect to its descendants are produced in conditions that are totally different to those based on genomic data that can be obtained directly at the embryo stage and require state-of-the-art techniques that are generally patented. Consequently, the Labogena laboratory carried out genotyping for almost all the selection stakeholders after it invested in 2008 in an Illumina sequencing platform (Illumina also manufactures DNA chips) for research and genomic selection. This Economic Interest Group (GIE) created in 1994 included, until 2013, INRA and professional members from the selection sector (including the National Union of Animal Breeding and Insemination Cooperatives (UNCEIA), the Federation of Chambers of Agriculture (APCA), the *Races de France* federation of animal breed associations and the Institut de l'Elevage). In 2013, following various financial problems and disagreements on the governance of the laboratory, Labogena was sold and bought by Evolution, a group born from the merging of several French selection companies, today one of the world's major cattle selection companies.

In parallel, although INRA still has a regulatory monopoly on the production of official genetic indexes according to the 2006 LOA, part of the indexing service has become a commodity. Thus, companies or regional structures develop and offer breeders their own genomic evaluation tools. Gène Diffusion, a selection company in northern France has joined forces with the Institut Pasteur in Lille and Wageningen University (NL) to develop its own evaluation system, GD Scan, based on its own criteria (foot health) for the Holstein breed. Ingenomix, a biotechnology company created by the French Limousin association has specialised in "genome-wide association studies between phenotypes and genotypes and in engineering of DNA tests to offer genomic technology"[14], and has developed Evalim®, a private (branded) genetic evaluation tool. Thus, genomic technologies replace the labour-intensive collective and public progeny testing with a private service, that of genotyping animals using DNA chips that provide genomic information on individual animals at a low cost (Labatut *et al.*, 2013). INRA and the Institut de l'Elevage are no longer the only R&D partners for selection

13 Method of harvesting oocytes and in vitro fertilisation used for embryo transfers, consisting in collection of oocytes in a live animal with the aid of an ultrasound probe.

14 http://www.ingenomix.fr/english.html, consulted on 7 May 2015

stakeholders, although these two institutes still continue to carry out indexing activities on common and historical selection criteria.

Some private companies are turning more and more to an integrative system that covers the various steps in data production and processing, such as buying out Labogena or projects to incorporate performance testing organisations in selection companies. Thus the National Genetic Database (*Système National d'Information Génétique*, SNIG), previously entirely public, is now in a transition phase where, even if data collection continues to be shared among all members, some parts of regional databases lend themselves to privatisation for use in R&D and genetic evaluation. Thus, some private partners can invite public research institutes to work with them on certain data or selection criteria without sharing and transferring the results with all the stakeholders in selection. Moreover, this integration of data collection with a breeding programme goes far beyond the historical partners. Thus, since the development of genomics, technology for sexing semen has boomed, leading to optimal and profitable use of genomics promoting the production of females in crosses between high-genetic-value animals. An American company, Sexing Technologies, holds the monopoly on this technology for which it has bought all of the patents and is now equipping selection companies around the world. Owing to the profits brought by this technological success, this company is now investing in the genetic selection of sires. As the owner of bulls, it is in a position to sell semen and invests in large experimental farms to produce the amount of data required for selection based on specific differentiation criteria.

Although this technological innovation disrupts the property rights regime of genetic information as we have just illustrated, it is also accompanied by important changes in terms of the second component of the common-pool resource system: that of genetic resources and the market for indexed semen. In the former regime, the genetics marketed for each breed was not differentiated (beyond individual variations from one bull to another); the selection targets, translated into ISU (a global merit index) were collegially determined within the breed organisation and common to all selection companies. In the new competitive context of the 2006 LOA and due to the possibilities offered by genomics (the potential to create new "private" selection criteria independently of the previous, labour-intensive progeny testing method), the selection companies now seek to distinguish themselves from their competitors through a segmented and diversified offer. These companies hire marketing consultants and invest in the creation of a brand image. They engage in studies that identify farmer typologies, and glean "behavioural segmentations" or user profiles from them to target their genetics products. Thus, in an introductory speech, one of the CEOs of these businesses, used as his catch phrase a citation from Christophe Lafougère (CEO of Gira Food, a market consultancy firm): "the future lies in segmentation", adding that "investment in the brand, the image, is truly an investment for the future" (*France Agricole*, 21 May 2014).

These companies are not selling Holstein bulls, but a segmented supply of semen from their "brand" of Holstein with an image of their own construction. They promote "cumulative" and not "corrective" genetic crosses to produce bulls that correspond to specific segments: the "production" segment, the "quality" segment, the "health" segment, the "endurance" segment. Some businesses have begun to sell "packs" of bull semen that correspond to these segments. The genetics products are thus no longer centred on the breed or the individual bull but rather on a breeder profile (particularly because in genomics, the bulls are replaced much faster in the product catalogues and are more numerous and thus less well known by farmers).

All of these elements lead us to identify the switch from a mass market structure in which a low number of "star" bulls was put on sale for all livestock farmers to a segmented market (in which the "star" bulls are still featured), the switch from a Fordist-type industrialisation to a flexible industrialisation with the creation of Holstein diversity answering to various segments. Thus this new regime is not fostering a change in animal selection towards a goal of enhanced sustainability but towards segmentation in which some of the segments will target the creation of more productive Holstein cows while others will target more “sustainable” or “robust” Holstein cows (e.g. in terms of disease resistance). This outlook, which gave rise to a consensus among several types of stakeholders, supposes that the various models are compatible with the corresponding production.

These observed changes will likely be enhanced by a new profound change in policy: the European Animal Breeding Regulation that is currently in the validation process and planned for implementation in 2018. This text, drafted to “simplify and align the conditions for sharing data and genetic material between different European countries” (Dantin, speech at the 2015 Paris International Agricultural Show), aims to replace the former selection policy organisations in each Member State in terms of maintaining the herdbooks, implementation of selection programmes, performance testing and genetic evaluation for cattle, sheep, goat, pig and equine species. Reinforcing the deregulation trend for the genetics market that has already begun, this regulation consists in “moving from a system that is still rather strongly administered through government agencies to a contract-based system (FGE press kit, 16 January 2015) and covered by its “own liability regime” (Dantin, 2015 PIAS speech). The regulation is structured around “Breed Societies” (BSs), that combine the missions of maintaining the herdbook and the implementation of a selection programme, and the related activities of performance testing and genetic evaluation (until now, these activities called for different operators that worked together in synergy in a collegial system). The certified breed societies can thus choose their service providers, for performance testing as well as for genetic evaluation, through calls for tender. This regulation also makes it possible to certify several breed societies for a single breed (up to now, only one breed organisation was authorised to define the selection targets for the whole breed). Thus, we hypothesize that each breed society, by integrating all the steps involved in selection and breeding and choosing their own selection targets and evaluation index, will participate in the momentum that has initiated differentiation among stakeholders in France since the 2006 LOA and the advent of genomics, and will encourage the development of a polycentric breed authority and increased segmentation of genetics products. At the time of this writing, the regulations are being debated within the French trade organisations and scientific institutes, with very divergent views. For the commercial trade stakeholders, this regulation will be the opportunity “to place the breeder at the centre of the system and create the conditions to restructure and streamline the organisations and companies that gravitate around the genetic sphere, to augment the competitiveness of European livestock producers” (FGE press kit, 16 January 2015). An audit carried out on behalf of the National Livestock Commission in 2016 sees this regulation as the opportunity to change the previous system considered by some to be complex and not very dynamic. However, the audit suggests keeping some of the collegial aspects, with a strong interprofessional governance system. For some European countries, this regulation provides the opportunity to set up “a deregulated landscape, autonomous but under government control, [giving] a freer range to creativity” (Michel Dantin, interview PIAS 2015). The scientists and public institutes who have until now been responsible for the regulatory aspects of evaluation worry that R&D activities will become uncoordinated and that scientific innovation in service of the breeder will decrease in efficacy over the long term. Each group of stakeholders is working on defining various scenarios of application of the regulation. The coming years will be critical for observing the trends in stakeholder positions and in the practical application of these profound changes that affect the organisation and implementation of selection policies.

Conclusion

This short historical recounting of holsteinisation and the breeding regimes that accompanied it lifts the veil on the various issues at stake in the management of common-pool resources and new forms of agricultural industrialisation. That which is a “common-pool resource” in the Holstein as a breed is an intangible good (in the sense that the production of genetic resources is the result of how the flow of produced resources is used) and it can be considered “uncontrollable”. Given its systemic dimension, this institution (the breed) cannot be controlled by the government, particularly given that the current breeding regime, centred on genomics, seems to favour a polycentric system of governance. In the near future, will there be several Holstein breeds within the one and same country? Are we headed to several breed “brands” and an upheaval of the “breed” concept? What are the stakes behind the maintenance of breed diversity? Would it be even more threatened by the development and spread of multiple Holstein “brands” (“long-lived” Holstein, “rustic” Holstein, etc.) that will perhaps be able to better compete on the same markets as the more rustic breeds with small population sizes? The cultural dimension of traditional local breeds will likely continue to help maintain some degree of biodiversity. Genomics is often touted as an opportunity to select for more sustainable animals (Institut de l’Elevage and INRA, 2011). The first observations tend to show that genomics is above all used to accelerate genetic progress and augment the market shares for the Holstein breed for the companies that segment their genetics (thus, the addition of a “health” criterion may well be accompanied by an increase in the weight given to the “milk yield” trait in a private composite index).

Although the previous dual cooperative-public model was widely criticised by some “alternative” breeders involved in movements to promote traditional varieties for the selection of plant resources, the French national scheme being considered too complex (Bessin, 2012), we should reflect on the way these stakeholders will react to the current deregulation trends with regard to selection and flexible industrialisation. What aspects of animal selection will remain in the public domain in the future? Are we experiencing the emergence of initiatives to rehabilitate common-pool resources?

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