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Cadre de réalisation de la thèse

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Introduction générale

1. Réduire l'usage d'antibiotiques en élevage : quels enjeux ?

1.1. L'antibiorésistance, menace mondiale pour les êtres vivants

Les antibiotiques, outil de l'arsenal thérapeutique pour la guérison de maladies bactériennes voient aujourd'hui leur efficacité menacée par l'existence de bactéries antibiorésistantes.

Depuis la découverte du premier antibiotique par Alexander Fleming en 1928 (Anonymous, 2014), de nombreuses molécules antibiotiques ont été développées et produites. Naturels ou de synthèse, les antibiotiques diffèrent par leur spectre d'action (bactérie Gram -, Gram +, ou spectre large), leur action sur les bactéries (bactéricide ou bactériostatique), leur mode d'action moléculaire. La nature de la molécule antibiotique, la galénique et le conditionnement pharmaceutique déterminent ensemble la voie d'administration, le temps d'action, les tissus dans lesquels l'antibiotique diffuse et donc la posologie des traitements. Les antibiotiques sont en général utilisés pour une visée curative, c'est-à-dire en traitement d'une maladie bactérienne. Ils peuvent également être utilisés à des fins préventives. Ils sont alors administrés avant l'apparition des signes cliniques de la maladie, pour prévenir le développement de ladite maladie.
Pour la santé des animaux d'élevage, les antibiotiques sont également utilisés de manière métaphylactique. La définition européenne de la métaphylaxie correspond au traitement de tous les animaux d'un lot, alors que seule une proportion des animaux de ce lot est atteinte par la maladie. Le traitement du lot permet alors de traiter les animaux malades et de prévenir une diffusion très probable des troubles de santé aux animaux encore sains (Fanuel, 2012).

En santé humaine, les premiers échecs thérapeutiques de traitement aux antibiotiques sont relevés dès les années 1940 (Anonymous, 2014). Ils signent le développement de l'antibiorésistance. L'antibiorésistance est un phénomène biologique naturel où une bactérie possède des moyens de lutte contre un antibiotique, le rendant partiellement ou totalement inefficace contre elle. Ce phénomène peut être inné, ou acquis, suite à une mutation du génome ou suite à l'acquisition d'un plasmide de résistance. La transmission de la résistance entre bactéries peut se faire par voie horizontale, grâce à la conjugaison bactérienne[1], ou verticale, grâce à la transmission de l'information génétique (plasmide ou gène) lors de la division cellulaire. Phénomène naturel, la diffusion de gènes de résistance au sein de la communauté bactérienne s'accélère sous la pression de sélection des antibiotiques. Pour chaque utilisation d'antibiotiques, les bactéries sensibles meurent, les bactéries résistantes demeurent et se développent, profitant de l'espace et des ressources laissés libres dans le milieu par la mort des bactéries sensibles. Chaque utilisation d'antibiotique sélectionne donc des bactéries résistantes. L'augmentation d'utilisation des antibiotiques évolue en parallèle de l'augmentation du niveau d'antibiorésistance global (Chantziaras et al., 2014). Jusqu'aux années 1970, la mise sur le marché de nouvelles molécules antibiotiques permettait de compenser la progression des niveaux d'antibiorésistance en offrant de nouvelles options de traitements antibiotique efficaces. Cependant la dernière découverte d'antibiotiques d'une classe totalement nouvelle remonte aux années 1980 (Anonymous, 2014). Depuis cette période, le déclin du développement de nouvelles options

[1] Transmission de plasmides via des pili sexuels

antibiothérapeutiques ne permet pas d'alternatives thérapeutiques face à la progression de l'antibiorésistance. Néanmoins, les dernières molécules antibiotiques mises sur le marché font face à des niveaux de résistances encore limités. Elles sont appelées antibiotiques d'importance critique (AIC) car leur efficacité est jugée comme à préserver, et en conséquence, leur usage à limiter.

Aujourd'hui, la minimisation de l'utilisation d'antibiotiques est un enjeu majeur permettant de limiter l'augmentation des niveaux d'antibiorésistance. La santé humaine tout comme la santé animale sont concernées par cette problématique mondiale.
Les grandes instances internationales (*inter alia* OIE, FAO, OMS, Sommet de Davos, OMC) ont estimé que la maîtrise de l'antibiorésistance était une des priorités pour l'avenir de l'humanité. En effet, l'antibiorésistance génère des coûts très importants en termes de vies humaines (25 000 morts par an en Europe (EU-28) attribuables à l'antibiorésistance (Laxminarayan et al., 2013)) et financiers (entre 21 et 34 milliards de dollars US par an pour le système de santé aux USA (Anonymous, 2014)). L'augmentation des niveaux d'antibiorésistance pourrait dans un futur proche compromettre la réussite d'opérations chirurgicales et de traitements aujourd'hui courants (Laxminarayan et al., 2013).
En France, il existe un plan visant une amélioration des pratiques de prescription et d'utilisation des antibiotiques en santé humaine (Plan Antibiotiques du Ministère des Affaires Sociales et de la Santé, depuis 2011).
Le secteur de la santé animale consomme environ 50% des antibiotiques produits dans le monde en volume, comptant pour entre 50 000 et 100 000 tonnes par an (Laxminarayan et al., 2013). En France, pour accompagner ces réductions d'utilisation d'antibiotiques, un plan national a été développé en santé animale (EcoAntibio 1, 2012-2017). Il visait une réduction d'utilisation des antibiotiques de 25% en 2017 par rapport à l'année 2012. En 2016, une diminution de 36,6%, toutes espèces animales confondues a été enregistrée. Le lancement du deuxième plan, EcoAntibio 2, intervient pour une nouvelle période de 5 ans, mais sans objectifs de réduction fixés chiffrés, excepté sur les AIC (Méheust et al., 2017).
Dans le cadre des travaux de recherche menés pour cette thèse, nous nous concentrerons sur la diminution et l'amélioration de l'utilisation des antibiotiques pour les animaux d'élevage, qui concentrent l'essentiel des consommations d'antibiotiques à destination des animaux (seuls 3% des tonnages vont vers les animaux de compagnie (Méheust et al., 2017)).

1.2. Législation française et initiatives des filières d'élevage

Les réglementations européenne et française encadrent strictement l'usage des antibiotiques pour la santé animale. Les dernières dispositions réglementaires, notamment intervenues dans le cadre du plan EcoAntibio1 viennent durcir le cadre de l'utilisation des antibiotiques afin de mieux en définir les conditions de prescription, de délivrance et d'administration. Certaines initiatives de filières dépassent le cadre réglementaire fixé pour limiter et améliorer l'usage des antibiotiques.

En France, la délivrance des antibiotiques est limitée à 2 types d'ayant droit de plein exercice : les pharmaciens et les vétérinaires, même si ces derniers ne peuvent tenir officine ouverte[1]. Toute délivrance d'antibiotiques en outre doit se faire sur la présentation d'une ordonnance établie par un vétérinaire.

[1] Les vétérinaires ne peuvent vendre des antibiotiques que « lorsqu'il s'agit d'animaux auxquels ils donnent personnellement leurs soins ou dont la surveillance sanitaire et les soins leur sont régulièrement confiés » (Article L610 du Code de la Santé Publique, modifié par la Loi n°92-650 du 13 juillet 1992-art.3 JORF 16 juillet 1992).

L'administration d'antibiotiques comme promoteurs de croissance, à des doses inférieures aux posologies recommandées, a été rendue interdite en Europe (EU-28) au 1er janvier 2006 (Règlement (CE) N° 1831/2003 du Parlement Européen et du Conseil du 22 septembre 2003 relatif aux additifs destinés à l'alimentation des animaux).
Par ailleurs, le décret prescription-délivrance (décret n°2007-596 du 24 avril 2007) est venu encadrer la prescription et la délivrance sans examen clinique préalable d'un animal par un vétérinaire ; ceci concerne notamment les antibiotiques. En effet, les éleveurs travaillent au quotidien à la gestion de la santé de leur troupeau sans systématiquement faire appel au vétérinaire pour le traitement d'affections bénignes ou courantes. Ce décret a permis un meilleur encadrement de ces pratiques puisqu'il impose aux éleveurs l'obligation de faire au moins une fois par an un Bilan Sanitaire d'Elevage (BSE) avec leur vétérinaire traitant pour établir un protocole de soin. Dans ce protocole est établie une liste des maladies les plus fréquemment rencontrées sur l'exploitation. Pour chaque maladie, le vétérinaire traitant définit les mesures de prévention, de traitement et les critères d'alerte adaptés au contexte. Les médicaments pouvant être intégrés dans ce protocole, dont les antibiotiques, peuvent alors être administrés par l'éleveur aux animaux pour les motifs de prescription établis lors du BSE sans visite préalable du vétérinaire. L'ordonnance du vétérinaire reste obligatoire. Ce mode de fonctionnement laisse une part importante de libre arbitre aux éleveurs pour la gestion quotidienne d'affections courantes, sous le contrôle à distance du vétérinaire.
Sur le plan des incitations à la prescription d'antibiotiques, les remises, rabais et ristournes faits aux vétérinaires pour l'achat de médicaments contenant des antibiotiques sont interdits depuis l'adoption de la loi d'avenir pour l'agriculture, l'alimentation et la forêt en 2014 (Loi n° 2014-1170 du 13 octobre 2014).
Enfin, un décret de 2016 (décret n°2016-317 du 16 mars 2016) encadre plus durement l'utilisation d'antibiotiques d'importance critique (AIC). Leur prescription n'est autorisée qu'après un examen complémentaire attestant de l'inefficacité des antibiotiques non critiques, ou dans le cas d'une urgence clinique.
Pour les années à venir, le plan EcoAntibio2 prévoit peu d'actions de type renforcement législatif. Cependant, à dire d'expert, une dernière modification de la loi pourrait interdire totalement l'utilisation préventive d'antibiotiques. Cette pratique est d'ores et déjà interdite pour les animaux d'élevage aux Pays-Bas depuis 2013 par exemple (Scherpenzeel et al., 2016). La pratique de la métaphylaxie ne serait quant à elle pas remise en cause.

Au-delà de ces évolutions réglementaires nationales, certaines filières de production animale se sont engagées dans des politiques d'amélioration de leurs pratiques d'utilisation d'antibiotiques. Par exemple, les filières porcine, aviaire et cunicole sont un exemple de progrès de pratiques d'utilisation d'antibiotiques. Elles ont en commun d'être le plus souvent sur des systèmes hors-sol, économiquement intégrées, avec des cycles de production rationalisés dans le temps. Par ailleurs, les consommations d'antibiotiques pour ces trois filières étaient élevées au début des années 2000 (Tableau 1).
Les acteurs de la filière porcine ont développé en concertation un moratoire sur l'utilisation des céphalosporines de dernière génération, incluses dans les AIC. Ceci a permis une réduction de 98,1% du nombre estimé de porcs traités avec ces molécules entre 2010 et 2017.

La filière cunicole a quant à elle mis en place une charte interprofessionnelle en décembre 2011 visant notamment une amélioration des pratiques d'antibiothérapie. La filière a pu enregistrer une nette amélioration des niveaux d'exposition aux antibiotiques des lapins (Tableau 1).

Tableau 1: Evolution de la mesure d'ALEA[1] pour les bovins, les porcins, les volailles et les lapins selon différentes années clefs : 1999 ; première année de mesure ; 2011, année de référence pour le plan national EcoAntibio1 ; 2016, dernière année de mesure publiée (Méheust et al., 2017)**. Seules les voies orales et parentérales sont prises en compte.**

ALEA[1]	1999	2011	2016	Evolution 2011-2016 (en %)
Bovins	0,266	0,328	0,248	-24,4
Porcs	1,268	1,103	0,645	-41,5
Volaille	0,655	1,005	0,574	-42,8
Lapins	2,446	3,176	1,980	-37,6

[1] ALEA : Animal Level of Exposure to Antimicrobials, indicateur de mesure de l'exposition retenue par l'Anses. Calculé en divisant le poids vif traité par la biomasse de la population animale potentiellement utilisatrice d'antibiotiques. Cet indicateur n'a pas d'unité.

L'utilisation d'antibiotiques dans les filières dites industrielles a beaucoup diminué au cours de ces dernières années (Tableau 1), dépassant les objectifs fixés par le plan national EcoAntibio 1. L'utilisation d'antibiotiques à destination des bovins a quant à elle moins évolué, n'atteignant pas les objectifs chiffrés du plan EcoAntibio 1 avec par exemple seulement une diminution d'utilisation de 14,5% des traitements intra mammaires.

1.3. Les filières bovines en France : principaux usages d'antibiotiques et progrès possibles

Le cheptel bovin français se divise en deux catégories : le cheptel laitier (3,7 millions de vaches laitières) et le cheptel allaitant (4,1 million de vaches allaitantes) (Cniel, 2017; Interbev, 2013).
Le cheptel laitier contribue à la filière lait de vache, mais aussi à différentes catégories commerciales de la filière viande de bovin : viande de vache, veau de boucherie, taureau et jeune bovin, bœuf, génisses (Figure 1). Le cheptel allaitant contribue à la filière viande de jeune bovin de boucherie (dénommée plus simplement par la suite JBB), et à la production de différentes catégories commerciales de viande de bovin : viande de taureau, vaches, génisses, bœuf (Figure 1). La France est ainsi le premier producteur d'Europe (EU-27) de lait de vaches (24 611 millions de litres de lait produits en 2015) et de viande de bovin (1,31 million de tonnes équivalent carcasse) (Maigret, 2016).

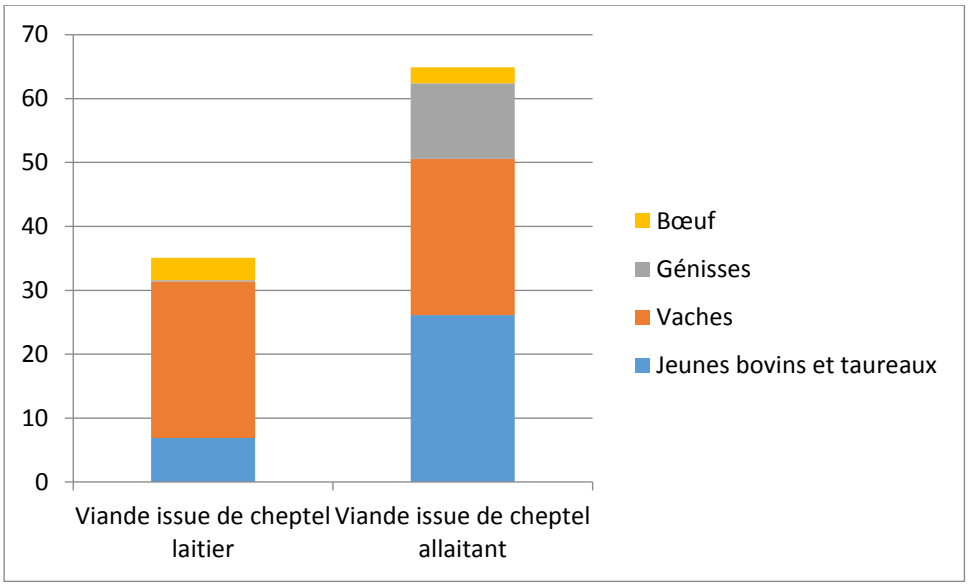

Figure 1 : Répartition de la production de viande bovine française (en % de tonne équivalent carcasse) selon le cheptel d'origine et le type de viande produit (Maigret, 2016)

La filière de lait de vache et la filière de viande de JBB issu du cheptel allaitant présentent des caractéristiques communes importantes pour aborder conjointement les questions de réduction d'utilisation des antibiotiques.

Deux maladies de production majeures sont la cause des principaux usages d'antibiotiques : les mammites pour les vaches laitières et les maladies respiratoires aussi appelées bronchopneumonies infectieuses (BPI) pour les JBB. Les mammites représentent 70% des motifs d'administration d'antibiotiques aux vaches laitières en France (Gay et al., 2012). Les BPI représentent en moyenne 75 à 80% des maladies observées sur la période d'engraissement des JBB (Assié et al., 2009). Pour la prévention et le traitement de ces maladies de production, les éleveurs bénéficient d'une relative autonomie, avec un appui à distance des vétérinaires (protocoles de soin et urgences).

Ces maladies ont d'importantes conséquences économiques. Les mammites seraient responsables d'un tiers des impacts économiques liés aux problèmes de santé des vaches laitières (Fourichon et al., 2001), comptant pour 61 à 97€ / vache dans les exploitations (Hogeveen et al., 2011). Les maladies respiratoires pourraient conduire jusqu'à une diminution de 26% des revenus d'une exploitation d'engraissement spécialisée (Bareille et al., 2007). Ces pertes sont liées à une baisse de production (moins de lait produit par les vaches ou croissance ralentie des JBB) pouvant aller jusqu'à la mort de l'animal dans le cas de BPI, au coût des traitements et au manque à gagner lié au retrait de certains produits de la consommation (lait). Ces maladies constituent également une atteinte au bien-être des animaux (douleur, lésions et maladie).

Pour la maîtrise de ces maladies de production, les éleveurs utilisent des antibiotiques à des fins préventives, métaphylactiques ou curatives (Tableau 2).

Tableau 2 : Pratiques actuelles d'utilisation des antibiotiques par les éleveurs et points de progrès sur les pratiques d'antibiothérapie pour les filières lait de vache et viande de JBB

	Filière lait de vache	Filière viande de JBB	Points de progrès
Usage préventif	Administration systématique au tarissement dans environ 70% des élevages (Pol and Ruegg, 2007a)	Administration systématique à l'entrée en engraissement des JBB sur environ 70% des broutards (Source : experts)	Arrêt des pratiques d'antibio-prévention systématiques

Usage métaphylactique	-	Utilisation sur un lot d'animaux lorsqu'une partie des animaux du lot exprime des signes d'atteinte clinique	Choix approprié des antibiotiques et du seuil de traitement
Usage curatif	Traitement de mammites avec AIC en première intention Traitement de mammites sub-cliniques[1]	-	Choix d'antibiotiques non critiques en première attention. Utilisation d'antibiotiques seulement dans des situations efficaces

Pour respecter les bonnes pratiques d'antibiothérapie et viser une diminution et une amélioration de l'utilisation des antibiotiques, les recommandations faisant consensus préconisent principalement : (i) ne plus avoir recours aux antibiotiques de manière systématique et préventive (diminution des quantités d'antibiotiques utilisées), et (ii) mieux utiliser les antibiotiques pour des motifs métaphylactiques ou curatifs (diminution et amélioration de l'utilisation des antibiotiques) (tableau 2). La question de la réduction d'utilisation des antibiotiques ne sera pas abordée dans les filières de production de viande de génisse, de veaux de boucherie, de vache, de taureau et de bœuf pour les raisons suivantes :

- La filière de production de viande de génisse allaitante peut se rapprocher de l'organisation de la filière de production de JBB, mais les volumes de viande produits sont moindres. La production de viande de génisse laitière est quant à elle anecdotique en volumes.
- La filière des veaux de boucherie correspond à la valorisation des veaux mâles essentiellement issus de la filière laitière. Les éleveurs engraissent sous contrat des veaux détenus par des entreprises spécialisées. Cette filière peut donc être rattachée aux filières dites « hors sol » très intégrées. Cette filière utilise d'importantes quantités d'antibiotiques (Gay et al., 2016). Cependant, comme pour les filières porcines, cunicoles et aviaires, des initiatives de filière visent à réduire considérablement les pratiques d'utilisation d'antibiotique dans les élevages d'engraissement avec notamment une charte interprofessionnelle de bonne maîtrise sanitaire et de bon usage des traitements médicamenteux mise en place en 2011 (Méheust et al., 2017).
- La filière de production de viande de vaches (cheptel laitier ou allaitant) utilise peu d'antibiotiques.
- Les viandes de taureau et de bœuf concernent des volumes de production et de consommation d'antibiotiques négligeables (Figure 1).

1.4. L'enjeu majeur des changements de pratiques au sein des filières animales

Par rapport aux pratiques actuellement observables, des voies de réduction et d'amélioration de l'utilisation des antibiotiques en filières lait de vache et viande de jeune bovin de boucherie sont identifiables a priori. Les principes de bonnes pratiques d'utilisation d'antibiotiques permettent en effet de mettre une priorité sur un arrêt des pratiques d'utilisation préventive d'antibiotiques et de limiter l'usage des antibiotiques aux traitements curatifs et métaphylactiques efficaces, réservant

[1] Poizat A. (2014) Pratiques et représentations sur les usages des antibiotiques et sur les possibilités de les réduire en élevage bovin et porcin. Thèse de doctorat vétérinaire, Faculté de Médecine, Nantes. Oniris : Ecole Nationale Vétérinaire, Agroalimentaire et de l'Alimentation Nantes Atlantique.

notamment les AIC aux traitements de seconde intention. Pourtant les évolutions d'exposition aux antibiotiques des bovins sont moindres que les baisses enregistrées dans d'autres filières.
L'enjeu est de réduire et d'améliorer les usages d'antibiotiques dans les filières lait de vache et viande de JBB, tout en tenant compte de l'organisation économique actuelle de ces filières et de leur niveau de performance. Le prérequis essentiel à une telle amélioration des pratiques est l'identification et l'analyse des verrous sociaux et économiques à leur adoption.

2. Des pratiques de soin ancrées dans un ensemble de mécanismes sociaux et techniques

2.1. Généralités sur l'étude des verrous et leviers aux changements de pratiques

L'utilisation d'antibiotiques comme intrant en productions bovines correspond à un régime sociotechnique stabilisé, ou verrouillage technologique. En effet, cette pratique est un standard partagé par le plus grand nombre, inscrit dans les routines cognitives des éleveurs (Geels and Schot, 2007). En filières bovines, le choix d'une technique - l'utilisation d'antibiotiques, parfois de manière préventive et systématique ou non justifiée - est aujourd'hui la forme technique dominante utilisée pour la maîtrise des maladies de production en élevage bovin que sont les mammites et les maladies respiratoires. Pourtant, ces usages génèrent une externalité négative, à savoir qu'ils accroissent les niveaux d'antibiorésistance (qu'ils soient en santé humaine, animale, ou dans l'environnement). Afin de limiter les usages, les connaissances actuelles permettraient aujourd'hui la mise en place de pratiques alternatives (prévention médicale par la vaccination, prévention zootechnique, changement de pratiques). Les utilisations préventives systématiques ou à mauvais escient sont par ailleurs déconseillées par les messages de politique publique (Anonymous, 2016). Ces derniers impriment ainsi une pression sur les systèmes dominants existants.

Ainsi, de nombreux constats scientifiques, dont les messages sont relayés par les pouvoirs publics, ont vocation à influer sur le régime sociotechnique dominant. Malgré cela, des verrous sociotechniques persistent concernant l'utilisation d'antibiotiques pour le contrôle des maladies de production en élevage bovin. Il s'agit alors d'analyser les mécanismes du verrouillage actuel, puis d'observer quels pourraient être les transitions vers un régime technologique plus respectueux des objectifs de santé publique et de réduction d'utilisation d'antibiotiques, tout en maintenant le niveau de performance des filières.

L'analyse des verrous de changements de pratiques, aussi appelés auto-renforcements ont fait l'objet d'études en agroécologie (e.g. Bidaud, 2013). L'agroécologie promeut des changements de pratiques agricoles visant à la fois une performance économique, sociale et environnementale. Les verrous d'une transition d'une agriculture forte consommatrice d'intrants (pesticides, herbicides, fongicides, fertilisants), à une agriculture plus respectueuse de l'environnement ont été décrits. Quatre mécanismes principaux d'auto-renforcements participent au maintien de régimes sociotechniques (Fares et al., 2012) :

- La mobilisation et l'état des connaissances. Ces mécanismes incluent les connaissances des agents eux-mêmes et leurs savoir-faire, celles de leur réseau de conseil et de leurs conseillers, et plus largement les connaissances et incertitudes liées à l'utilisation de technologies alternatives au régime dominant (Labarthe, 2010).

- La compatibilité avec les standards. Si les pratiques alternatives au régime dominant s'inscrivent dans les systèmes de production existants au sein du régime dominant, l'adoption large de ces pratiques pour une transition vers un nouveau régime dominant pourra être facilitée.
- Les rendements croissants à l'adoption. Plus la proportion d'agents adoptant les pratiques du régime dominant est importante, plus les réseaux accompagnant ces usages sont développés, ainsi que les effets d'apprentissages permis par ces pratiques. Par ailleurs, l'adoption de certaines techniques donne un avantage économique ou technique qui incite à son adoption par le plus grand nombre.
- Les effets d'irréversibilité. Lorsque des investissements importants ont été effectués en lien avec une technologie, ou que l'usage d'une technologie a déstabilisé le système de production originel (les sols par exemple), les changements de pratiques sont plus compliqués à mettre en œuvre.

Les sous-parties suivantes présentent les connaissances disponibles et les travaux scientifiques réalisés sur les différents mécanismes de verrouillage d'un régime sociotechnique ; en agriculture en général, et sur les questions de santé animale en particulier.

2.2. Les preuves de concept apportées par les connaissances scientifiques et techniques

La transition vers des usages plus durables d'antibiotiques en élevage n'est pas freinée par un manque de savoirs techniques sur le sujet. En effet, le niveau de preuve scientifique aujourd'hui disponible sur les mammites et BPI permet de comprendre, prévenir et de traiter efficacement ces maladies afin de limiter au minimum nécessaire l'utilisation d'antibiotiques et d'utiliser des technologies de prévention alternatives (gestion zootechnique, vaccination, etc.).

Mammites et BPI sont des maladies de production ayant pour particularité d'impliquer plusieurs agents pathogènes, principalement bactériens (et viraux pour les BPI). L'expression clinique de ces maladies dépend (i) des pathogènes impliqués (pathogénicité et virulence), (ii) des niveaux de contamination bactérienne. Les niveaux de contamination sont dépendants des facteurs du milieu (hygiène, ambiance de bâtiment, etc.), qui rendent plus ou moins favorables les conditions de multiplication et de dispersion des agents pathogènes, (iii) des échanges bactériens entre animaux, et (iv) de facteurs individuels comme le niveau des défenses immunitaires, notamment influencé par le stress des animaux. Les conditions d'élevage et les niveaux de stress des animaux participent donc à l'augmentation des risques de développement clinique ou sub-clinique de maladies de production. Les moyens de prévention des maladies de production doivent donc s'articuler autour de mesures globales prenant en compte les paramètres du milieu et le renforcement des défenses immunitaires des animaux.

Les agents bactériens et viraux responsables de mammites et de BPI sont connus et ont été décrits : physiologie, réservoir épidémiologique, caractéristiques de résistance dans le milieu, voies de transmission, etc. (e.g. De Vliegher et al., 2012; Fulton, 2009) (Tableau 3).

Une bonne connaissance des pathogènes impliqués dans le développement des mammites et BPI permet d'établir et de hiérarchiser les facteurs de risque d'apparition et de transmission de ces

maladies au sein des élevages (e.g. Hay et al., 2014; Robert et al., 2008; Sanderson et al., 2008) (Tableau 3).

Tableau 3 : Résumé des connaissances scientifiques sur les mammites et BPI (Watts, 1988)

	Mammites	BPI
Principaux agents pathogènes	Staphylococcus spp. Mycoplasma spp. Escherichia coli Streptococcus spp. Corynebacterium spp. Listeria monocytogenes Klebsiella spp. Salmonella spp. Enterobacter spp. Proteus spp. Yercinia spp. Pseudomonas aeruginosa	Mannheimia haemolytica, BVDV (Bovine Viral Diarrhoea), BHV-1 (Bovine HerpesVirus 1), BRSV, PI-3V, BCV (Bovine CoronaVirus), Mycoplama spp. , Pasteurella multocida, Histophilus somni
Réservoir	Intramammaire ou environnemental	Intranasal ou environnemental
Voies de transmission	Lors de la traite ou via le milieu (litière)	Contact ou via le milieu (air)
Facteurs de risque principaux	Hygiène de traite (désinfection trayons, propreté des mains, fonctionnement machine à traire), hygiène bâtiment, parité, stress, niveau de production (Litres/jour)	Ambiance de bâtiment (température, humidité, vide sanitaire), conditions météorologiques, stress, âge, niveau de production (GMQ), mélanges d'animaux venant de différentes exploitations

Les connaissances actuelles sur les facteurs de risque de mammites et de BPI permettent de développer différentes stratégies de prévention. Ces moyens de prévention sont bien décrits pour chacune de ces deux maladies (e.g. Hay et al., 2016; Leblanc et al., 2006).

Il y a tout d'abord des moyens de prévention non médicale. Ce sont des mesures qui, basées sur une bonne connaissance des maladies, impliquent la mise en place de mesures d'hygiène ou de conduites d'élevage (Wilson et al., 2016). Il s'agit par exemple de pratiques de traite ou de gestion d'ambiance en bâtiment d'élevage.

Des moyens de prévention médicale existent également (Leblanc et al., 2006). Tout d'abord, il existe notamment des vaccins pour la prévention des maladies respiratoires et pour les mammites. Les vaccins prévenant l'apparition de maladies respiratoires chez les JBB ont cependant une durée d'action limitée à 6 mois et un effet de protection limité (Larson and Step, 2012). En outre, la voie d'administration (injection ou administration intra-nasale) nécessite une manipulation parfois dangereuse des animaux. Enfin, la protection contre les BPI n'est pas totale et limite « seulement » l'importance des signes cliniques (Makoschey et al., 2008). Un vaccin est commercialisé en France pour la prévention des mammites, mais il nécessite un nombre important d'injections (3 injections par lactation) pour un effet protecteur limité (contre Staphylococcus aureus, les bactéries coliformes et les staphylocoques coagulase-négatifs)[1]. Pour les mammites, deux autres moyens de prévention médicale existent. Un immunostimulateur à administrer par voie injectable (2 injections) permet d'augmenter les défenses immunitaires des vaches pour prévenir les mammites post-vêlage.

[1] RCP du vaccin, informations disponibles au 21/11/2017 sur : http://www.ema.europa.eu/docs/fr_FR/document_library/EPAR_-_Product_Information/veterinary/000130/WC500068578.pdf

L'utilisation d'obturateurs de trayons permet, durant le tarissement, de prévenir de nouvelles infections de la mamelle.

Enfin, les pratiques de traitement sont également bien décrites, pour les mammites (e.g. Cabrera and Ruegg, 2011; Crispie et al., 2004; Gruet et al., 2001; Halasa et al., 2009a, 2009b) comme pour les maladies respiratoires (e.g. Abell et al., 2017; O'Connor et al., 2013; Stegner et al., 2013). L'utilisation d'antibiotiques et les posologies associées pour le traitement des mammites et des BPI est connu. Les traitements peuvent être accompagnés de l'utilisation d'autres molécules, comme les anti-inflammatoires, pour gérer la douleur et l'inflammation des tissus en complément de l'action antibiotiques. Les traitements phytothérapeutiques ou homéopathiques ne bénéficient pas encore de suffisamment de preuves scientifiques pour être utilisés de manière curative (Mullen et al., 2014). Des pistes sont encore à explorer sur ce point car peu d'alternatives aux antibiotiques existent lorsqu'il s'agit de traitement curatif de mammites ou de BPI.

2.3. La diffusion de l'information et la relation complexe entre l'éleveur et ses conseillers

Concernant la diminution d'utilisation des antibiotiques, l'ensemble des connaissances semble aujourd'hui disponible pour permettre une transition vers un régime sociotechnique moins consommateur de cet intrant. Cependant certains travaux ont montré que les éleveurs, notamment en élevage porcin et bovin, pourraient manquer de connaissances sur les enjeux de l'utilisation des antibiotiques et de l'antibiorésistance (Friedman et al., 2007; Moreno, 2014). La mobilisation des connaissances disponibles pourrait donc être un mécanisme expliquant les verrous d'un changement de pratiques d'utilisation d'antibiotiques.

Par ailleurs, les réseaux de conseil ont une importance primordiale pour accompagner l'utilisation d'antibiotiques et un arrêt des pratiques systématiques. Le passage d'une pratique systématique à une pratique sélective d'utilisation d'antibiotiques nécessite de nouveaux apprentissages (Vaarst et al., 2006) qui, s'ils ne sont pas accompagnés constituent un frein au changement de pratiques (Labarthe, 2010).

Les sources d'information utilisées par les éleveurs pour s'informer sur les pratiques d'élevage et de traitement diffèrent selon les études. Leur propre expérience (connaissances, expériences empiriques) et les conseils d'agriculteurs voisins pourraient avoir plus d'importance que les preuves scientifiques (Friedman et al., 2007; Vaarst et al., 2006). Cependant, les vétérinaires sont souvent cités par les éleveurs comme étant la première source d'information crédible et de conseil sur l'utilisation d'antibiotiques (S Mcdougall et al., 2017; Russell and Bewley, 2013). Cette relation de confiance pourrait être moins développée chez des éleveurs en agriculture biologique par rapport aux éleveurs en agriculture conventionnelle, les premiers sollicitant moins les vétérinaires que les seconds (Vaarst et al., 2006). D'autres études montrent également l'importance des conseillers autres que les vétérinaires pour amener à une diminution d'utilisation des antibiotiques (Pardon et al., 2012). Les magazines spécialisés et techniques (Russell and Bewley, 2013), les sources d'information gouvernementales (Heffernan et al., 2008) ainsi que les informations venant de laboratoires pharmaceutiques (Vaarst et al., 2006) seraient beaucoup moins exploitées par les éleveurs, faute de temps, de crédibilité ou parce que perçues comme étant une contrainte.

Le vétérinaire, seul prescripteur d'antibiotiques autorisé par la loi, est donc une source importante d'information et de conseil pour les éleveurs. Le comportement de prescription des vétérinaires a été largement étudié. Le choix des molécules prescrites est influencé par la pression des éleveurs, par d'autres acteurs de réseaux (laboratoires,…), mais aussi par leur propre expérience et par la maladie soignée (Busani et al., 2004; De Briyne et al., 2013; Gibbons et al., 2013; S Mcdougall et al., 2017; Mcintosh and Dean, 2015; David C. Speksnijder et al., 2015). Les décisions des vétérinaires sont d'autant plus influencées qu'ils sont jeunes, mais les vétérinaires les plus vieux se sentent moins concernés par les enjeux de l'antibiorésistance (David C. Speksnijder et al., 2015). Ce dernier point est en cohérence avec la relative nouveauté de cette problématique. Le vétérinaire pourrait avoir un rôle contrasté sur la mise en place de bonnes pratiques d'antibiothérapie. Une étude française en filière lait de vache montre que 48% des traitements effectués par les éleveurs ont fait l'objet d'une interaction avec un vétérinaire[1]. Aux Etats-Unis, sur un échantillon d'éleveurs laitiers, seulement un tiers a abordé le sujet de l'antibiorésistance avec son vétérinaire au cours des 6 derniers mois précédant l'étude, aucun message particulier n'ayant été retenu par les éleveurs (Friedman et al., 2007). Ces études ne permettent pas d'analyser le rôle de la relation éleveur – vétérinaire et des autres conseillers en élevage sur les pratiques d'utilisation d'antibiotiques par les éleveurs.

Les travaux de cette thèse apportent un éclairage sur un potentiel verrou sociotechnique à une amélioration des pratiques d'utilisation d'antibiotiques : l'accès à l'information à l'échelle des individus (éleveurs) et plus largement, à l'échelle de leur environnement de conseil (vétérinaires et conseillers techniques). L'analyse des freins et motivations des éleveurs, de leur vétérinaire et de leur technicien sur les questions d'utilisation et de diminution d'utilisation d'antibiotiques permet de mieux comprendre les verrous et les leviers liés aux biais informationnels. Des approches qualitatives inspirées de méthodes de sociologie sont classiquement utilisées pour explorer ces questions (e.g. Duval et al., 2016; Vaarst et al., 2007). L'évaluation des effets d'un apport de connaissances et d'un suivi de conseil pour une amélioration des pratiques permet d'envisager l'efficacité d'un potentiel levier d'action.

2.4. Les usages d'antibiotiques en élevage, compatibilité avec les standards de filière

Des mécanismes d'auto-renforcement peuvent être liés à la compatibilité avec les standards des pratiques. Ces mécanismes d'auto-renforcement existent si les pratiques alternatives à la pratique dominante s'insèrent difficilement dans les systèmes de production agricoles existants, limitant ainsi une adoption plus large de pratiques plus vertueuses (Bidaud, 2013). Une analyse des mécanismes d'auto-renforcement de l'utilisation prophylactique ou des mésusages d'antibiotiques liés à un contexte et une organisation économique de filière n'a pas été réalisée.

Des travaux de recherche en agronomie ont permis de montrer les freins potentiels à des changements de pratiques d'utilisation d'intrants en lien avec l'organisation économique des filières. La structure organisationnelle d'une filière pourrait constituer un verrou. La structure organisationnelle d'une filière comprend l'ensemble des liens financiers et contractuels qui modulent les règles de partage de

[1] Source : Anses, Bulletin épidémiologique santé animale – alimentation, 2013, numéro 53 : Spécial antibiotiques et antibiorésistance, disponible le 22/11/2017 sur : http://www.civ-viande.org/wp-content/uploads/2013/01/ANSES_BE53.pdf

la valeur entre l'amont et l'aval (Fares et al., 2012). Ainsi, cette structure pourrait constituer un verrou à l'adoption de pratiques plus vertueuses si elle freine la diffusion de valeur en lien avec des pratiques plus vertueuses, réduisant ainsi la capacité de l'amont à s'engager dans une transition vers des pratiques plus vertueuses. Par exemple, des configurations organisationnelles peu intégrées pourraient freiner la mise en place d'investissements nécessaires à un changement de pratiques (Fares et al., 2012).
Des travaux de recherches montrent que la qualité et les niveaux de coordination entre les acteurs permettent d'améliorer la performance des filières (Coronado et al., 2010). Les attitudes coopératives entre les membres d'une chaîne de production dans un secteur donné permettent par exemple d'atteindre un profit plus élevé (Loader, 1997) et l'adoption de standards de qualité complexes (Coronado et al., 2010). L'échange d'information entre les acteurs économiques d'une filière permet notamment d'augmenter l'efficacité économique du fonctionnement et la qualité des produits (Coronado et al., 2010). A l'inverse, un manque de coordination entre les acteurs d'un même secteur de production ne permet pas d'amélioration de la qualité des produits (Gaucher et al., 2002). Les contrats ont souvent été étudiés comme étant un levier sur les attitudes et performances (Fraser, 2005), en permettant notamment une meilleure coordination entre les acteurs (Mesquita and Brush, 2008). L'organisation économique des filières, via l'organisation des échanges commerciaux d'animaux joue également un rôle dans la transmission de pathogènes (Paul et al., 2013).

L'organisation de la filière viande de jeunes bovins de boucherie (JBB) présente deux organisations de production possible : (i) naissance puis engraissement des animaux dans la même exploitation, (ii) naissance dans un élevage spécialisé dit « naisseur », puis transport et engraissement dans un élevage spécialisé dit « engraisseur ». Le cycle de production de viande de JBB implique donc parfois le travail successif de différents acteurs. Il existe aujourd'hui 35 270 éleveurs naisseurs spécialisés et 9 360 éleveurs naisseur-engraisseurs[1]. Au cours du cycle de vie des JBB, la période critique de développement des maladies respiratoires correspond aux premières semaines d'engraissement. Pour gérer le risque de maladies respiratoires, la plupart des engraisseurs demandent qu'une injection systématique d'antibiotiques soit faite avant l'arrivée des broutards dans leur bâtiment. Cette situation pourrait concerner jusqu'à 70% des animaux (source : communication personnelle d'un expert)[2]. Les engraisseurs gèrent donc actuellement le risque de maladies respiratoires par une injection systématique et préventive d'antibiotiques. Les facteurs de risque de BPI peuvent pourtant être maîtrisés par une prévention aux étapes antérieures de production. L'organisation de la filière, complexe, peu contractualisée (Marty et al., 2015) et méconnue, pourrait donc avoir une influence sur les pratiques de prévention et d'utilisation d'antibiotiques pour la maîtrise des maladies respiratoires.

L'analyse développée dans cette thèse permet d'apporter un éclairage sur l'influence des standards liés à l'organisation économique et technique d'une filière sur l'utilisation d'antibiotiques. Les approches, construites sur des problématiques de santé publique, sont empiriques. Afin d'étudier les niveaux de coordination entre les acteurs permettant le maintien ou l'émergence des innovations, Geels (2002) a proposé une approche par une perspective multi-niveaux (multi-level perspective). Le

[1] Les proportions d'animaux produits dans ces différents types d'élevage ne sont pas disponibles. Source : Interbev, disponible au 21/11/2017 sur http://www.interbev.fr/wp-content/uploads/2014/10/LIVRET-VIANDES-BOVIN-2017_HD-Web_2.pdf

[2] Certains travaux menés aux USA décrivent une utilisation systématique préventive d'antibiotiques contre les maladies respiratoires dans au moins 40% des ateliers d'engraissement (Sneeringer et al., 2015).

cadre théorique est cependant assez large. Deux cadres théoriques empruntés à l'économie-gestion ont donc été choisis pour donner un cadre d'analyse au recueil des données de terrain : l'analyse des filières par la chaîne de valeur d'une part ; la théorie des coûts de transaction d'autre part (Fares et al., 2012).

2.5. Leviers d'une transition vers un nouveau régime sociotechnique

Les changements de régime sociotechnique sont approchés en regard d'analyses multi-niveaux (multi-level transition pathway). Une transition vers un régime sociotechnique nouveau nécessite la conjonction dans le temps de trois facteurs (Geels and Schot, 2007) : (i) l'existence de niches d'innovations permettant un support pour les apprentissages et améliorations dans la population générale, (ii) l'existence d'une pression sur le régime sociotechnique existant (venant par exemple des consommateurs ou des politiques publiques), (iii) une déstabilisation du régime permettant d'ouvrir une fenêtre d'opportunité pour une transition. Les déterminants de l'innovation sont donc tout à la fois sociaux, culturels, économiques et politiques (Vanloqueren and Baret, 2009).
L'utilisation d'antibiotiques en agriculture fait aujourd'hui l'objet de pressions de la part des pouvoirs publics, notamment avec un durcissement réglementaire progressif limitant les usages d'antibiotiques, et avec les plans nationaux mis en place depuis 2012 et visant une réduction d'utilisation. En outre, certaines niches, comme les filières labellisées en agriculture biologique pourraient utiliser moins d'antibiotiques, les usages prophylactiques sont par ailleurs interdits. Cependant, pour les filières viande de JBB, pour lesquels la labellisation d'agriculture biologique n'existe pas, d'autres niches d'innovations sont à explorer. Une déstabilisation du régime d'utilisation d'antibiotiques ne semble cependant pas être en cours puisque les pratiques d'utilisation prophylactique des antibiotiques demeurent courantes dans les filières lait de vache et viande de JBB.
Les innovations peuvent être en inadéquation avec les standards existants, être « théoriquement possibles », mais « non faisables », ou plutôt de type incrémentales, s'insérant progressivement dans les standards existants (Vanloqueren and Baret, 2009). La réduction d'utilisation d'antibiotiques semble plutôt suivre une transition de type incrémentale. Ce sont des changements de pratiques progressifs qui permettent des apprentissages et une réduction d'utilisation d'antibiotiques sur des échelles de temps longues.

Les travaux de thèse permettent de donner un éclairage empirique sur l'influence de formes de gouvernance et de systèmes de production sur les verrous à des changements de pratiques. Ceci permet enfin d'envisager des leviers d'actions afin de permettre que des innovations de niche permettant une moindre utilisation d'antibiotiques puissent s'insérer progressivement dans les standards existants.

D'autres mécanismes d'auto-renforcement permettent le maintien d'un régime sociotechnique.
Il existe par exemple un phénomène de rendements croissants d'adoption concernant les pratiques d'utilisation actuelles des antibiotiques. L'utilisation systématique et préventive, ou à mauvais escient d'antibiotiques permet de couvrir efficacement et pour un coût acceptable un risque réel (mammite ou BPI). La mise en place de techniques alternatives (prévention par la gestion zootechnique des élevages, l'hygiène, la vaccination) demande des apprentissages et un effort pour une efficacité qui n'est pas certainement connue. Il est donc possible de considérer qu'en tant qu'acteurs économiques, les éleveurs ont intérêt à utiliser les antibiotiques pour prévenir un risque de maladies non nul.

Les effets d'irréversibilité liés à l'utilisation des antibiotiques sont a priori inexistants, contrairement à ce qui est observé pour les pratiques agricoles.

3. De l'analyse de mécanismes d'auto-renforcement à l'identification de leviers, quels objectifs scientifiques ?

Compte tenu de l'existence d'objectifs de santé publique incitant à une réduction d'utilisation d'antibiotique, on pourrait s'attendre à observer une transition de régime sociotechnique vers des pratiques moins utilisatrices d'antibiotiques. Cependant, dans les filières lait de vache et viande de JBB, les régimes sociotechniques existants utilisent encore les antibiotiques de manière prophylactique. Dans ces filières où les acteurs sont indépendants, peu de travaux permettent d'explorer les mécanismes d'auto-renforcement des pratiques de mésusages ou d'usages prophylactiques des antibiotiques en lien avec la mobilisation des connaissances ou les standards économiques et techniques.

Porté par des enjeux de santé publique, l'objectif scientifique de cette thèse consiste donc en l'analyse des mécanismes d'auto-renforcement des pratiques d'antibiothérapie actuelle dans les élevages bovins français, ainsi qu'en l'identification et l'évaluation de leviers d'action pour manager les transitions.

Le caractère empirique de cette thèse, portée par une question appliquée de santé publique, place le travail de recherche à la croisée de plusieurs domaines scientifiques. En effet, l'analyse est portée sur les comportements individuels et collectifs de gestion sanitaire, dont les déterminants sont à la fois techniques, sociologiques et économiques. L'analyse des choix opérés par les acteurs, de l'influence de l'environnement social, et des leviers incitatifs à une modification des pratiques sont donc très dépendants des composantes épidémiologiques et médicales du domaine d'étude. Ainsi, des connaissances multiples sont mobilisées pour répondre à la question de recherche de cette thèse – à savoir quels sont les mécanismes d'auto-renforcement des pratiques d'antibiothérapie dans les filières bovines – aussi bien en épidémiologie, qu'en sociologie ou qu'en économie. L'approche holiste soutenue par cette thèse ne repose donc pas sur un paradigme unique, mais s'appuie sur plusieurs approches scientifiques et méthodologiques afin d'éclairer la question sanitaire sous-jacente. En outre, ce choix de positionnement scientifique est soutenu par le fait que les connaissances empiriques sur le sujet (aussi bien en recherche en sociologie ou en économie, qu'en termes de données disponibles) sont très limitées. La visée exploratoire de cette thèse constitue donc un front de science en soi, puisqu'elle permet de lever des interrogations multiples sur les déterminants des choix des agents.

Les travaux de cette thèse s'articulent donc autour de trois parties principales.
Le chapitre 1 apporte un éclairage (i) sur les verrous existants en filière lait de vache liés aux biais informationnels individuels des éleveurs et de leurs conseillers en élevage (vétérinaires et techniciens), (ii) sur les effets d'un dispositif visant à lever les verrous d'une transition vers un nouveau régime sociotechnique n'utilisant pas de manière systématique et préventive les antibiotiques et diminuant les mésusages.
Le chapitre 2 permet de mieux comprendre les verrous à une amélioration des pratiques d'utilisation d'antibiotiques liés aux standards de production économiques et techniques existants dans la filière

viande de JBB. Deux approches théoriques, la chaîne de valeur et les coûts de transactions, permettent de donner un cadre à l'analyse empirique qualitative.

Le chapitre 3 fournit un approfondissement pour la compréhension des verrous et leviers à une amélioration des pratiques d'utilisation d'antibiotiques liés aux standards de production économiques et techniques existants dans la filière viande de JBB. Un volet d'analyse de données quantitatives permet de décrypter les mécanismes de verrous liés à l'organisation économique de la filière. Une analyse qualitative comparant des innovations de niche en France et au Canada permet d'envisager des leviers pour une transition vers un régime sociotechnique utilisant moins d'antibiotiques.

Chapitre 1 : Mobilisation des connaissances, verrous et leviers liés aux biais informationnels

La recherche en sociologie a montré que la diffusion et l'adoption large d'innovations fait parfois l'objet d'un verrouillage sociotechnique, à savoir que le régime sociotechnique en place (stratégies technico-économiques communément adoptées) freine à son adoption. Un des points-clés de ce verrouillage sociotechnique est l'accès à l'information, et un des moyens de le lever est l'acquisition et la mobilisation de connaissances nouvelles, tant à l'échelle de l'individu qu'à celle de l'environnement social. La réduction d'usage d'antibiotiques en élevage constitue une innovation de pratique qui, pour être adoptée, nécessite que les acteurs du système (éleveurs et conseillers pour la santé des troupeaux) modifient leurs pratiques et acquièrent des savoirs nouveaux.
En effet, les éleveurs gèrent au quotidien les problèmes de santé animale touchant leurs troupeaux, appuyés par les conseils et prescriptions des vétérinaires pour l'utilisation des antibiotiques, et par les conseils des techniciens d'élevage pour la gestion zootechnique et la prévention de maladies. Explorer l'influence des connaissances et perceptions des éleveurs, en interaction avec leurs conseillers, sur l'amélioration des pratiques d'utilisation d'antibiotiques est donc un point important pour comprendre les verrous et envisager des leviers pour des changements de pratique. Les éleveurs laitiers constituent un archétype de terrain adapté pour explorer cette question de recherche. Ils travaillent au quotidien avec des troupeaux bovins dont ils gèrent la santé, le plus souvent de la naissance des animaux jusqu'à leur réforme.
Ce chapitre est ainsi consacré à cette question, avec en premier lieu l'exploration des verrous et leviers existant pour une amélioration des pratiques d'utilisation d'antibiotiques (chapitre 1A), et ensuite l'analyse des effets d'une étude d'intervention visant à initier un changement de pratiques vers une réduction d'utilisation d'antibiotiques (chapitre 1B).

Grâce à l'analyse d'entretiens semi-directifs (n=51), les résultats du chapitre 1A montrent que les éleveurs laitiers et leurs conseillers (vétérinaires et techniciens) expriment le plus souvent des points de vue convergents dans la volonté de réduire les utilisations d'antibiotiques, par exemple en faveur de traitements sélectifs au tarissement, mais malheureusement aussi dans la justification et la défense de pratiques d'utilisation d'antibiotiques moins vertueuses (mésusages ou pratique systématique de l'antibiothérapie au tarissement). Cette convergence des attitudes entre éleveurs et conseillers montre l'importance de ces derniers (vétérinaires et techniciens d'élevage) pour les choix de pratiques d'antibiothérapie dans la gestion des mammites.
Par ailleurs, les éleveurs, par la description de leurs pratiques, ont montré certaines lacunes concernant les bonnes pratiques d'utilisation d'antibiotiques. En outre, vétérinaires et conseillers techniques exprimant des freins pour le changement de certaines pratiques, les biais informationnels auxquels sont soumis les éleveurs expliquent en partie la faible évolution des pratiques vers une réduction d'utilisation d'antibiotiques dans la population générale.

Compte tenu de l'importance (i) du potentiel manque d'information et de connaissance des éleveurs sur les bonnes pratiques d'antibiothérapie et les répercussions sur l'antibiorésistance, (ii) de l'importance des conseils vétérinaires pour le respect de l'utilisation vertueuse des antibiotiques et pour une transition vers des pratiques sélectives d'antibiothérapie au tarissement, la mise en place d'un protocole d' étude d'intervention (recherche-action) portant sur les pratiques d'antibiothérapie

est à même d'évaluer l'importance et le rôle (i) d'un apport de connaissances auprès des éleveurs et (ii) de l'établissement d'une relation de conseil visant une réduction d'utilisation d'antibiotiques. Le chapitre 1B revient sur la mise en place et sur les résultats d'une telle étude d'intervention de type exposé / non exposé dans 33 élevages. La formation, et plus largement, le dispositif d'accompagnement des éleveurs a permis une amélioration des connaissances des éleveurs. Les éleveurs ont par ailleurs mieux compris et intégré l'importance du protocole de soin, qui permet un accompagnement de fond et de long terme par les vétérinaires pour une amélioration des pratiques de prévention et de gestion des maladies d'élevage. Les éleveurs ont également diminué leur consommation d'antibiotique pour la gestion des mammites en lactation et au tarissement. Les autres pratiques d'élevage ont cependant peu évolué au cours de l'étude. Une durée plus longue d'observation des pratiques (au-delà d'une année) pourrait peut-être permettre de mieux voir des changements de pratiques qui s'inscrivent sur des pas de temps longs.

Chapitre 1A : Influence du conseil en santé animale et des systèmes d'élevage sur l'utilisation d'antibiotiques par les éleveurs pour le contrôle des mammites

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Abstract

Mastitis is a bacterial disease common in dairy farms. Although knowledge about mastitis and its optimal technical management and treatment is now available, some dairy farmers still use antibiotics in inappropriate ways. Antibiotic use by farmers can be influenced by personal restraints and motivations, but it can be assumed that external drivers are also influential. The main purpose of this article is thus to analyse the choices of antibiotic and alternative medicine use for mastitis treatment and investigate the possible influence of two unexplored external drivers in dairy farms: (i) the health advice offered to farmers by farm advisors and veterinarians, (ii) the dairy farming system, as defined by combining the market valuation chosen for the milk, the level of intensification, and the perceived pressure related to investments. Research was based on 51 individual semi-structured interviews with farmers and their corresponding veterinarians and farm advisors. Based on verbatim, the use of antibiotics and alternative medicine by farmers for mastitis treatment, the vet-farmers interactions, and the dairy farming systems are described. The advisory relationships between farmers and farm advisors and between farmers and veterinarians influenced the implementation of selective dry cow therapy, but had very little effect on the use of alternative medicines by farmers, who were more willing to experiment alternative medicines than their advisors. The dairy farming system had very little influence on antibiotic use: some misuse of antibiotics was found whatever the farming system. Systematic dry cow therapy was also a widespread habit in all dairy farming systems except organic. The use of alternative medicine was common in all farming systems.

Keywords

Veterinarians, farm advisors, qualitative approach, alternative medicine, intensification, milk valuation.

1. Introduction

Mastitis is a production disease widespread in dairy farms, and its effective control is important for economic and public health reasons. Indeed, mastitis in dairy farms was deemed responsible for one third of the economic impact related to dairy health disorders in Western France (Fourichon et al., 2001). On the public health side, in 2012, each cow in the dairy sector received on average the equivalent of 1.58 antibiotic treatments for mastitis per year in France (Chevance and Moulin, 2013), amounting to 70% of all the antibiotics administered to dairy cows (Gay et al., 2012) . However, the use of antibiotics increases the proportion of antibiotic-resistant bacteria and thus decreases antibiotic effectiveness for both livestock and humans (Gonggrijp et al., 2016). This is a growing concern worldwide (OECD, 2014).

Nowadays, knowledge about mastitis and its optimal technical management and treatment is available (De Vliegher et al., 2012; Sant'Anna and Paranhos da Costa, 2011). At the farm level, the prevalence of mastitis is decreased by improving preventive measures and thus the need for antibiotics. Antibiotics use is also decreased by implementing prudent antibiotic practices. Prudent practices can be defined as the decrease of antibiotic misuse and systematic treatments, and the increased use of substitution treatments, where relevant, such as alternative medicines. Nevertheless, dairy farmers are still regularly using antibiotics in an inappropriate manner (Oliveira and Ruegg, 2014).
Farmers' restraints and motivations to implement prudent antibiotic practices have thus to be explored so as to nudge them towards these more desirable practices. Some deviations from what is considered "prudent" can be explained by technical considerations: for example Lhermie et al. (2014) assume that farmers would rather implement curative than preventive measures on the grounds that they are more easily self-evaluated. In addition, the farmers' decisions to implement strategic health management decisions are undoubtedly affected by behavioural factors. Psycho-sociological factors such as farmers' motivations and representations are particularly important in the decisions-making process (Russell and Bewley, 2013). Health management practices on farms can be influenced by farmers' attitudes and behaviour (Valeeva et al., 2007), farmers' perception (Lam et al., 2011) as well as farmers' personal experience (Garforth, 2011) and farmers' decision-making processes (Murray-Prior, 1998) regarding their performance and their perception of risk. In a Dutch study, for example, at least thirty to fifty percent of the variation in different parameters of milk quality output (in terms of milk somatic cell counts and mastitis incidence) could be explained by farmers' perception and attitudes (Jansen et al., 2009).

Besides these internal determinants, it is assumed that antibiotic use by farmers is also influenced by external determinants, namely: (i) the recommendations provided by farm advisors and veterinarians and (ii) the dairy farming system.
First, as veterinarians are responsible for antibiotic prescription, their influence on antibiotic use is expected to be important. Other farm advisors can influence the self-selected medication habits of farmers, even if they themselves do not prescribe antibiotics. Previous research on the attitudes and perceptions of veterinarians regarding the reasons for their prescription habits demonstrated multiple conflicting interests and a widespread perception of the importance of reducing antibiotic use (Speksnijder et al., 2015a, 2015b). However, the interplay between those restraints and motivations to reduce antibiotic prescription and farmers' habits on-farm has not been yet explored. Moreover, the interplay between farmers and veterinarians regarding antibiotic use and reduction has only been investigated from the veterinarian's point of view (Speksnijder et al., 2015b). However it is very important to include the priorities of all stakeholders to develop public health strategies and programs that will be appropriate to field constraints (Catley et al., 2012).
Second, societal pressure is encouraging the improvement of farming practices. On farms, this can lead to a change for differentiated products (organic or PDO) or to a change of practices. This could subsequently lead to a reduction in antibiotic use. Antibiotic use might be impacted by the dairy farming system in which the farmer operates. The farming system can be constrained by certifications and their consequent specifications. For example, organic certification limits the use of antibiotics (Conseil de l'Union Européenne, 2007). The choice of farming system can also be linked to the farmer's personal beliefs (e.g. attitude towards biodiversity, ecology, tradition, etc.) and influence antibiotic use. These certifications determine the market valuation of the milk, which in turn affects farm income.

In addition, health management practices, such as prevention or the use of medication, can also be impacted by the financial resources available, depending on the cost of the different practices. Financial resources are dependent on the level of investments and on the gross margin. Veterinarians consider the availability of financial resources to be strongly related to the compliance of farmers with veterinary advice (Speksnijder et al., 2015). The level of intensification varies between farming systems (work productivity and agronomic intensification) and also impacts the organisation of labour on the farm, such as the work load (Visschers et al., 2014). The practices and habits of farmers are often limited by labour resources.
Thus health management and antibiotic usage can be influenced by health advice and the characteristics of the farming system.

Our objective in this article is to analyse the choice of use of antibiotics and alternative medicine[1] for mastitis treatment by describing the possible influence of two unexplored factors in dairy farms: (i) the health advice offered to farmers by farm advisors and veterinarians, (ii) the dairy farming system, as defined by the market valuation chosen for the milk, combined with the level of intensification and the level of investment.

2. Material and methods

2.1. Context of drug use in France and general study design

In compliance with French law, veterinarians are the sole prescribers of drugs. Farmers can buy antibiotics from two authorised parties, namely veterinarians and pharmacists, but only under a prescription. Since 2007, a decree allows farmers to buy antibiotics with a prescription but without any clinical examination of the animal or batch if the veterinarian establishes a treatment protocol at least once a year, which is specific to a given disease often encountered in the farm. This decree legalises and supervises an old French habit of self-medication by farmers. Since 2016, the use of critical antibiotics has been strongly restricted and, apart from some exceptions, these molecules can no longer be used as first-line treatment.

In this context, a survey focusing on antibiotic use in dairy farms was carried out in France in 2015. The aim was to study the trajectories of change regarding farmers' practices with respect to antibiotic use, farmers' restraints and motivations to reduce it, and their decision processes leading to the treatment of an animal with antibiotics. The interactions within the "farmer-veterinarian-farm advisor" triptych were assumed to be influential in the decision to use antibiotics. This survey was based on a qualitative approach involving 51 individual semi-structured, separately-conducted interviews with 24 farmers, 14 farm advisors from the National Milk Record group and 13 veterinarians. Farm advisors and veterinarians were contacted based on farmers' indications. Some veterinarians or farm advisors were involved with two different farmers in the sample. This explains why some triptychs were incomplete. In this study, we used the information collected in the survey and focused on the choices of antibiotic and alternative medicine use by farmers and the possible influence of two external factors affecting antibiotic and alternative medicine use by farmers to treat mastitis, namely the farming system and health advice.

[1] In this article, "alternative medicines" takes into account two major categories of products: (i) homeopathy, products where active ingredients are at an infinitesimal dose; (ii) herbal substances, at non-concentrated or concentrated doses (called aromatherapy).

2.2. Selection of farmers

Farmers were selected with the collaboration of French technical institutes. We aimed to include farmers who had marked a break, either in light of their choice to produce differentiated milk (organic, or PDO), or in light of their expressed intention to reduce antibiotic use.

First, we included diverse milk valuation systems in order to explore the influence of milk valuation on farmers' practices. Thus the main selection criterion was based on the commercial valuation of the milk (organic, Protected Designation of Origin (PDO) or conventional). Within these commercial groups, the selected sample was assumed to include a wide range of intensification levels. Organic and conventional farmers were mainly located in western France because this area is the most important dairy cattle region in France with 35.8 percent of the French production volumes (Martin-Houssart et al., 2016). PDO-labelled farmers are milk producers for "Epoisse" cheese and located in Burgundy (eastern France). The valuation of milk from PDO and organic farmers differs from that of conventional producers. Farmers are paid more for milk if they respect a set of quality requirements and specifications. In the case of "Epoisse", the use of a particular breed (Montbéliarde, Pardo, or French Simmental), and specific management practices (animal feed) are required.

Second, other criteria were then added in order to select farmers who expressed concern about antibiotic reduction or had reduced antibiotic use. Selection was based on information obtained from the farm advisors i.e., (i) farmers whose cows had a good level of udder health, in order to discuss the issue of antibiotic use under correct sanitary conditions, (ii) farmers implementing or planning to implement selective dry cow therapy, or, (iii) farmers that were known to have done training in the use of antibiotics or alternative medicines.

2.3. The qualitative semi-structured interview approach

The aim in the semi-structured interview approach is to describe a wide range of possible circumstances regarding a certain field, rather than to evaluate it in a quantitative and representative way (Kvale, 1996). This qualitative method makes it possible to take a wide range of topics into account. The length of each exchange (approximately two hours) encourages a more authentic discussion, even if some ex-post re-organisation of personal histories is always possible (Brinkmann and Kvale, 2015). Qualitative methods are used to understand sociological and economic drivers (Speksnijder et al., 2015). In contrast to quantitative questionnaires with closed-ended questions, this methodological approach allows the emergence of unpredicted answers, for instance regarding farmers' practices.

Interviews were conducted according to an interview guide structured into five main themes: (i) general presentation of personal career and professional structure, (ii) global perception of antibiotics, (iii) practices regarding antibiotic use, (iv) the information network and sources of information, (v) business contact with peers and other farm stakeholders. The interview guide was a non-rigid support designed to provide open follow-up questions and reminders.

Data were collected by four interviewers (students in animal science, veterinarian or sociological fields). With the informed consent of the interviewees, interviews were recorded and completely transcribed in order to avoid *a posteriori* interpretation. Interviewees were informed that they could stop the recording at any time.

2.4. Variables of interest

A grid, focussing on the main topics, was developed to describe and analyse the interviews. This form of interview presentation made it possible to divide the farmers into groups and ensure better

discussion and interpretation of the results. The grid covered three domains. The first one described the practices regarding animal medicine use, particularly the use of antibiotics to treat mastitis. It was summarized into four variables:

- The first variable concerned antibiotic use and assessed antibiotic misuse (*No or non-explicitly evoked during interview/One misuse/More than two misuses*) (See below for antibiotic misuse description).

We defined antibiotic misuse as occurring when:
- critical antibiotics were used as first choice therapies;
- an antibiotic was used for repeated treatments of the same udder quarter;
- deviation from the dosage schedule was observed;
- an intramuscular antibiotic was systematically used with an intramammary antibiotic, which is often unnecessary and favours the development of antimicrobial resistance (Barkema et al., 2006; Reyes et al., 2015);
- an antibiotic was used to treat subclinical or chronic mastitis during the lactation period, which might be useless because of the reported absence of positive effect (Barkema et al., 2006).

- The second variable concerned the use of critical antibiotics (Y*es/No or non-explicitly evoked during interview*),
- The third variable, concerned the implementation of selective dry cow therapy (*Yes/No*), and
- Finally, the fourth variable concerned, the use of alternative medicines (*None/Past trials, now-abandoned/Antibiotics used as initial therapies, alternative medicines used as adjuvants/Alternative medicines sometimes used as initial therapy, otherwise adjuvants to antibiotherapy/Alternative medicines used as initial therapies*).

  The last two variables really represent a choice that farmers want to make, and imply a change in care. These changes are directly dependent on the farmer's willingness and motivation to modify his/her practices and treatments. They also require the development of new habits and knowledge, and the testing of new methods. They may also generate a health risk or modify the existing health risks (Berry and Hillerton, 2002).

The second domain concerned the consulting offers from veterinarians and described the situation with 3 variables:

- Existing advisory services (veterinarians' point of view) (*Yes/No*),
- Advice requests by farmers (farmers' point of view) (*Emergency only/Frequently but no regular monitoring contract/Regular monitoring contract*),
- The main advisor chosen by the farmer (farmers' point of view) (*None/Farm advisor/Vet/Vet and farm advisor*).

The third domain described the dairy farming system. The target here was to characterise different farming systems regarding the level of intensification on-farm (work productivity and agronomic intensification), perceived pressure related to investments, and milk valuation. Different levels of intensification on farms were taken into account. The focus in the literature is usually on work productivity (Charroin et al., 2012) or on agronomic levels of intensification (Pavie, 2002). Scientific points of view differ because the criteria can vary, depending on whether the question being addressed is economic or agronomic. We therefore chose three indicators to describe both work productivity and

the agronomic level of intensification on farms: milk yield per cow per year, milk yield per hectare per year, and milk yield per full-time equivalents (FTEs). These indicators were calculated from the raw data collected on farms during the interviews, namely the annual milk production per cow, number of cows, surface of Utilised Agricultural Land (UAL) and number of FTEs. We also noted the perceived pressure related to investments according to the farmer (*No major investment or non-explicitly evoked during interview / Investments now paid /Committed investments, under control / High level of committed investments, penalising farm profitability*).

The characterisation of the farming system was based on four variables related to intensification (on animal, land and labour resources) and financial constraints. A principal component analysis (PCA) was carried out to combine these four variables into a single variable. This created a typology of farming systems divided into three categories: “extensive”, “intermediate”, and “intensive”. The PCA was carried out in R (R Core Team, 2016), on three calculated variables (milk yield per cow per year, milk yield per hectare per year, and milk yield per full-time equivalents) and on the perceived level of investments according to the farmer (coded based on their declaration in the interview). An Ascending Hierarchical Classification of Ward was then applied to the group of farmers with the closest characteristics (Husson et al., 2010). The final classification (see appendix) was adjusted by applying the K means algorithm.

2.5. Analysis of data related to the farmers’ choices of medicine use to control mastitis and the influence of advice and farming system

The grid constructed to analyse the interviews, was divided into three domains and served as a support to organise and present the analysis of verbatim regarding (i) the diversity of farmers’ practices for antibiotic and alternative medicine use, (ii) the potential influence of health advice, (iii) the potential influence of farming systems. The comparison and analysis of verbatim provided the support for discussion. The wealth of verbatim was also used to describe the differences between groups.

In order to comply with anonymity requirements, stakeholders are described as follows in the article, with X indicating the farm number:

- Farmers are labelled according to their milk commercial valuation: Orga$X$, when they work under organic regulations; Conv$X$ when they work under the conventional practices; PDOX when they work under the Epoisse PDO;
- Farm advisors are labelled with the prefix Adv, respectively AdvOrga$X$, AdvConv$X$ and AdvPDOX. One farm advisor is working with all farmers in the PDO group and, is thus labelled as AdvPDO;
- Veterinarians are labelled with the prefix Vet, resp. VetOrga$X$, VetConv$X$ and VetPDOX.

3. Results

3.1. Description of farmer’s decisions regarding medicine use, their interaction with advisors and veterinarians and their dairy farming system

3.1.1. Farmers’ decisions regarding medicine use

Most of the farmers reported a systematic use of antibiotics at drying-off. In our sample, the systematic use of antibiotics was widespread (Table 4: 14 out of 24 farmers). Farmers who preferred systematic antibiotic administration did not consider setting up the method of selective dry cow therapy for various reasons:

- (i) they were scared to fail, or were used to systematic dry cow therapy and thought selective treatment was too hazardous to change their practices:
  "*I am used to it* [systematic treatment] *and I would be afraid if I had to change*". (Conv7)
  "*I did try selective treatment but I stopped because it is too unsafe*". (Conv9, Conv12)
  "*I don't feel confident in selective treatment strategies*". (Conv13)

- (ii) the systematic use of antibiotics provided a good cost-benefit ratio:
  "*I don't want to burden myself with this* [selective treatment] *and it* [systematic treatment] *is not that expensive*". (Conv2)

- (iii) they thought selective treatment resulted in too many constraints and required too much organisation:
  "*Doing selective treatments represents additional work and I am afraid to fail in applying it*". (Conv10)
  "*Doing selective treatment… That would be a good idea. But then we'd have to stand back and in practice, I don't have enough time to do this*". (PDO1)

However, some farmers chose to apply selective dry cow therapy for different reasons and they followed different paths:

- Only one farmer implemented this health management strategy following his vet's advice:
  "*I do selective treatment at drying-off and use a sealant, it is comforting*." (Conv8)
  "*This farmer could use even less antibiotics. We have already accompanied him in setting up selective treatments at drying-off*." (VetConv8)

- One other farmer applying selective treatments had been devising a strategy with the active collaboration of the farm advisor: "*With the advisor from the milk recording company, we divided the animals into 3 different categories: healthy - we put a sealant – uncertain, and infected - we gave an antibiotic*." (PDO4)

- Other farmers developed their strategy by seeking advice from their peers working in organic systems and by themselves. They had innovative personality traits and they were willing to "*anticipate, change and not to wait until change is legally forced* (on us)" (PDO2). One of these farmers was also responsible for a pig fattening unit and was hence very "*gifted for hygiene and disinfection management*" (VetConv3), which might have helped him implement rigorous methods for dry cow therapy.

As shown in Table 4, a large proportion of the farmers (10 out of 24) said they were using drugs which contained critical antibiotics and 11 out of 24 revealed some antibiotic misuses among their practices, *e.g.* PDO5: "*We use Trademark1 to treat lameness, Trademark2 to treat mastitis, Trademark3 to treat calf diarrhoea*".[1]
The habit of using alternative medicines on a regular basis was increasing. A very large majority of the farmers (Table 4: 20 out of 24) declared that they used them at least in association with antibiotics. To justify the use of alternative medicines, seven out of twenty farmers invoked a financial rationale:

[1] All those products contain critical antibiotics, respectively: Ceftiofur for the former two, Cefquinome for the latter.

"*Since we've been using it [alternative medication], the vet's bill has been reduced by two-thirds. This is a big argument. The vet couldn't believe it, until he saw the results… We have 10 essential oils for the cows, they last 3 to 4 years. It's the price of a single antibiotic! It's effective and it's cheap*." (PDO2)

"*It used to be about €50 per LU (Livestock Unit), now it's about 6*". (Orga5)

"*Essential oils are good because we don't have to throw the milk away*". (Conv1)

"*Regarding the costs, it [essential oil] costs nothing*". (Conv3)

The cost of alternative medicines was put forward as an important argument, especially because a lot of farmers complained at the same time about the price of antibiotics. In this case, the use of alternative medicines was a goal in itself, as a part of their overall strategy to reduce health- and antibiotic –related costs.

Farmers chose to use homeopathy or aromatherapy but rarely did both at the same time. They usually made a precise choice after trying different techniques: "*Many farmers use aromatherapy rather than homeopathy. It looks way easier to use*." (AdvOrga5)

Many farmers were aware of the greater potential harm of using aromatherapy, rather than homeopathy:

"*I don't know much about essential oils. We fear they are more dangerous than homeopathy, I'm afraid we might make a small mistake and cause even more damage*". (Orga5)

"*Those products are very strong; we must be careful*". (Conv10)

"*Essential oils are not innocuous. We cannot make any dosage mistake*". (PDO2)

Table 4: Description of dairy farming systems, medicine use and vet-farmer interactions (n=24 farmers)

	Medicine use				Vet-Farmer interactions			Dairy farming system				
Farmer[1]	Antibiotic misuse	Use of critical antibiotics	Selective treatment	Use of alternative medicines[2]	Vet advisory services	Farmer – vet interaction[3]	Preferred advisor[4]	Milk Yield (L) / cow / year	Milk Yield (L) / ha / year	Pressure related to investment (perceived)[5]	Milk yield (L) / FTE[6] / year	Cluster (PCA[7] on calculated values)
Orga1	0	Yes	Yes	4	Yes	0	0	7 000	3916	2	162 000	Extensive
Orga2	0	No	Yes	2	No	0	0	6 800	5417	1	180 555	Extensive
Orga3	0	No	Yes	4	No	0	0	4767	2479	3	129 000	Extensive
Orga4	0	Yes	Yes	3	Yes	2	2	5 000	3642	1	171 555	Extensive
Orga5	0	No	Yes	4	No	0	1	6 000	2941	2.5	125 000	Extensive
Orga6	2	Yes	Yes	2	Yes	2	3	7 000	7125	3	190 000	Extensive
Conv1	0	No	No	3	No	0	1	7 900	4408	4	184 000	Extensive
Conv2	0	No	No	3	Yes	2	0	8 600	4853	2	364 000	Intermediate
Conv3	1	No	Yes	0	Yes	1	2	10 500	3664	2.5	201 500	Intermediate
Conv4	0	No	No	2	Yes	0	1	6 000	7581	3	157 000	Extensive
Conv5	0	No	No	4	Yes	0	1	7 500	8261	1	304 000	Intermediate
Conv6	1	Yes	No	2	No	0	1	9 400	14667	1	366 667	Intermediate
Conv7	0	No	No	2	No	0	1	9 000	12115	3.5	504 000	Intensive
Conv8	0	Yes	Yes	2	Yes	1	2	9 149	7742	4	480 000	Intensive
Conv9	1	No	No	0	Yes	0	0	8 500	13304	3	596 000	Intensive
Conv10	2	Yes	No	2	Yes	0	1	8 000	9346	2.5	250 000	Extensive
Conv11	2	Yes	No	1	Yes	2	2	9 250	8814	4	693 300	Intensive
Conv12	2	Yes	No	2	Yes	2	2	10 000	8000	1	300 000	Intermediate
Conv13	0	No	No	4	Yes	0	1	6 850	4091	4	264 700	Extensive
PDO1	2	No	No	2	No	0	1	6 280	923	3	80 000	Extensive
PDO2	0	Yes	Yes	4	No	0	1	5 000	1210	3	95 656	Extensive
PDO3	2	No	No	0	No	0	2	6 700	1500	3.5	400 000	Extensive
PDO4	1	Yes	Yes	2	Missing	0	0	7 200	3000	3.5	150 000	Extensive
PDO5	2	No	No	2	Yes	0	1	8 000	1544	1	221 300	Extensive

[1] *Orga = Organic farmers / Conv = Conventional farmers /PDO = PDO farmers*

[2] 0 = *None / 1 = Passed trials, now-abandoned / 2 = Antibiotics used as initial therapies, alternative medicines used as adjuvants / 3 = Alternative medicines sometimes used as initial therapy, otherwise adjuvants to antibiotherapy / 4 = Alternative medicines used as initial therapies*

[3] 0 = *Emergency only / 1 = Frequently but no advisory service contract / 2 = Regular advisory service*

[4] 0 = *None / 1 = Farm advisor / 2 = Vet only / 3 = Vet and farm advisor*

[5] 1 = *No major investment or non-explicitly evoked during interview / 2 = Investments now paid / 2,5 = Committed investments about to become paid / 3 = Committed investments, under control / 3,5 = High level of investments about to become under control / 4 = High level of committed investments, penalising farm profitability*

[6] *Full Time Equivalent*

[7] *PCA = Principal Component Analysis*

3.1.2. Farmers' interaction with advisors and veterinarians

According to the veterinarians' interviews, most veterinarians (11 out of 18) proposed or aimed to propose long term advisory services. However, according to the farmers' interviews, only a few vet-farmer interactions took place on very regular basis (at least frequent contact, even in the absence of long term advisory services) (Table 4: 7 out of 24 veterinarians with farmer-vet interaction greater than or equal to "*Frequently but no advisory service contract"*):

> "*Veterinarians from the clinic come on average once a month. They monitor feeding and breeding*" (Orga6).
> "*We interact a lot by telephone*". (Conv3)
> "*If I'm in doubt, I call the vet*". (Conv10)

This was consistent with the general farmers' discourse regarding their preferred herd health advisor. Veterinarians were the referent advisor in only a quarter of the situations (7 out of 24 farmers), whereas farm advisors were the referent advisors in half of the situations (12 out of 24 farmers) (Table 4):

> "*He [the farm advisor] is really good. The vet, we don't see him very often*." (Orga5)
> "*The farm advisor is the one I see the most*". (Conv7)

A small but non-negligible proportion of the farmers (6 out of 24) had no preferred health advisor in their daily work: "*We are very autonomous*." (Orga2)

3.1.3. Dairy farming systems

Thirteen farmers produced under a conventional system, whereas six farmers ran organic farms and five produced under a PDO scheme. The intensification level regarding annual milk yield per cow was diverse (mean: 7 517 L/cow/year; standard deviation: 1 586 L/cow/year), annual milk yield per hectare (mean: 5 856 L/ha/year; standard deviation: 3 863 L/ha/year), and annual milk yield per FTE (mean: 273 760 L/FTE/year; standard deviation: 162 364 L/FTE/year) (Table 4).
Farm size in this sample was also diverse (standard deviation: 29 dairy cows; 86 hectares). Regardless of the milk commercial valuation, the herds were small (e.g. 38 dairy cows on 31 hectares, conventional) or large as were the UALs (e.g. 135 dairy cows on 166 hectares, organic).

The principal component analysis showed that the intensification level (dimension 2) and the perceived pressure related to investment (dimension 1) were independent (appendix). Dimensions one and two explained 55.6% and 26.9% of the inertia, respectively. On dimension one, the milk yield per full-time equivalents was best represented (cos^2=0.79). The annual milk yield per cow and the annual milk yield per hectare were also quite well represented (resp. cos^2=0.69 and cos^2=0.73). On dimension two, the perceived pressure related to the level of investments according to the farmer was best represented (cos^2=0.97). Organic and PDO farms were classified as non-intensive. The perceived level of pressure of investments according to the farmers (PLI) did not depend on the milk valuation. Some farmers in organic, PDO and conventional productions perceived financial limitations:

> "*We invested in a barn with hay-drying facilities. This was a big investment to depreciate*" (Orga3)
> "*A tool like ours [that produces hay using a barn with hay-drying facilities] is a big investment. At the beginning, we (…) were scared*." (PDO4)

"*We invested in the new barn for lactating cows and for the automatic milking system; this is a big step to depreciate. We are calming down*." (Conv11)

Applying the K means algorithm to the dendrogram of the perceived pressure related to the elements of investment and level of intensification (Wards' Ascending Hierarchical Classification), revealed three clusters (Appendix):

- An "intensive" group consisting of 4 conventional farms. These farmers had high perceived levels of investment (greater than 3.5-4), the highest levels of milk yield per cow per year (mostly more than 9 000 L/cow/year) and the highest levels of milk yield per FTE per year (more than 480 000 L/FTE/year).
- An "extensive" group consisting of 14 farms, i.e. 6 organic farmers, 5 PDO farmers and 3 conventional farmers. This group was characterised by its rather low level of annual milk yield per cow or per hectare or per FTE (generally below 7 000 L/cow/year; 4 500 L/ha/year; 200 000 L/FTE/year) and a variable level of perceived level of investment (from 1 to 4).
- An "intermediate" group (6 conventional farms), in which farmers had a controlled or low perceived pressure related to the level of investment (less than 2.5), and a moderately high level of intensification.

3.2. Systematic dry cow therapy under the influence of health advice and dairy farming system

3.2.1. Comparison of veterinarians, farm advisors, and farmers' opinion on systematic dry cow therapy

Many farmers and advisors supported the use of systematic dry cow therapy, but only a few were already adopting or promoting it. The restraints or motivations expressed by farmers were generally shared by the veterinarians and farm advisors (Table 5). Nine out of twelve duos or trios shared the same opinion regarding the best dry cow therapy strategy (2 out of 3 being in favour of systematic dry cow therapy), and only three out of twelve expressed different opinions on this topic.

Table 5: Verbatim of restraints and motivations of farmer-vet-farm advisor's triptych regarding the implementation of selective dry cow therapy (n=12)

	Farmer	Vet	Farm advisor
Farmers and veterinarians or farm advisors both in favour of systematic treatment			
Conv4	Systematic		Selective treatment has too many protocols and he likes to be safe.
Conv7	I use systematic treatment (antibiotics + sealant), out of habit and because I'm too scared.		I advise systematic treatment (antibiotics + sealant) by precaution.
Conv10	I use systematic treatment (antibiotics + sealant).	Selective treatment is complicated on field.	No selective treatment. The sealant is already complicated.
PDO1	Selective treatment is a good idea, but I have no time to do it.		I would never advise a selective treatment for him, I am too scared, it's too tough.
PDO3	The vet advises antibiotics + sealant. We have to treat with antibiotics + sealant at drying-off.		We are for the use of a sealant, but with antibiotics. We cannot take the risk any more.

PDO5	Our vet gives us a strong treatment at drying-off.		Using only the sealant is often difficult because of hygiene problems.
Farmers and veterinarians having different opinions on selective treatment			
Conv3	I do selective treatment with a sealant.	Selective treatment is dangerous.	
Conv6	Systematic (antibiotics + sealant +/- injection of antibiotics)	Less than 20% of the farmers use a selective treatment.	I recommend selective treatment therapy, but farmers prefer systematic treatment.
Conv11	Systematic (antibiotics + sealant +/- injection of antibiotics)	This farmer could do a selective treatment.	I have already advised selective treatments. This farmer doesn't want to hear about that.
Farmers and veterinarians or farm advisors both in favour of selective treatment			
Orga4	Selective	Selective dry cow therapy is quite wide-spread	
Orga5	[Now] I do systematic treatment with homeopathy; before, it was with antibiotics.		Quite a lot of farmers use selective dry cow therapy.
Orga6	We do selective	He uses a sealant and Trademark1 when there are cells.	We did check together.

The veterinarians and farm advisors expressed the same arguments as the farmers, but sometimes evoked the inability of farmers to handle selective dry cow therapy successfully. These remarks concerned selective dry cow therapy in general (e.g. VetConv10, VetConv3, AdvConv4) or were tempered according to the farmers' characteristics (e.g. AdvPDO1, VetConv11).

However, some advisors were attempting to change and adapt their recommendations to new constraints:

"*I advise it [selective dry cow therapy] more and more often*." (AdvConv10)

"*I am already setting up selective treatments in farms. I accompany farmers in this process*." (AdvConv11)

"*I do sometimes advise it [selective dry cow therapy]*." (AdvConv6)

"*I helped this farmer to implement selective dry cow therapy*". (VetConv8)

When they recommended selective dry cow therapy, they raised the subject of economic motivation, showing that the economic issue is a shared concern with farmers:

"*One farmer implementing selective dry cow therapy on 85 cows will save 300€*[1]*. The bigger the herd, the higher the amount saved*." (VetConv3)

3.2.2. Farmers' choice of dry cow therapy in different farming systems

All organic farmers used selective dry cow therapy. Implementation of this good farming practice was linked to the constraints of the organic regulations even if it was also linked to personal convictions.

Four out of eighteen farmers working in a conventional system or under a PDO constraint were applying selective dry cow antibiotic therapy (Table 6). Two of them belonged to the "intermediate"

[1] Annual vet expenditures for an average dairy farm size: about €3,800 (vet fee and drugs included) (Chevalier, 2007).

group and were in a PDO system. The other two, one in the "intermediate" group and the other in the "intensive group", were in a conventional system.

Table 6: Medicine use according to commercial milk valuation and to level of intensification (number of farmers)

	Total number of farmers	Selective dry cow therapy	Antibiotic misuse*	Use of critical antibiotics	Use of alternative medicines**
Commercial milk valuation					
Organic	6	6	1	3	6
Conventional	13	2	6	5	10
Protected Designation of Origin	5	2	4	4	4
Cluster on intensification level					
Extensive	15	8	6	8	13
Intermediate	5	1	3	2	4
Intensive	4	1	2	2	2

*One or more antibiotic misuse

**Farmers using alternative medicines as adjuvants or initial therapies

3.3. Antibiotic misuse and use of critical antibiotics under the influence of health advice and dairy farming systems

3.3.1. Comparison of farmers' practices with the opinion of veterinarians and farm advisors on antibiotic misuse and use of critical antibiotics

None of the interviewed farm advisors expressed any precise opinion on antibiotic misuse or on the use of critical antibiotics, but one said that: "*He could reduce his consumption* (of antibiotics)" (AdvConv6). The only explicit reference corresponded to their legal restriction to advise farmers on antibiotic use:

> "*We have no right to mention antibiotics*" (AdvOrg6)
>
> "*We do give very little advice on antibiotic treatments. I avoid giving my opinion on those products*". (AdvPDO4)

Veterinarians expressed their opinion on antibiotic use more frequently. Two veterinarians out of thirteen criticized farmers' antibiotic use or the quantity or type of antibiotic used:

> "*He treats one out of two cows with Trademark1[1], this is not good*". (VetOrg6)
>
> "*Sometimes, he [Conv12] uses antibiotics a bit too often*". (VetConv11-12)

Nonetheless they were able to justify the current use of antibiotics and in particular the use of critical antibiotics for their effectiveness and their ability to respond to farmers' constraints:

> "*The problem is that it works too well*". (VetConv3)
>
> "*Critical intramammary antibiotics, convenient and effective*". (VetConv8-9)
>
> "*The working time, that's what makes farmers use critical antibiotics*". (VetConv3)

However, four veterinarians expressed their intention to change their prescription habits:

[1] Trademark1 contains a critical antibiotic: Cefquinome

"*The EcoAntibio plan, I am really into it*". (VetConv13)
"*I no longer give antibiotics by oral route*". (VetOrga4)
"*I do sometimes propose incorrect treatment protocols. So we are trying to change this*". (VetConv8-9)
"*Critical antibiotics are effective; we prescribe them as little as possible*". (VetConv11-12)

Only one vet expressed a strong disapproval of veterinarians' prescription habits: "*Fifty years of bad veterinarian habits. I despaired when I went out from vet school*" (VetOrga6).

3.3.2. Antibiotic misuse and use of critical antibiotics in different dairy farming systems

The information collected confirmed that farmers were not always familiar with the notion of critical antibiotics, and they clearly had no knowledge regarding antibiotic misuse:

"*We use "Trademark2*[1] *to treat lameness. But it's not an antibiotic because anyway we can use the milk*". (PDO4)
"*We use "Trademark2" to treat lameness, "Trademark3" to treat mastitis, "Trademark4" to treat calf diarrhoea*".[2] (PDO5)

Those farmers in the sample who were using critical antibiotics and who revealed antibiotic misuses (Table 6) were doing this: (i) regardless of their milk commercial valuation system and (ii) regardless of their choice of intensification (extensive, intermediate or intensive).

3.4. Use of alternative medicines as influenced by health advice and farming systems

3.4.1. Comparison of farm advisors', veterinarians' and farmers' practices and opinion on alternative medicines

The use of alternative medicines was poorly supported by the farm advisors and veterinarians, even though the veterinarians and farm advisors were aware of the farmers' willingness to use them: "*There is a big demand from farmers*". (AdvConv3) "*More and more farmers are trying to find alternative solutions*." (AdvPDO3).
But unlike the farmers, veterinarians and farm advisors were rather reluctant to use and supervise the use of alternative medicines:

"*The problem is that we don't use them. We know approximately the expected effects, but we won't go further*". (AdvOrga6)
"*I learnt allopathic medicine, I will go on using allopathic treatments*". (VetOrga6)
"*It's interesting but it's more a philosophy. One must work to improve preventive actions*". (VetConv4-5)

Farm advisors and veterinarians often barely used or supervised the use of alternative medicines because of a lack of proof of efficacy:

"*The success is not mathematic.*"(AdvOrga6)
"*I don't believe in homeopathy, but one of the advisors developed minimum skills*". (VetConv13)
"*The vet was not opposed to alternative medicines but he was sceptical*". (PDO2)
"*But they [the farmers] use essential oils without having any guarantee of success. At present, we don't know and we have little feedback.*" (AdvPDO3)

[1] Trademark2 contains a critical antibiotic: Ceftiofur.
[2] All those products contain critical antibiotics, respectively: Ceftiofur for the former two, Cefquinome for the latter.

Veterinarians were almost absent from the alternative medicines domain:

"*I use them but there are very few discussion partners*". (Conv10)

"*Veterinarians are not present in this branch*". (AdvPDO1)

"*No, we don't use them. Our vet is not in favour of alternative medicines*". (PDO3)

"*I use essential oils, but I don't have any advice from veterinarians. I don't talk with him about that*". (PDO4)

"*She uses phytotherapy for deworming, but not with me*." (VetPDO5)

As a consequence, in contrast with the implementation of a selective dry cow therapy, veterinarians and farm advisors seldom expressed the same restraints and motivations as the farmers (Table 7: 2 out of 11).

Table 7: Restraints and motivations of the farmer-vet-farm advisor triptych regarding the use of alternative medicine1

	Farmer	Vet	Farm advisor
Farmer and vet or advisor having different opinions on alternative medicines			
Orga4	Essential oils	The placebo effect is important but this is interesting. I believe in homeopathy, not in aromatherapy.	
Orga6	We use essential oils a lot today.	We have been educated to use allopathy, I will use allopathy.	We are not trained to know this by heart.
Conv4	I use homeopathy even if there is a lack of proof.	It's interesting but it is rather a philosophy.	
Conv5	Homeopathy and essential oils		
Conv6	I use essential oils and homeopathy when there are cells but no mastitis.		There is no rigorous training.
Conv13	I've been using homeopathy for 3 years, essential oils too.	I don't believe in homeopathy.	
PDO1	I use aromatherapy		He wants to try to use plants intra-mammary. It is forbidden.
PDO2	We use it. The vet was sceptical.		
PDO4	I use phytotherapy but we don't talk about this with the vet.		
Farmer and vet both having positive opinions on alternative medicines			
PDO5	I use it for mastitis.	He uses phytotherapy but not with me. But I am training myself on this, it's very interesting.	
Farmer and advisor both having unfavourable opinions on alternative medicines			
PDO3	We don't use it. The vet is not in favour of this.		At present, we are not sure of success.

[1]The missing triptychs have been omitted here because no one in the triptych evoked this issue during the interview.

Only two veterinarians and one farm advisor expressed their desire to have training and to improve their knowledge so as to be able to use alternative medicines. They were however aware of the current limited proof of efficacy regarding alternative medicines:

"*I am receiving training in phytotherapy. It's very interesting; it might give good results so long as it is applied alongside good and appropriate herd management*." (VetPDO5)
"*We know there is an important placebo effect, but we are still interested. I am convinced by homeopathy but not by aromatherapy*". (VetOrga4)
"*We have asked for training in phytotherapy to be organised by the PDO institution*". (AdvPDO)

Finally, without sufficient advice provided by their farm advisor or vet, farmers conducted rough trials with alternative medicines and looked for information on their own. Farmers built up a system of reference to frame their use of alternative medicines, and obtained information from various sources:

- Experience shared by their peers,
- Books, reviews and other sources of literature: "*I trained myself*" (Orga5), "*I did a training course in homeopathy*". (Conv2), "*I had the dictionary of essential oils for my birthday*". (PDO5)
- Farm advisors well known for being specialists in those medicines: "*We did training with a homeopath*." (Orga6) "*I've used homeopathy for three years. I did training courses with a specialized vet and with the Animal Health Protection Group (AHPG)*". (Conv13)
- Sellers without any recognized competence: "*I use essential oils bought from sellers in the region. I wish I could have more training to be able to mix the oils*." (PDO4)

3.4.2. Farmers' use of alternative medicines in different farming systems

Farmers of all groups use or have tried alternative medicines. All organic farmers are using alternative medicines. Only four farmers in the sample were not using alternative medicines at all. Two of them belonged to the "intensive" group, one to the "intermediate" group and one to the "extensive" group. According to their advisors or veterinarians, all four farmers were technically efficient and managed animal health with care. Nevertheless, they differed regarding the technical aspects which would potentially explain their animal health management strategies:

- Three of them were exceeding their structural capacity and were involved in too many tasks on their farm. They had to deal with lack of time and financial pressure (PDO3, Conv9, Conv11),
- One was managing a piglets fattening unit and was thus very technical and efficient in health management and prevention (Conv3).

The farmers in the sample evaluated the efficiency of these medicines in very different ways and it was even sometimes difficult to understand how they proceeded. In some cases, alternative medicines were seen as a tool to improve practices and use fewer antibiotics, regardless of alternative medicine efficacy. Farmers used alternative medicines, regardless of their efficacy, to feel active and dynamic:

"*I use homeopathy even if there is a lack of proof of efficiency*". (Conv4)
"*He [PDO1] tried something. It drove him again into a positive dynamic*". (AdvPDO1)
"*It's free to believe in it*". (PDO2)
"*We think: we don't use antibiotics, we try something else*". (PDO5)

4. Discussion

Whatever the farming system, the practices of antibiotic use in dairy farms were diverse. The degree of diversity for all the levels of intensification was similar. The dairy milk valuation only influenced antibiotic practices when a specification explicitly constrained farming practices (organic), and only

influenced systematic antibiotic use. Antibiotic misuses and systematic dry-cow therapy were described even if our aim was to select rather proactive farmers, willing to improve antibiotic use. In our sample, the discourses of the veterinarians and farm advisors on systematic antibiotic treatment at drying-off were consistent with the farmers' observed practices. While farmers complied with their advisors on antibiotic use, they tended to be independent when it came to the use of alternative therapies.

4.1. Importance of external drivers to improve antibiotic use

Regulations influence antibiotic use in different ways. This lever appears to be variably effective and could be reinforced to bind practices.

The requirement specification of the organic regulation seems to be effective, as all farmers implemented selective dry cow therapy. Organic farmers tend to use fewer antibiotics than conventional farmers regardless of the period of treatment and disease (Zwald et al., 2004). In this case, the personal convictions of organic farmers can also influence animal health management and some farmers brought up the subject of their personal motivation to explain their quest for a more prudent use of antibiotics.

At the beginning of the survey, the use of critical antibiotics was under the same legal constraints as other antibiotics. The use of critical antibiotics was quite common among farmers, and veterinarians admitted that they sometimes prescribed them as an initial therapy. Nevertheless, the extent of critical antibiotic use might have been underestimated because, in this survey, their assessment was not a major objective. This is why the design of the qualitative semi-structured interviews did not include explicit, systematic questions about antibiotic trademarks and the frequency of antibiotic use.

The professional training received by the various interviewers was very different and those with no veterinary background might have put less focus on antibiotic misuse in the different sections of the interviews. Some farmers are unaware of the notion of critical antibiotics, as shown here, and would be unlikely to mention them. However, even considering this confounder and limitations, antibiotic misuses were highlighted within all the groups of farmers.

On the one hand, veterinarians are clearly aware of the issue of critical antibiotics. On the other hand, in their discourse, very few adopted a strong position to limit their use in their prescription strategy.

The legislative system is possibly not binding enough regarding the prescription process and it does not give veterinarians the opportunity to be the principal advisor regarding animal health. For instance, in Denmark, a regulatory system has been enforced (higher taxes and "yellow card" system) and pig farmers are compelled to rely on veterinarian expertise on a more regular basis (at least once a month) (Ministry of Environment and Food of Denmark, n.d.). This has had positive but moderate effects on the level of antibiotic consumption (Bager et al., 2014). However, since April 2016 in France, the prescription of critical antibiotics as first-line treatment is prohibited. This is a powerful measure likely to induce a change in practices.

In our sample, the farmers did not consider the cost of antibiotics used at drying-off as an obstacle to their systematic use. On the contrary, it was perceived as an effective and efficient tool for systematic dry cow therapy, when compared to the generated costs. The price of antibiotics could be adjusted and be used as a tool to change practices.

4.2. Prudent antibiotic use, importance of advice

Systematic dry cow therapy was frequent within the sample. This was consistent with the discourses of the farm advisors and veterinarians, who often advocated the use of antibiotics and the implementation of systematic dry cow therapy.

The farmers in our survey were selected according to their participation in training in the use of antibiotics or alternative medicine; or according to the perception by farm advisors from technical French institutes that they intended to reduce antibiotic use at drying-off. This sampling strategy impaired representativeness and induced a selection bias towards farmers assumed to use less systematic treatments. However systematic dry cow therapy was widely used by the farmers in the sample. We suppose this could be explained by a lack of knowledge, on the part of the farm advisors, regarding the farmers' actual herd health management strategies.

The prudent use of antibiotics is complex and the results revealed a need to accompany the farmers in decision-making. Indeed, to develop and implement an appropriate selective antibiotic treatment strategy, cows have to be considered differently depending on their previous mastitis and somatic cell counts (Scherpenzeel et al., 2014). This process requires the acquisition of additional knowledge and know-how by the farmers, who express concerns about this and the need to change a comforting practice (Vaarst et al., 2006). The prudent use of antibiotics during the lactating period is also very complex. The use of appropriate molecules in appropriate situations requires a veterinary accompaniment. However, these potential "helpers" expressed the same restraints as the farmers regarding both lactating and drying-off antibiotic treatments. The similar discourse of the veterinarians and farmers concerning those topics was consistent with the literature, showing that veterinarians and consultants were the major information source for farmers (Russell and Bewley, 2013).

An accompaniment from appropriate advisors is really important on a long term basis to change deep-rooted practices. However, in our sample, veterinarians were rarely considered as being the preferred herd health advisor on a regular basis. This is consistent with other studies showing that, in organic production systems, the veterinarian is involved in treatment decisions but not in the animal health management strategy (Duval et al., 2016; Vaarst et al., 2006). A legislative tool developed in France, imposes a visit by the veterinarian to farms on a yearly basis to construct a health care protocol for the delivery of treatments for current diseases without doing a clinical examination of each new case (Ministère De L'Agriculture De L'Agroalimentaire Et De La Forêt, 2007). This protocol should be used as a tool by veterinarians to carry out a check-up and improve the animal health management strategy.

Farmers are generally considered to be adverse to risk, even if there is a strong impact of personal perception (Meuwissen et al., 2001). In our sample, farmers used critical antibiotics and systematic dry cow therapy to control a risk. They wanted their actions to be as efficient as possible. This could suggest that the future improvement of health recommendations to accompany farmers should guarantee that the risk is under control. For instance, in pig farming systems, antibiotics were often systematically included in the composition of animal feed during the critical weaning period to prevent diarrhoea. Farmers changed their treatment habits by stopping the systematic use of antibiotic and instead used a dosing pump. This tool represents a safety measure that farmers can use to rapidly treat animals through the drinking water system (Fortané et al., 2015).

4.3. Diverse influence of dairy farming systems on medicine use

In contrast to the milk valuation systems, the level of intensification and perceived level of investment had very little influence on antibiotic use. This result was relatively surprising.

Indeed, in a recent study, veterinarians estimated that farmers did not implement their recommendations, mostly because of financial and time restrictions (Speksnijder et al., 2015b). In the present research, we considered two different indicators to roughly estimate the financial restrictions and work load, namely the perceived level of investment and the annual milk yield per FTE. We expected a link with medicine use and the level of intensification or perceived level of investment, but did not observe such links.

Contrasted habits of antibiotic use were revealed between the commercial milk valuation systems. The organic regulation had a stronger influence than the PDO label. However, this difference could also be explained by the farmer's personal convictions. Indeed, adoption of the organic regulation may correspond to personal motivations to produce with specific requirements and targets. Adoption of the PDO label is more a geographical opportunity to value the milk production at a better price. Furthermore, the specifications of the PDO label "Epoisse" give rules for some operating practices (e.g. breed, feed), but not for herd health management. This could explain why organic farmers used medicines differently to PDO and conventional farmers in the sample.

4.4. The strong demand of farmers to have "something to do"

The use of alternative medicines was widespread among farmers in the sample. This could result from our inclusion criteria: farmers had changed their production system (organic and PDO), or had attended training on alternative medicines with a technical institute. The use of alternative medicines might be less frequent in the general population. Farmers were not accompanied by veterinarians in the use of alternative medicines, which is consistent with another study (Duval et al., 2016). Farmers used those medicines when the health status of an animal was disturbed but not critical. The trend, especially on organic farms, is for farmers to develop their own system of reference, without any veterinary advice (Vaarst et al., 2006). In using alternative medicines, farmers may be looking for more independence in the control of animal health. One possibility is that farmers chose to use alternative medicines so that they felt they were improving the health of their despite the current lack of scientific proof of their effectiveness. Farmers', veterinarians', and farm advisors' perception regarding alternative medicines may vary in countries depending on the national context and regulations. It would be interesting to further explore the ways in which farmers develop their own experience and systems of reference to use alternative medicine.

The selection strategy might have biased the selection of farmers implementing a more prudent use of antibiotics, and more alternative medicine treatments than the general population. Taking this limitation into account, interviewees nevertheless, reported systematic antibiotic uses and antibiotic misuses in all farming systems. The need to improve prudent antibiotic use could be even greater in the general population. Due to the small number of interviewees, the sample is not representative and does not allow quantitative analysis. We described the observed link between advice and farming system, and we cannot extrapolate the conclusions to other populations. Nevertheless, it would seem worth investigating the ways in which the role of advisors could be improved to change practices in antibiotic use. Moreover, no farming systems can be excluded a priori from strategies to promote prudent use of antibiotics.

5. Conclusion

In our sample, the importance of the advisory relationships between farmers and farm advisors and veterinarians, differed according to the type of medicine use considered. Farmers' use of antibiotics at drying-off seemed to be positively influenced by veterinarians and farm advisors. In the sample, the dairy farming system under which the farmer was working had very little influence on his/her antibiotic use, except that all organic farmers implemented selective treatments, unlike the farmers in other dairy farming systems. This would suggest the important role played by farm advisors and veterinarians in inducing a change in antibiotic use on farms. On the contrary, the veterinarians and farm advisors interviewed were seldom involved in the use of alternative treatments, whereas farmers were more willing to experiment with such medicines, regardless of prudent or negative advice. It would be interesting to confirm these results in different national contexts with different legislative systems, health advisory services and veterinary training structures. As regards farmer practices for medicine use, it seems important to check the real influence of the health recommendations from veterinarians in order to best adapt their health advice approach.

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APPENDIX

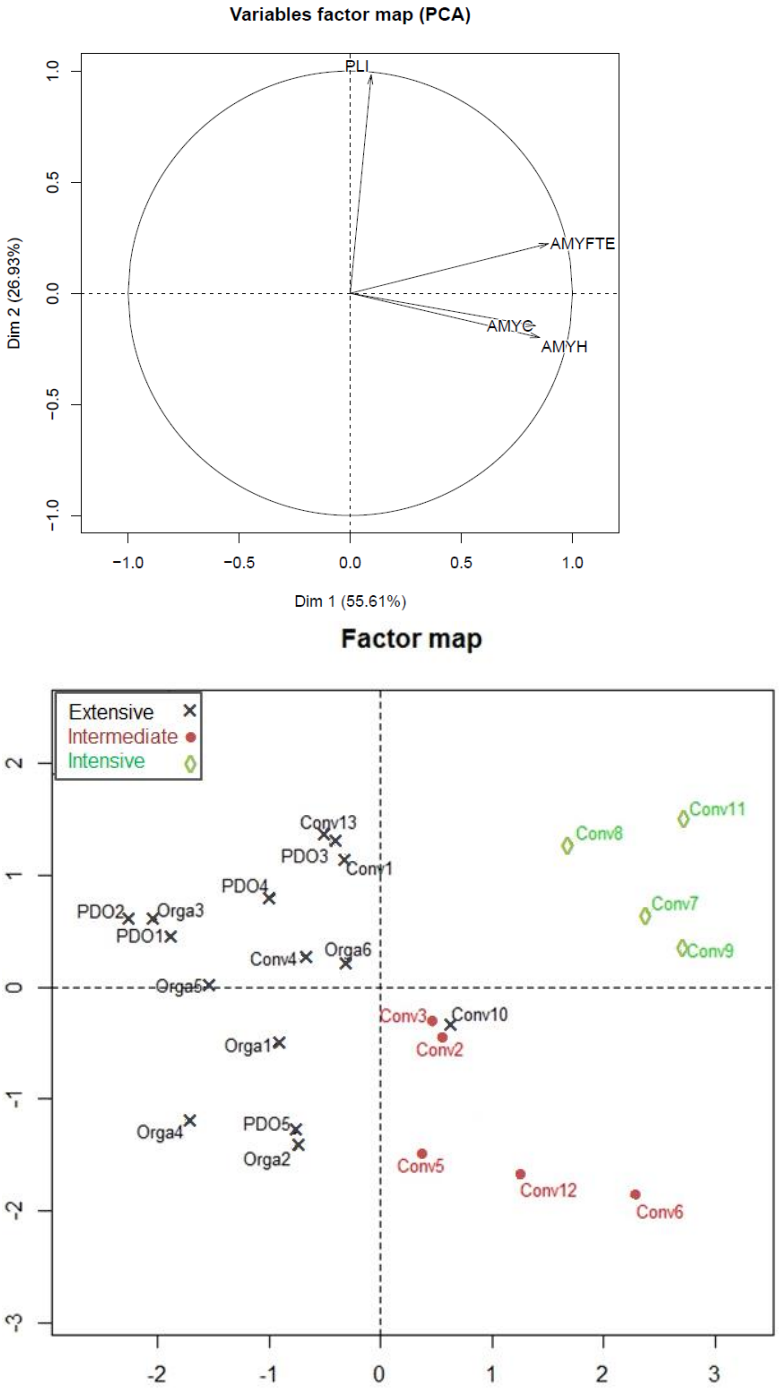

Figure 2: Graphical representation of the Principal Component Analysis (individuals) run on intensification level, and associated clusters*

*AMYFTE = milk yield per full-time equivalents; AMYH = annual milk yield per hectare; AMYC = annual milk yield per cow; PLI = perceived pressure related to the level of investments according to the farmer.

Individuals are separated according to the first and second dimensions explaining respectively 55.61% and 26.93% of the inertia. On dimension one, the milk yield per full-time equivalents is best represented (cos^2=0.79). The annual milk yield per cow and the annual milk yield per hectare are also quite well represented (resp. cos^2=0.69 and cos^2=0.73). On dimension two, the perceived pressure related to the level of investments according to the farmer is best represented (cos^2=0.97).

Chapitre 1B : Apprentissages tirés d'une étude d'intervention pour réduire l'utilisation d'antibiotiques dans la filière bovin lait, basée sur un programme de formation innovant

Note d'avancement : Ce chapitre, après travail supplémentaire à réaliser, devra être soumis à la revue Preventive Veterinary Medicine.

Abstract

Regarding antibiotic resistance issue, antibiotic use has to be reduced. In the dairy sector, antibiotics are mostly used for the control and treatment of mastitis. We designed an exposed/non-exposed study to evaluate effectiveness, strengths and weaknesses of an innovative training program: one classroom-training day, virtual classrooms, and an individual support with the farmer in Western France. The main issue was the improvement of mastitis prevention during lactation for farmers having herd experiencing frequent clinical mastitis. We built different sets of data to evaluate evolution of knowledge, perception and practices of farmers, as well as their appreciation of the program. Respectively 18 and 15 farmers were included in the exposed and non-exposed groups. Some farmers appreciated the virtual classroom training method because it was flexible (frequency, timetable, etc.) and little time consuming. This provides further insight to improve and develop this tool. However, connection or computing logistic problems made the participation in the virtual classrooms difficult. Results also showed limited improvement of knowledge, perception and practices of farmers. Improvement of knowledge and perception was significant. Both exposed and non-exposed farmers did improve their practices of antibiotic use at dry-off, which could show a trend in the general population for the improvement of practices at dry-off. The duration of the program (one and a half year) was relatively short to observe a change in practices, longer program could provide better results.

Keywords

Virtual classroom; sharing of practices; multi partner method; exposed/non-exposed survey; participatory diagnosis; udder health.

1. Introduction

Mastitis is a production disease widespread in dairy cattle farms. It could be responsible for one third of the economic impact related to dairy cattle health disorders in Western France (Fourichon et al., 2001). In 2016, a dairy cow received on average the equivalent of 1.43 intramammary treatments in France (Méheust et al., 2017). Antibiotics used for mastitis amount to 70% of all the antibiotics administered to dairy cows (Gay et al., 2012). However, worldwide, antibiotic-resistant bacteria decrease antibiotic effectiveness for both livestock and humans (Gonggrijp et al., 2016). Reducing antibiotic use could limit the spread of antibiotic-resistant bacteria. Improving mastitis prevention as well as avoiding unnecessary antibiotic use are thus of paramount importance for public health and economic reasons.

In theory, scientific and technical knowledge gained about mastitis could allow to implement the best preventive measures, and to limit antibiotic use to a minimum (De Vliegher et al., 2012; Sant'Anna and Paranhos da Costa, 2011). However, the health indicator of udder health did not improved over the

last 18 years[21]. In addition, dairy farmers are still regularly using antibiotics in an inappropriate manner during lactating period (Oliveira and Ruegg, 2014; Poizat et al., 2017), and about two third of French dairy farmers could be implementing systematic dry cow therapy[22].

Theoretical frameworks, such as the Theory of Planned Behaviour, stipulate that the intention of an actor is necessary to trigger a change in practice (e.g. Panter-brick et al. 2006). Behavioural beliefs (attitudes), normative beliefs (social norms) and belief in self efficacy constitute intrinsic circumstances that are expected to influence the intention to a change of practices. Extrinsic circumstances such as community, culture and society, general knowledge, skills and ability influence the willingness to change practices as well (Ellis-iversen et al., 2010). Van Den Borne et al. (2014) showed that farmers' knowledge could influence their practices and dairy herds performances (van den Borne et al., 2014a). However, public concerns about antibiotic resistance and the importance of a reduction in antibiotic use are quite recent. Research shows that farmers could have a limited knowledge on antibiotic use and limited motivation to reduce antibiotic use (Friedman et al., 2007; Moreno, 2014; Visschers et al., 2015). This could limit the change towards a reduction in antibiotic use (Scherpenzeel et al., 2016; Valeeva et al., 2007). In addition, literature showed the paramount importance of veterinary and non-veterinary advice, as well as exchange of knowledge between farmers for the implementation of preventive actions, and better antibiotic use (Friedman et al., 2007; S Mcdougall et al., 2017; Pardon et al., 2012; Poizat et al., 2017; Russell and Bewley, 2013; Vaarst et al., 2006). We thus hypothesise that improving knowledge and perception of farmers on mastitis prevention and management could improve their practices and their dairy herd health status.

Our objective was to evaluate the impact of an innovative training and advisory program focused on improvement of udder health prevention and antibiotic use on farmers' knowledge, perceptions, and practices, as well as its impact on herd health.

2. Material and methods

2.1. General approach and study design

The national project named RedAB started in 2015 in France. It aims at testing innovative tools for technical training and support to promote practices to reduce antibiotic use in the dairy cattle sector. This project had three target audiences: farmers, students and teachers from agricultural education. We focus here on the farmers' audience, who participated in an intervention study aiming at reducing their antibiotic use for the treatment of clinical mastitis.

The intervention study was performed on conventional farms in western France; with an exposed and a non-exposed groups of farmers to the educative program associated to follow-up visits. In the unexposed control farms, a basic advice program was implemented. Western France was chosen because this area is the most important dairy cattle region in France with 35,8% of the French production volumes (Martin-Houssart et al., 2016).

The impact of the training program was assessed using an adapted form of the process evaluation framework used for complex interventions (Moore et al., 2015) (Figure 3). The framework allows taking

[21] Somatic Cell Count (SCC) did not improved between 2005 and 2015 (Source : Résultats de contrôle laitier des espèces bovine, caprine et ovine – France 2015 – Institut de l'Elevage & France Conseil Elevage, available the 11/29/2017 at: http://idele.fr/recherche/publication/idelesolr/recommends/resultats-de-controle-laitier-france-2015.html).

[22] Source: French expert.

into account different elements that could influence the impact of the training program on farmers' knowledge, perception, practices, and animal health (udder health and antibiotic use): (i) compliance of farmers to the training sessions (instructor-led learning and virtual classrooms), (ii) compliance of farmers and advisors to farm advisory visits, (iii) ability of the training program to influence farmers' knowledge, perception and practices and animal health. The effectiveness of the program was evaluated comparing knowledge, perception, practices and udder health measures (i) for exposed farmers between the beginning of the training program (t0) and the end of the training program (tf); (ii) at tf between exposed and non-exposed farmers. To control for the selection bias of exposed and non-exposed farmers and the effects of the program, we compared knowledge, perception, practices and udder health measures (i) at t0 between exposed and non-exposed farmers, (ii) for non-exposed farmers at t0 and tf.

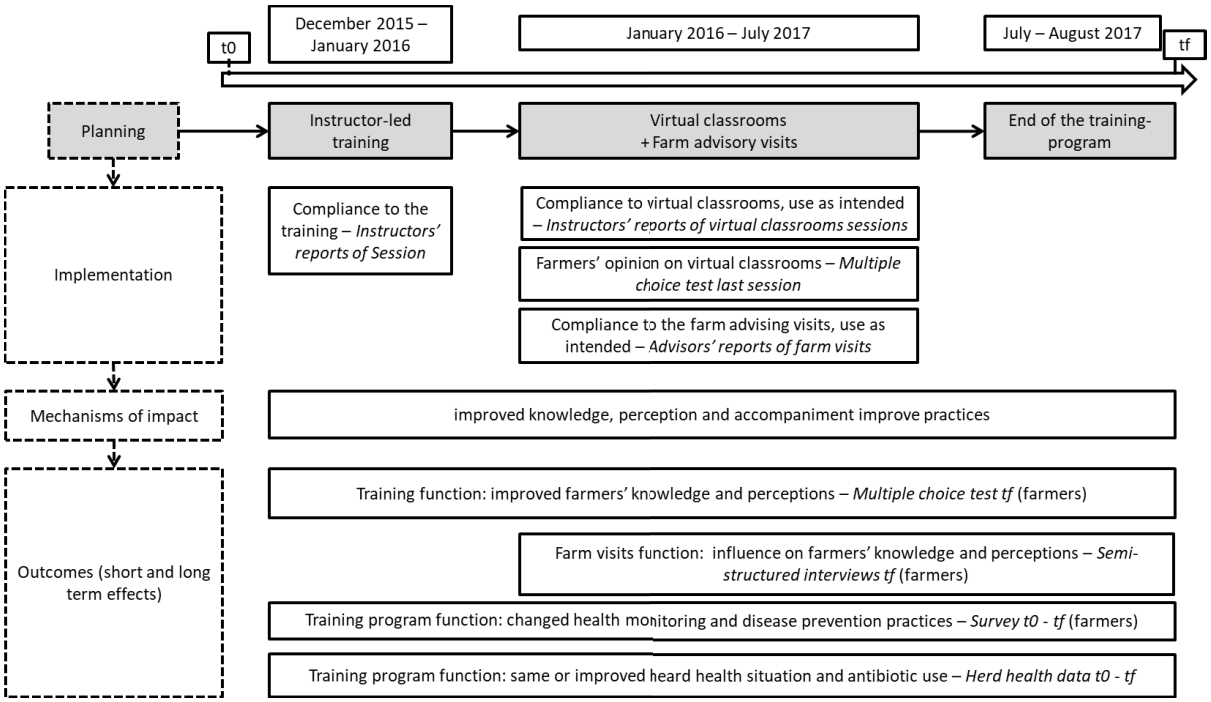

Figure 3: The designed and tested training program and process evaluation framework. The training program consisted of several consecutive activities (grey boxes). An evaluation framework was designed to measure different elements (farmers' compliance, improved knowledge, a change in perception and practices) that can explain its impact on herd health. The origin of the data is described in italics. "t0" is the beginning of the implementation of the program, tf is the end.

2.2. The tested training and advisory program

We developed the training program in two ways: (i) training tools designed by the training department of "Chambre d'Agriculture" (local or regional public establishment of administrative character supporting farmers' development, applied research and extension services), and (ii) technical content designed with large consultation of private veterinarians, animal health association (Groupements de Défense Sanitaire, GDS), French Livestock Institute, French National Milk Record, and veterinary school of Nantes (Oniris). Veterinarians and dairy technical advisors of GDS and French National Milk Record were involved in the different steps of the design and implementation of the program. They were invited to all training sessions to improve harmonisation of advice transmitted to farmers.

Farmers committed formally to the program by signing a document that explained the different steps of the program before the initial meeting (t0).

The training part of the program was based on two main actions. First an instructor-led training was used to give pieces of information on following topics: antimicrobial resistance, mastitis prevention

strategies at dry off (selective versus systematic treatment), selective dry cow therapy methodology explained step by step. It was designed as such to stimulate group cohesion and exchange of knowledge, perception and practices between farmers. Indeed, exchange of knowledge between farmers could be more important than scientific proofs for them changing their practices (Friedman et al., 2007; Vaarst et al., 2006). Second, four virtual classrooms were implemented from December 2015 or March 2016 during 18 or 12 months.

A technical test was performed before the first virtual classroom to prevent technical issues linked to the use of the software, internet connection or computer equipment. Virtual classrooms were planned in consultation with farmers. They always had a reminder, by text message or by e-mail less than seven days before the virtual classroom date. The D day, they received a text message and a phone-call if they were late or did not notify their absence. Veterinarians and farm advisors were invited to participate in the sessions in order to harmonise the content of advice provided to farmers. A computer technician attended to all virtual classrooms to help farmers and instructors to deal with technical issues and mishaps. Virtual classrooms focused on specific issues: milking machine and housing; mastitis treatment during lactating period; dry-off; presentation of two farmers' audit results. Instructors promoted questions and discussions. Moreover, they commented on and rectified wrong practices, perception or knowledge described by farmers.

The individual advisory programs aimed at improving dairy udder health, mainly by the reinforcement of prevention, but also by avoiding unnecessary antibiotic treatments. Advisors and farmers autonomously organised four visits from December 2015 or March 2016 during 18 or 12 months. To facilitate appropriation by farmers of mastitis risks factors at dry off for their farm and to trigger discussions between farmers and farm advisors, farmers filled in a self-diagnosis survey about their practices to prevent and treat mastitis. This document was used to support the first discussions and advice between the farmer and farm advisor during the first advisory visit.

2.3. Exposed and non-exposed farmers' selection

Farmers from GDS and National Milk Record subscribers' list, as well as lists of clients from private veterinary practitioners were selected. There was a succession of different steps (Figure 4): first selection of farmers according to udder health criteria[23]. Then a random selection of farmers was assigned to the exposed group. With the help of the technical advisors of GDS and National Milk Record, farmers' behavioural profile regarding attitude to advice was determined:

- 1: Farmers of habits; reliant on advice they are prone to follow. However, they are more risk adverse.
- 2: Willing farmers; prone to follow technical advice, often working in bigger structures and able to spent time on training.
- 3: Innovative and independent farmers; used to several sources of information and prone to criticise technical health advice.

Then the remaining farmers were randomly assigned to the unexposed group and matched with the behavioural profiles of farmers in the exposed group. Farmers with a behavioural profile which were not corresponding to the ones of the exposed farmers were eliminated from the study.

[23] Cows having more than 50 clinical mastitis per 100 cows per year.

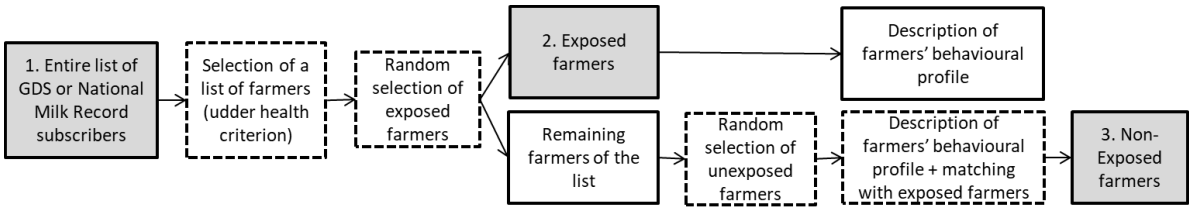

Figure 4: Exposed and non-exposed farmers' selection.

In total, 20 exposed farms and 20 non-exposed farms were selected. Farmers from the exposed group were split between two groups in order to enhance discussions between farmers inside each group.

2.4. The process evaluation framework and data collection

Compliance of farmers to the training sessions (instructor-led learning and virtual classrooms)

Instructors reported to the research team participation of farmers after each training session (Fig. 1). In addition, for the virtual classrooms, instructors also reported technical problems encountered.

Compliance of farmers and advisors to the advisory visits

Farm advisors reported after each advisory visit to the research team using a report sheet given to the farmer (Fig. 1). This sheet reported on the main observations and recommendations made by the advisor to the farmer.

Evaluation of users' opinion on the training sessions and on the program in general

Users' opinion took into account instructors' and farmers' opinions on the training sessions and on the program in general. We collected qualitative data. Qualitative data is relevant in the evaluation of complex interventions to provide a detailed understanding of satisfaction of participants and feasibility to further improve and develop the intervention (Moore et al., 2015).

Instructors of instructor-led learning sessions and virtual classrooms gave their opinion and feelings about the program and exchanges made during the sessions. They reported interactions between themselves, farmers, and veterinarians. Instructors could also evoke what they had found easy or difficult to implement (Fig. 1).

At the end of the last virtual classroom, farmers gave their opinion on the virtual classroom sessions using a short online multiple-choice test.

To explore farmers' opinions on the program, qualitative semi-structured interviews were conducted. Interviews were conducted using an interview guide structured into four main themes: (i) the farm, the farmer and its herd health, (ii) changes in mastitis prevention and management linked to the program, (iii) personal view on the program, (iv) conclusion. The interview guide was a non-rigid support designed to provide open follow-up questions and reminders. Data were collected by a veterinary student in its last year of curriculum. With the informed consent of interviewees, interviews were recorded.

Evaluation of the program on farmers' knowledge and perception

Farmers' knowledge and perception were evaluated at two different steps of the program using a single multiple-choice test (Fig. 1): (i) first, to evaluate the initial level of knowledge and perception of farmers, the test was submitted to exposed and non-exposed farmers before the instructor-led training (t0), (iii) second, to evaluate the general evolution of farmers' knowledge and perception, the test was submitted to exposed and non-exposed farmers at the end of the program (tf).

The answers of the multiple-choice test were evaluated using a four point Likert scale. The Likert scale measured the gap between the answer of the farmer and the correct answer.

To compare the results of farmers to the multiple-choice test between different groups, a Mann and Whitney test (when comparing 2 exposed *versus* non-exposed farmers) or a Kruskal (when comparing 3 groups of farmers having different behavioural profiles) test were implemented using R. To compare the results of farmers to the multiple-choice test inside their group between t0 and tf, a Wilcoxon test was used.

Evaluation of the program on farmers' practices

To report farmers' practices, a form that went over most important preventing and dry cow practices was used. Farmers' practices were recorded during farm visits after the first instructor-led training session and at tf (Fig. 1). During the final visit, particular attention was given to take into account advices provided during advisory visits and to compare them with the practices implemented by the farmers at the time of the collection of data (tf).

Evaluation of the program on dairy herd health

The collection of data regarding dairy herd health included (i) for t0 data of the year prior to the beginning of the program, (ii) for tf data of the year prior to the las visit to collect data.

Data from the French National Milk Record was collected to calculate major indicators of udder health: somatic cell count (SCC) in the herd milk; somatic cell count in the bulk; frequency of clinical mastitis (number of antibiotic treatment decisions).

During the on-farms visits, information on antibiotic use on farms was collected (inspection book and veterinarian bills). To complete the collection of data when information collected on farms was not exhaustive, attending veterinarian of farmers were contacted to provide more details on antibiotic use on farms.

Antibiotic use was evaluated using the following indicators: Animal Daily Dose[24] (ADD) to treat mastitis during lactating period; ADD for antibiotics used at dry-off; ADD total for all antibiotics used for udder health issues.

To compare antibiotic consumption of farmers between the exposed and non-exposed group, we used a Chi-square test or a Fisher exact test; in a same group between t0 and tf, we used a Bhapkar test.

3. Results

3.1. Farmers' selection, behavioural profile and farm characteristics

20 exposed farmers were selected for the exposed group and non-exposed group. However, due to difficulties in data collection and availability of two of the exposed farmers, they had to be removed from the intervention study. Same difficulties happened with non-exposed group of farmers, and only 15 of them remained in the analysis. There was thus only partial matching of psychological profiles of exposed and non-exposed farmers in the "prevention" group (Table 8).

Differences between farm characteristics and behavioural profile of farmers were non-significant (Table 8).

[24] ADD is the dose of antibiotic needed to treat an animal during one day.

Table 8: Behavioural profile and farm characteristics of exposed and non-exposed groups.

	Exposed (n=18)	Non-exposed (n=15)	p-values (Exposed/Non-exposed*)
Behavioural profile of farmers (%)			
1 Farmers of habits	33	27	NS
2 Willing farmers	50	66	
3 Innovative and independent farmers	17	7	
Farm characteristics			
Number of workers of farm (full time equivalent)	2.52	2.63	NS
Number of cows on the farm	72.2	68.6	NS
Annual production per cow (l/year)	7447	8007	NS
Utilised agricultural land (ha)	136	123	NS

*NS=Non-significant

3Compliance of farmers to the training sessions

3.2. Compliance of farmers to the training sessions

The instructor-led trainings were followed by all exposed farmers. Farmers' compliance to the virtual classrooms sessions varied. Compliance rates varied between 33 to 100 percent depending on training sessions. Most virtual classrooms had a participation rate of approximately 80 percent. The number of farmers attending the virtual classrooms reduced over time: from 16 to 14, and finally 6 participants. Sending an SMS or calling farmers at the beginning of the virtual classrooms increased by one or two the number of farmers attending the training sessions.

Virtual classrooms lasted from one hour to one and a half hour. Due to technical problems (at the instructors' workplace), two virtual classrooms' appointments were moved. There were between one to five technical problems at the beginning or during each virtual classroom (most often two technical problems). Technical problems were linked to poor accessibility of the internet and computer equipment (microphone). The computer technician's work was thus of paramount importance to tackle technical problems without interrupting the training sessions. Technical problems however limited the participation to the session for two farmers.

3.3. Compliance of farmers and advisors to the advisory visits

Due to its reliance on advisors on field, some unexpected events disturbed the schedule of farm visits. The number of farmers and advisors implementing farm visits reduced over time. All exposed farmers had their first visit, but then only 12 and 5 for the last visit.

Depending on the advisors involved, some of them wrote clear reports, others did not give any piece of information about their visits and the advice provided to each farmer.

3.4. Evaluation of users' opinion on the training sessions

Instructors reported that depending on the group, interactions and discussions between farmers and between farmers and veterinarians or themselves met uneven success.

Discussions and sharing of practices seemed very appreciated by farmers. Exposed farmers worked largely on prevention measures to prevent mastitis. This covers a large area of mighty virtuous practices and farmers were interested in sharing and learning about that.

Farmers appreciated the most the duration of virtual classrooms (20/20 quote). Meetings were planned approximately at the end of the morning, before lunch time and lasted less than one hour and a half. However, efficiency, usefulness and interest of contents were diversely appreciated (resp. 7.5/20; 13.3/20; 14.4/20). Farmers seemed to be sceptical regarding the possible expansion of such training support (10/20).

3.5. Evaluation of the program on farmers' knowledge and perception

The poorest level of knowledge at the beginning of the program was related to antimicrobial resistance (Table 9). In their answers, farmers underestimated the impact of mastitis on farm income and on dairy industry.

One of the poorest mark regarding the knowledge of farmers on mastitis showed that farmers were not yet able to implement rigorous mastitis control using tools that exist (Supplementary material).

Table 9: Average marks related to farmers' knowledge and perception (exposed and non-exposed) on main domains of the multiple-choice test (best mark: 3)

Explored domain of knowledge and perceptions	Exposed (n=18)		Non-exposed (n=15)		p-values*			
	t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf)[1]	E (t0/tf)[2]	NE (t0/tf)[3]
All questions	**1,83**	**2,18**	1,95	1,97	NS	**++**	**++**	NS
Mastitis	**1,92**	**2,29**	2,16	2,20	+	NS	**++**	NS
Impacts of antibiotic resistance and mastitis	1,72	2,02	1,57	1,71	NS	+	+	NS
Antibiotics and antibiotic resistance	**1,87**	**2,23**	2,04	1,95	NS	**++**	**++**	NS

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program.

At the beginning of the program, exposed farmers tended to have lower marks than non-exposed farmers in general and on questions related to mastitis in particular. However, at the end of the program, exposed farmers significantly increased their knowledge and perception whereas the non-exposed farmers did not change their marks between t0 and tf.

Farmers having behavioural profile 2 ("willing farmers", n=9) did better improved their knowledge compared to farmers having profile 1 ("farmers of habits, n=6), who better improved their knowledge compared to farmers having profile 3 ("innovative and independent farmers", n=3). The difference was statistically significant considering all questions of the multiple-choice test (p-value<0.10); and considering questions on antibiotic and antibiotic resistance (p-value<0.05).

3.6. Evaluation of the program on farmers' practices

Farmers' practices implemented to prevent mastitis during milking did not significantly improved during the program (Table 10).

Farmers' practices regarding the use of a sealant did significantly improve for exposed farmers during the duration of the program (p-value<0.05): more farmers did use sealant at dry-off, with or without antibiotics (Table 10). At the end of the program, exposed farmers significantly acknowledged more the existence or usefulness of health protocol provided by veterinarians to improve their practices for mastitis treatment.

Table 10: Comparison of farmers' preventive practices implemented during milking and to treat mastitis between t0 and tf

		Exposed (%) (n=18)		Non-exposed (%) (n=15)		p-values*			
		t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf) [1]	E (t0/ tf)[2]	NE (t0/ tf)[3]
Prevention practices during milking									
Use of milking gloves	Never	59	59	60	60	NS	NS	NS	NS
	Sometimes	12	6	13	7				
	Always	29	35	27	33				
Teat pre-dipping	No : without soap	39	33	27	13	NS	NS	NS	NS
	Yes : disinfectant	61	67	73	87				
Foremilking	Never	23	18	13	7	NS	NS	NS	NS
	Yes on selected cows	12	18	13	14				
	Systematically	65	64	14	79				
Teat post-dipping	No	0	0	0	7	NS	NS	NS	NS
	Yes: disinfectant	28	22	13	7				
	Yes: teat dip	72	78	87	86				
Cows constrained after milking	No	56	55	20	21	NS	**++**	NS	NS
	With feed fence	22	28	33	21				
	No possible access	22	**17**	47	**58**				
Disinfection of liners during milking	Never	28	17	22	7	NS	NS	NS	NS
	Yes after selected cows	44	55	64	73				
	Yes after all cows	28	28	14	20				
Practices of mastitis treatment									
Mastitis treatment during lactation	1, always the same	33	28	20	13	NS	NS	NS	NS
	2, for 1st and 2nd line treatment	17	22	27	33				
	Individually adjusted	50	50	53	54				
Alternative treatment	Never	78	78	86	74	NS	NS	NS	NS
	Maybe (reflexion or training ongoing)	11	11	7	13				
	Yes, sometimes	11	11	7	13				
Dry-cow therapy	Uniform protocol	33	33	33	27	NS	NS	NS	+
	Protocol adapted to each cows	39	28	53	33				
	Sometimes without antibiotics	28	39	14	40				
Sealant	Never	**28**	**6**	27	20	NS	NS	**++**	+
	Yes	50	55	60	40				
	Yes, and sometimes without antibiotics	22	39	13	40				
Health protocol	Don't know / useless	33	6	38	36	NS	+	**++**	NS
	Know, useful	**67**	**94**	62	64				

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program

3.7. Evaluation of the program on udder herd health

Few changes related to practices of mastitis treatment and antibiotic use were observed.
Exposed farmers tended to reduce their antibiotic use for treatments of clinical mastitis (p-value<0.10), and for treatments implemented at dry-off (p-value<0.05) (Table 11).
Non-exposed farmers did also significantly improve their antibiotic use over the period, mainly at dry-off. At tf, the difference of practices between exposed and non-exposed farmers was non-significant.

Table 11: Comparison of udder herd health and antibiotic use over a year between t0 and tf for exposed and non-exposed farmers

	Exposed (n=18)		Non-exposed (n=15)		p-values*			
	t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf)[1]	E (t0/ tf)[2]	NE (t0/ tf)[3]
Antibiotic use practices								
ADD mastitis per lactating period per cow (days)	3,1 (1,1-8,5)	2,6 (0,6-5,3)	3,6 (1,2-6,8)	3,6 (1,0-8,7)	NS	NS	+	NS
ADD dry-off per cow (days)	**0,9** (0,1-1,1)	**0,6** (0,1-1,2)	**1,0** (0,8-1,4)	**0,6** (0,4-1,1)	NS	NS	**++**	**++**
ADD total per cow (days)	**4,0** (2,0-9,6)	**3,1** (0,9-5,9)	4,6 (2,3-8,0)	4,33 (1,4-9,1)	NS	NS	**++**	NS
Udder herd health								
SCC (herd) (x 1000 cells/mL)	265 (161-373)	255 (121-381)	295 (156-473)	286 (120-423)	NS	NS	NS	NS
SCC (bulk milk) (x 1000 cells/mL)	**220** (147-324)	**210** (119-356)	**238** (140-279)	**228** (122-307)	NS	NS	NS	NS
Occurrence of clinical mastitis (cases per 100 cows per year)	**95,6** (51,4-164,2)	**66,5** (18,9-109,4)	**98,4** (47,8-147,8)	**64,9** (26,0-104,0)	NS	NS	**++**	**++**

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program

Differences of improvements between exposed farmers of different behavioural groups were non-significant (p-value>0.10). However, a trend in the evolution of scores could be noticed, and were consistent with the improvement of knowledge marks: farmers of profile 2 did more reduce total ADD (-1.21) than farmers of profile 1 (-0.42) and 3 (-0.56).
The number of mastitis did significantly reduce between t0 and tf both for exposed and non-exposed farmers (p-value<0.05).

4. Discussion

4.1. Main impacts of the program on farmers' knowledge, practices, and on dairy herd health

The results of data about knowledge and perception of farmers on mastitis and antimicrobial resistance confirmed the possibilities for improvement. First, farmers underestimated impact of mastitis on farm income and on dairy industry, while economic levers are important to trigger changes of practice (Russell and Bewley, 2013). In addition, farmers' knowledge on antimicrobial resistance was

deficient. This is consistent with the only recent concern for antimicrobial resistance (Friedman et al., 2007). However, the knowledge is also a lever to change practices (Ellis-iversen et al., 2010). Finally, the results showed that farmers are still not able to precisely manage mastitis with existing tools. They also did not rely enough on the scientific expertise of advisors and veterinarians.

These elements confirmed the paramount importance of improving both perception and knowledge of farmers through training and advisory programs. A significant improvement of knowledge for exposed farmers was observed on mastitis, impacts of antibiotic resistance, and on antibiotic resistance itself. However, evolution of knowledge was better for farmers prone to follow technical advice than for other behavioural types of farmers.

A reduction of antibiotic consumption was observed, including treatment implemented at dry-off, but to a limited extent. However only marginal improvement of prevention practices during milking was recorded. This could be linked first to the duration of the program. Second, the organisation of data collection could explain the limited evolution of practices. Due to schedule constraints, data collection for tf included records registered during the implementation of the program, as advisory visits were still in progress. To stand back and better evaluate the impact of the program, the collection of data on practices and udder herd health should have started at the end of the program. A change in practices is a process that requires new knowledge and time to be implemented (Ellis-iversen et al., 2010; Panter-Brick et al., 2006). Finally, farmers included in the intervention study were no voluntary applying for the program. Their motivation could thus have been limited.

4.2. Strengths and weaknesses of the evaluative method

The design of the evaluation framework measuring the impact of the training program took into account different elements: knowledge, perception, practices, herd health, antibiotic consumption. Methods used are of qualitative and quantitative nature, allowing evaluating the impact of the whole program with more precision (Duval et al., 2017; Moore et al., 2015).

The epidemiological design allowed for the control of important parameters influencing the results. First, the willingness of farmers to follow advice was evaluated, which showed an influence on the improvement of exposed farmers on knowledge, perception and practices. Second, the program showed similar effects on the two exposed groups of farmers, which demonstrates a certain reproducibility of the results. Third, the comparison of the results between exposed and non-exposed groups showed that exposed farmers' improvement of antibiotic use at dry off could also be linked to a more general trend, as non-exposed farmers also improved their practices. Veterinarians could be increasingly advising for selective dry-cow therapy.

Some limitations can also be addressed. The training program was complicated, time consuming and long for farmers involved in the process. Having non-exposed farmers was important. However, this increased constraints and complexity of the program and data collection. In addition, non-exposed farmers were not involved in the project. Five of them gave up during the program, whereas only two exposed farmers gave up. At the end, only 33 farmers were included in the analysis of the results, which limited the power of statistical analysis.

Evaluation of farmers' perception and practices is difficult. Perceptions are abstract concepts and linked to personal evaluations. Practices evolve on longer periods than the one considered for the program. And evaluation of practices is difficult as farmers can implement the same preventive practices in a correct or non-correct way. This would have an impact on farmers' ability to prevent mastitis, but would not change the results of the analysis.

4.3. Contributions and limitations of the innovative training program

The design of the training program took into account different important elements to trigger an improvement of farmers' practices. From a theoretical point of view, the program aimed at improving both perception and knowledge of farmers, which are two important levers. From a practical point of view, the program mobilised different tools, some of them of an innovative form: training, virtual classroom, advisory program and farmers sharing practices. This program thus used the three major farmers' channel of information (Friedman et al., 2007; S Mcdougall et al., 2017; Russell and Bewley, 2013; Vaarst et al., 2006). However, the initial design of the training program was complex and time consuming both for farmers, instructors and computer technicians. This could limit the extension to a larger scale of this kind of program.

Virtual classrooms present advantages compared to instructor-led trainings and Massive Open Online Courses (MOOC).

First, the organisation of the virtual classrooms was flexible as meetings can be easily modified without any logistical constraints. In addition, the duration of the meetings (maximum one hour and a half) are less time consuming and less expensive for farmers than other traditional trainings which need at least half a day or a complete evening. Finally, the software can be programmed to automatically send reminders, which proved to be effective. All those elements combined, the attendance to the virtual classrooms (20% in the worst case, but most often between 60 to 89%) seemed to be better than the attendance to more traditional trainings, or other MOOC where attendance is close to 10% (Goldberg et al., 2015). Social interactions during MOOC are important to involve participants (Goldberg et al., 2015; Redondo-Duarte and Valencia, 2017). Shorter MOOC programs could be more successful in case of shorter periods of interactions (Goldberg et al., 2015).

Second, the constraint of meeting date and the live exchange during virtual classrooms increased social involvement and gave an advantage compared to the organisation of more "traditional" MOOC sessions (Watson et al., 2017). The diminishing of farmers' involvement is very strong in MOOC sessions and was limited for our virtual classrooms.

However, technical difficulties linked to the use of the software (complicated interface to use), internet connection or computer equipment were numerous and did not diminish over time. This discouraged some farmers and sometimes increased the delay between two virtual classrooms. Those limitations could be linked to the nature of the software, to the farmers' familiarity with computer use, or to the network coverage. All points should be improved in the coming years.

Finally, advisory visits were implemented by advisors who were not involved in the conception of the program. They were invited to all training sessions, but they were not all available to come. The form of accompaniment developed in the program was innovative for them too, and they complied to it showing uneven efforts. Advisory visits were thus different among exposed farmers.

5. Conclusion

This intervention study succeeded in improving knowledge and perception of farmers when room for improvement was the most important and when farmers where more willing to. However, the design of the study (including the short schedule for data collection) limited the possibilities to evaluate the evolution of farmers' practices and antibiotic use. They did improve to some limited extent. However, farmers did commit to follow the training program because they were looking for such a program. Developing tools for trainings and advisory programs adapted to farmers' constraints at a larger scale requires further evolution, especially regarding computing and technical tools. To this effect, new

forms of virtual trainings could be further developed. However, the impact of such programs should be further confirmed with larger field research.

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Supplementary material

Table 12: Comparison of knowledge marks (from 0 to 3) on pathology and aetiology (exposed and non-exposed farmers)

Statements	Exposed (n=18)		Non-exposed (n=15)		p-values*			
	t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf) [1]	E (t0/ tf)[2]	NE (t0/ tf)[3]
Somatic cells are the expression of an udder inflammation	1,83	2,33	1,93	1,93	NS	NS	+	NS
A high number of somatic cell count means that the cow is fighting against intramammary infection	1,72	1,72	1,93	2,33	NS	NS	NS	NS
A high number of somatic cell count means that the cow is protected against intramammary infection	2,44	2,61	2,53	2,47	NS	NS	NS	NS
A high number of somatic cell count means that the cow has a mastitis	**1,78**	**2,50**	2,60	2,13	**++**	NS	**++**	NS
Mastitis bacteria can be found on teat skin and in infected udder	**2,00**	**2,72**	2,13	2,27	NS	**++**	**++**	NS
Mastitis bacteria are found in litter and soil	**2,39**	**2,83**	2,40	2,53	NS	+	**++**	NS
Bacteria responsible for mastitis are also in the air	1,17	1,56	1,67	1,73	NS	NS	NS	NS
Mean	**1,92**	**2,29**	2,16	2,20	+	NS	**++**	NS

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program

Table 13 : Comparison of knowledge marks (from 0 to 3) on impacts of mastitis (exposed and non-exposed farmers)

Statements	Exposed (n=18)		Non-exposed (n=15)		p-values*			
	t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf) [1]	E (t0/ tf)[2]	NE (t0/ tf)[3]
Mastitis are the third health expense in a dairy farm	**1,11**	**1,61**	1,27	1,33	NS	NS	**++**	NS
Mastitis diminish the quantity of milk produced	2,61	2,72	2,80	2,73	NS	NS	NS	NS
Mastitis in my herd can also have an impact on the downstream of the sector	2,28	1,89	1,80	1,67	+	NS	NS	NS
The taste of a milk coming from an infected udder is not modified	1,06	1,61	0,67	1,40	NS	NS	+	+
Milk from an infected udder has the same industrial potential (cheese, etc.)	**1,94**	**2,78**	1,60	2,13	NS	**++**	**++**	NS
Mastitis in my farm might have health consequences for the consumer	1,33	1,50	1,27	1,00	NS	NS	NS	NS
Mean	1,72	2,02	1,57	1,71	NS	+	+	NS

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program

Table 14: Comparison of knowledge marks (from 0 to 3) on antibiotics (exposed and non-exposed farmers)

Statements	Exposed (n=18)		Non-exposed (n=15)		p-values*			
	t0	tf	t0	tf	E/NE (t0)[1]	E/NE (tf)[1]	E (t0/ tf)[2]	NE (t0/ tf)[3]
Antimicrobial resistances exists only for pathogen bacteria (responsible for infections)	**0,83**	**1,83**	0,93	1,33	NS	NS	**++**	NS
Using antibiotics always triggers resistant bacteria selection	**1,78**	**2,22**	2,00	1,40	NS	**++**	**++**	NS
Give to veal the milk containing antibiotics is a good solution	2,56	2,83	2,40	2,60	NS	NS	NS	NS
Give to veal the milk discarded from milking can trigger diarrhoea for the calf	1,72	2,00	1,60	1,47	NS	NS	NS	NS
Antimicrobial resistance threatens effectiveness of antibiotic treatments	2,50	2,61	2,53	2,47	NS	NS	NS	NS
Antibiotics are useful to treat mastitis	2,44	2,28	2,33	2,07	NS	NS	NS	NS
Using antibiotics during lactating period prevents new udder infections	2,00	2,39	2,40	2,07	NS	NS	NS	NS
It is necessary to use antibiotics to stop the udder milking secretion?	2,00	2,17	1,87	1,80	NS	NS	NS	NS
Antbiotics are necessary to condrol udder health	**2,00**	**2,28**	1,87	2,07	NS	NS	**++**	NS
Antibiotics are always very effective to treat mastitis	2,00	2,50	2,13	1,93	NS	+	+	NS
Antibiotic use to treat a 4 months old mastitis scarcely permit healing	**2,22**	2,22	**2,74**	2,27	**++**	NS	NS	+
It is relevant to implement intramammary treatment when somatic cell count is high but there are no clinical signs	1,33	1,56	1,60	1,33	NS	NS	NS	NS
It's relevant to treat clinical mastitis with intramammary antibiotics	2,67	2,56	2,87	2,67	NS	NS	NS	NS
We don't have tools to evaluate the effectiveness of treatments against mastitis during lactating period	**0,83**	**2,00**	1,27	1,60	NS	NS	**++**	NS
We have tools to know when new udder infections happen	**1,17**	**2,00**	2,07	2,13	**++**	NS	**++**	NS
Mean	**1,87**	**2,23**	2,04	1,95	NS	**++**	**++**	NS

*NS = Non-significant; "+" = 0.05<p-value<0.10; "++" = p-value<0.05.

[1]E/NE = Comparison of exposed and non-exposed farmers at the beginning (t0) or at the end (tf) of the program.

[2]E (t0/tf) = Comparison of exposed farmers at the beginning and at the end of the program.

[3]NE (t0/tf) = Comparison of non-exposed farmers at the beginning and at the end of the program

Chapitre 2 : Organisation économique de filière, verrous liés à la compatibilité avec les standards

Afin d'initier des changements de pratiques à une large échelle, l'environnement social, ici représenté par la filière de production et ses dynamiques, a une potentielle influence sur les comportements individuels. En particulier, les standards de production communément admis peuvent influer sur les pratiques et constituer des verrous à une amélioration des pratiques. De façon plus marquée qu'en filière lait de vache, la filière de viande de jeunes bovins de boucherie présente une structure économique, organisationnelle et de production complexe. Comprendre l'influence de l'organisation et des dynamiques existant au sein de cette filière et ayant une influence sur les pratiques d'utilisation d'antibiotiques fera l'objet des deux sections de ce chapitre.
Elles visent à comprendre l'influence de l'organisation de la filière viande de jeunes bovins de boucherie sur les pratiques d'utilisation d'antibiotiques aujourd'hui observées. Elles abordent cette question par deux cadres théoriques différents : la première section de ce chapitre aborde l'analyse par le cadre théorique de la chaîne de valeur, la deuxième aborde la question par la gouvernance des transactions et la théorie de la firme.

Dans le chapitre 2A, l'analyse d'entretiens qualitatifs semi-directifs (54) et d'observations de terrain (6) permet de partiellement confirmer l'hypothèse d'un frein à une amélioration des pratiques d'antibiothérapie lié à l'organisation économique de la filière jeunes bovins de boucherie. L'organisation économique et technique de la chaîne de valeur repose en partie sur une utilisation systématique et préventive d'antibiotiques. La transaction des broutards entre les élevages naisseurs et engraisseurs est un point central expliquant l'existence de standards de production, qui ne permet pas aujourd'hui une réduction d'utilisation d'antibiotiques dans la majorité des cas. Pour des questions de logistique de transport et d'allotement des broutards, les risques de maladies respiratoires sont ainsi souvent augmentés. Les verrouillages observés se déclinent techniquement sur deux points principaux. Premièrement, le manque de transmission d'information quant au niveau de risque de maladies respiratoires des broutards en début d'engraissement ne permet pas d'adapter les mesures de prévention, et donc l'utilisation d'antibiotiques, au risque observé. Deuxièmement, la vaccination préventive des broutards ou leur faible niveau de risque sanitaire (peu de transport, peu de mélanges d'animaux de provenances différentes), ne sont pas économiquement valorisés au sein de la filière.

Dans le chapitre 2B, l'analyse d'entretiens qualitatifs semi-directifs (54) et d'observations de terrain (6) confirme que le mode d'organisation industrielle dans la filière jeunes bovins de boucherie a une influence sur la prise en compte et la gestion du risque de maladies respiratoires des broutards. Il existe en effet une diversité de modes de gouvernance des transactions de broutards au sein de la filière des jeunes bovins de boucherie, allant du marché spot jusqu'à l'intégration verticale (éleveurs naisseur-engraisseur). Des formes intermédiaires de gouvernance, comme des contrats de long terme (un an ou plus) écrits ou des contrats relationnels concernent une part importante des transactions. Les éleveurs naisseurs fonctionnent avec des gouvernances moins fortement coordonnées comparés aux éleveurs engraisseurs. Les asymétries d'information, notamment concernant les caractéristiques de santé des broutards sont fortes dans la majorité des formes de gouvernance. Les acteurs, selon leur rôle dans la filière (éleveur, commercial ou vétérinaire) définissent diversement la qualité des broutards. Les attributs de qualité des broutards liés aux questions de santé, ne peuvent être évalués

qu’avec une transmission d’information. Ces attributs sont rarement pris en compte dans les transactions et semblent être souvent négligées par les acteurs (éleveurs et commerciaux). L’augmentation du niveau de coordination des transactions semble accompagner une diminution des risques de maladies respiratoires, une meilleure transmission de l’information liée à ces risques, et de meilleures pratiques de prévention des maladies respiratoires (davantage de vaccination et moins d’utilisation systématique préventive d’antibiotiques).

Chapitre 2A : Comment l'organisation de la chaîne de valeur des jeunes bovins de boucherie influence les risques de santé et l'utilisation d'antibiotiques pour le contrôle des maladies respiratoires bovines ?

Note d'avancement : Ce chapitre de thèse a été soumis en l'état à la revue Preventive Veterinary Medicine le 27 novembre 2017. La proposition d'article a été rejetée le 24 janvier 2018.
L'objectif pour ce papier est de le retravailler en vue de le soumettre à un journal dans les disciplines d'économie-gestion.

Abstract

Bovine respiratory disease (BRD) is a production disease mainly influenced by pathogen transmission and individual immunity status. In the French young beef bulls sector, systematic preventive antibiotic use, to reduce BRD symptoms in weanlings, is frequent at the beginning of the fattening period. Weanlings are male beef calves approximately 6 to 9 months old which enter the fattening unit after weaning. The sector has to organise the transfers of weanlings from the cow-calf farms to the units for fattening young bulls. We hypothesised that the particular features of this organisation would promote a frequent occurrence of BRD during the first two weeks after entry into the fattening units, and thus increase antibiotic use and impair animal performance.

Our aims in this study were to describe the roles of different stakeholders in the young beef bulls value chain, the main characteristics of the French organisation of young bulls sector and how these influence the risk of BRD development in fattening units.

We collected information from (i) technical, legislative and economic document to understand the context of the sector, and (ii) data obtained from cow-calf producers, middlemen, and fatteners based on 54 qualitative semi-structured interviews and 8 field observations conducted in the primary beef cattle regions in France.

Major coordination issues were apparent due to an irregular supply by the cow-calf producers (few weanlings available at the same time, heterogeneous weanling weights in a given batch) and a regular demand by the fatteners (10 to 15 weanlings of homogeneous weight in a given batch). This led to complex and diverse physical flows of weanlings from the cow-calf producers to the fatteners. Some physical flows involved middlemen, who bought and sorted weanlings from different farms and dispatched them as homogeneously weighted batches. However, in those complex systems, the upstream-to-downstream flow of information along the value chain, and vice versa, was sharply reduced. As the complexity of physical flows within the young bulls' value chain increased, the risk of BRD occurring at the beginning of the fattening period, and the loss of information also increased, leading to few possibilities for preventive action. Despite attempts by some middlemen and producers' organisations to reduce BRD risks and improve information flow, this concerned only a negligible proportion of the weanlings traded.

Keywords: BRD risks; cow-calf producer; fattener; middleman; vertical coordination.

1. Introduction

In the beef sector, antibiotics are mostly used in young bulls to control bovine respiratory diseases in fattening units (Radostitis et al., 2006). Bovine respiratory disease (BRD) is the most common multifactorial production disease occurring in young bull farms during the first two weeks of fattening and is responsible for 75 to 80 percent of all diseases occurring during the fattening period (Assié et al., 2009). BRD is responsible for considerable economic losses and can be responsible for a 26 percent decrease in farm income (Bareille et al., 2007), linked to production losses (mortality, impaired growth performance of animals,…) and related treatment costs (drugs, vet fees,…). These impacts can be reduced by the systematic administration of preventive long-action antibiotic preparations, specifically marketed for metaphylactic and curative treatments of BRD. However the inappropriate and extensive use of antibiotics is step-by-step reducing antibiotic effectiveness (Gautier-Bouchardon et al., 2014). Antibiotic resistance is also threatening future antibiotic effectiveness in general, both for humans and livestock (Gonggrijp et al., 2016; OECD, 2014). Thus, the reduction of antibiotic use in the young bull sector is of great concern in terms of public health and the competitiveness of animal production.

BRD is a multifactorial disease, potentially involving different pathogens and where the individual animal's characteristics are important in clinical expression of the disease. The risk of developing BRD is first linked to pathogen transmission between animals. The risk of transmission is higher when animals from different farms are batched together (Cernicchiaro et al., 2012a; Sanderson et al., 2008). The risk of developing BRD is also linked to the individual animal's immune status. Weaning, transportations and handling of weanlings (male beef calves approximately 6 to 9 months old) all increase the level of stress and increased stress is known to decrease the immune response (e.g. Faber et al., 1999; Ribble et al., 1995b; Sanderson et al., 2008). In France, the young bulls sector needs to better organise the transfer of weanlings from the cow-calf farms to the fattening units. At present, the features of this organisation are complex and the transport and mixing of weanlings from different farms is common. It can thus be assumed that these characteristics and their vertical coordination influence the risk of BRD occurrence and in turn, antibiotic use.

The conceptual framework of value chain is used to describe complex networks of material and non-material flows in a given sector (Aramyan et al., 2006; Croom et al., 2000). Since the nineties, this approach has been increasingly used to analyse performance in industrial and agricultural sectors as it takes their vertical organisation into account. The links between animal health issues and the vertical coordination of stakeholders in a value chain have rarely been described in the academic literature. Nevertheless, this approach has been used to understand the importance of the value chain in the spread of epidemic diseases (e.g. Martin et al., 2011; Paul et al., 2015). The value chain framework can be of particular value when investigating the effects of vertical organisation of a complex sector on an endemic, multifactorial disease, where the flows of animals and information influence the risks of disease outbreak. A better understanding of the value chain in the young bull sector and its impact on young bull health could improve and facilitate future efforts to reduce antibiotic use.

The objective of this study was to identify those features of the young bulls' value chain which influence the level of BRD risks. More precisely, it was aimed to (i) understand the general structure of the sector and its main drivers, (ii) describe the interactions between the different stakeholders and institutions in this value chain, and the influence of this organisation on the risk of BRD occurring in

fattening units, and (iii) describe the existing strategies and ways to improve vertical coordination within the value chain and their effects on both economic performance and health.

2. Materials and methods

2.1. General study design

The study was divided into three phases.

Our first aim was to understand the legislative and historical construction of the value chain for young bulls, based on technical, legislative and economic documents as well as reports from the French Livestock Institute, conference proceedings, and French legislation (decree, etc.).

Our second aim was to describe the organisation of this sector and the interactions between stakeholders, based on qualitative research interviews, and field observations. Quantitative analyses, including representative surveys and measurement of animal flows, were preferred to describe the organisation of stakeholders. When field information is non-existent or rare, qualitative methods can provide a comprehensive approach to complex systems, especially to understand the sociological and economic drivers (David C. Speksnijder et al., 2015). The aim in a semi-structured interview approach is to describe a wide range of possible circumstances regarding a certain field, rather than to answer a question in a quantitative and representative manner (Kvale, 1996; Lagarde, 2006; Sivertsson and Tell, 2015). This qualitative method also allows a wide range of topics to be taken into account. Long exchanges promote more authentic discussion, even if an ex-post re-organisation of personal histories is always possible (Brinkmann and S. Kvale, 2015). We thus chose to use the semi-structured qualitative method. We also carried out field observations to understand the different types of work done by the stakeholders and their daily challenges, and interactions.

Our third aim was to use the value chain framework to analyse the collected material by combining an analysis of the material and non-material flows from raw product to consumer with an analysis of the BRD risk factors.

2.2. Field survey

2.2.1. Interview guide and data collection

We first prepared guidelines for interviewing the different stakeholders, focusing on the organisation of the French young beef bulls sector and the associated interactions. Interviews were structured as follows: (i) general presentation of personal career and professional structure, (ii) everyday interactions with other stakeholders in the value chain, (iii) practices regarding health management and antibiotic use, (iv) understanding of current changes, fears and motivation linked to future prospects.

Three interviewers, two master students in agriculture and one veterinarian, were responsible for data collection. Interviews were usually recorded and entirely transcribed in order to avoid *a posteriori* interpretation. However, four interviews with macroscale stakeholders could not be recorded, due to their mistrust. We therefore took precise notes during and just after the interviews in order to summarize the interviewees' conversations as accurately as possible.

2.2.2. Selection of interviewees

Our aim was to be as thorough as possible in describing the value chain and the wide range of stakeholders involved, their functions and economic goals. We focused our selection on the two major French regions of weanlings and/or young bulls production, namely Western France and Central France[25].

Farmers and farm technicians were chosen in close collaboration with the French Livestock Institute and agricultural cooperatives to include different farming and marketing systems. The veterinarians of the interviewed farmers were then contacted. To enrich the individual stakeholders' approach, we also included important institutional stakeholders in the value chain, such as managers of cooperatives, managers of producer organisations of non-commercial nature (PONC), employees at the "Chambre d'Agriculture" (local or regional public establishment of administrative character supporting farmers' development, applied research and extension services) and slaughterhouse managers. This qualitative approach was based on 54 semi-structured interviews and completed with 8 field observations (see Table 15).

Table 15: Description of semi-structured interviewees and field observations implemented

Profession	Number interviews / field observations	Depending institution	French region considered
Semi-structured interviews			
Cow-calf producers	6	Cooperative or independent	Western or Central
Cow-calf and fatteners	12[2]	Cooperative or independent	Western or Central
Fatteners	5	Cooperative or independent	Western or Central
Middlemen	11[1,2]	Cooperative or independent	Western or Central
Farm advisors	4	Cooperative	Western
Veterinarians	8	Cooperative or liberal	Western or Central
Middlemen superiors	3	POC or PONC[3]	Western or Central
Chamber of Agriculture	1[1]	-	Western
Meat producers' Union	1	-	Western
Slaughterhouse director	1[1]	-	Western
Senior Official	2[1]	French Ministry of Agriculture	National
Field observations			
Specialised fattening units	4 (one day)	-	Western
Livestock Market	2 (one day each)	-	Western or Central
Sorting centre	2 (2 hours each)	Cooperative	Western

[1] One interview with no record

[25] Source: Anonyme, 2014. Les filières de l'élevage français. Les cahiers de FranceAgrimer

[2] One middleman (MM 4[C]) was also a breeder-fattener, we considered him as a middleman. One breeder-fattener (BF 8[C]) only fattened heifers; however, we recorded him in the breeder- fattener category.
[3] POC = Production Organisations of Commercial nature. Include cooperatives and producers' groups. They buy and sell cattle.
PONC = Production Organisations of Non-Commercial nature. Play an interface role by gathering farmers and middlemen in their association. Do not buy or sell cattle.

To respect the requests for anonymity, we only quoted middlemen, cow-calf producers, fatteners and cow-calf producers and fatteners. We used the following code, *X* indicating the stakeholder number, [C] and [W] indicating if stakeholders came from Central or Western France. We used the following abbreviations: middleman *X* became MM *X*; cow-calf producer *X* became CC *X*; fattener *X* became F *X*; breeder- fattener *X* became BF *X*.

2.3. Value chain framework for data analysis

The results concerning organisation of the young bulls sector, based on a value chain framework and extracted from the documentation and interviews, were analysed as follows:
First, to describe the main features of the organisation of this sector: (i) vertical, with the succession of buyer-supplier relationships at each level, (ii) horizontal, with the number of stakeholders at a same level (Lambert and Cooper, 2000).
Second, to consider the major stakeholders and flows in the value chain. We studied the material (e.g. raw product and various derived processed products, resources) and non-material (e.g. information, supply management strategies, added value, practices) network flows from the source of the raw material to the final product and the consumer (Croom et al., 2000; Paul et al., 2013). Because of the health issue we wanted to investigate, we focused on the upstream portion of the value chain and did not consider the slaughtering and supplying to consumer steps. The material flows of weanlings and young bulls were analysed. As the exchanges involved live products, they integrate perishability and bulkiness characteristics (Sporleder and Sporleder, 2007). Perishability is negligible in weanlings and young bulls because the production cycles are longer than in other animal productions such as poultry or pigs. However, the bulkiness characteristics and weights of weanlings and young bulls might influence logistic and vertical coordination. We then analysed monetary flows, and finally, the information flows in the value chain. Agricultural supply is specific because of the nature of goods exchanged. Raw agricultural goods are of biological nature, which increases variability and risks (Sporleder and Sporleder, 2007). In addition, the quality of animals, defined as their growth potential, is complex, difficult to evaluate or measure, and varies according to the stakeholders' point of view. This could influence the flow of information in the value chain.
Finally, we reviewed the literature concerning the BRD risk factors related to animal flows. All these elements (value chain analysis and BRD risk factors) were then combined to determine the health issues linked to the risks of BRD in weanlings at the beginning of the fattening period in the young bull's value chain.

3. Results

3.1. Main features of the young beef bulls sector

3.1.1. Geographic development of the French young bulls' value chain

The beef cow-calf sector in France is the largest of all European countries (EU-27) with 4.1 million livestock units of suckler cow (Interbev, 2013). The localisation of young bulls production on a national and regional European scale is determined by interdependent drivers. The zootechnical, geographic and historic characteristics of the steps in young bull production are important to explain the organisation of this value chain.

First, cow-calf farming systems are generally pasture-based and extensive. In contrast, young bulls are fattened in barns in intensive farming systems, and receive fodder and high-energy concentrates. As soil quality in Central France is poor and the climate unsuitable for intensive agricultural crops, most cow-calf producing farms are located in this region. On the contrary, in Western and Eastern France and in the Po valley region (Northern Italy), both soil and climate are suitable for intensive crop production, but competition for arable land is fierce. Cropping activities produce high-energy fodder (e.g. maize silage) and other by-products (pulp, spent grain, etc.) that can be used as concentrated feed to fatten weanlings in these regions.

Second, as the cow-calf sector in France has been developed in disadvantaged areas, it is of paramount importance for rural development. Public policies have therefore been strongly subsidising this sector since the eighties through the common agricultural policy (CAP). Different premiums support different stages in the young bulls' value chain. For example, one premium is given to cow-calf producers at each calving (suckler cow premium), another premium supports fatteners for each young bull slaughtered (slaughter premium). In 2017, the suckler cow sector is still one of the last agricultural sectors in which support is directly linked to the level of production (number of suckler cows, number of calvings, etc.). These subsidies from the CAP can account for one third of farm incomes[26].

This French regionalisation of agriculture has been strengthened by the implementation of milk quotas in France, which until April 2015 limited the development of dairy cow units. This led to an increased expansion of fattening units in milk-producing regions to enhance land use and develop a non-labour-intensive, subsidiary activity.

3.1.2. Main market issues and challenges for the French young bulls' value chain

The young beef bulls' value chain is mostly export-orientated with fifty percent of both weanlings and young bulls' meat being exported[27]. France faces European and international competition in a context of decreased demand in both markets (weanlings and young bulls' meat). This is limiting the opportunities to improve quality and health standards.

First the fifty percent of French weanlings exported are mostly fattened in Italy and Spain; the other fifty percent are fattened in France[28]. The Italian market demand has been decreasing over the past few years[29]. New outlets are possible, and there was a strong demand for weanlings on the Turkish

[26] Source: Prices and margins observatory (*Observatoire de la formation des prix et des marges*), 2015.
[27] Source: Idele, Dépliant Chiffres clés 2016.
[28] Source: Institut de l'élevage, 2015. Economie de l'élevage. Institut de l'élevage. Dossier annuel. 464
[29] Source: Institut de l'élevage, 2015. Economie de l'élevage. Institut de l'élevage. Dossier annuel. 464

market, for example, from 2011 to 2015. However, these market openings remain unstable because of non-tariff barriers (sanitary requirements, political issues, etc.).

Second, most of the fifty percent of French young bull's meat exported goes to Italy, Greece, and Germany[30]. Competition is on an international scale and exclusively based on price and volume, which is not favourable to the French product. French products compete with other beef-producers, such as South American countries, which produce young bulls' meat in a highly extensive and cheaper way (e.g. 429€/100 kg carcass weight in France vs 277€/100kg in Argentina)[31]. The competition based on price and volume is accentuated due to the quasi-absence of quality or distinction labels for French young bulls' meat.

3.2. Stakeholders and major flows in the young bulls' value chain

3.2.1. Expectations of stakeholders involved in the young bulls' value chain

Three major stakeholders are involved in this value chain: cow-calf producers, middlemen and fatteners. Each of them described similar managing practices and targets:

- First, the cow-calf producers were responsible for rearing beef calves, known as weanlings, until they were 6 to 9 months old. The optimum production level was defined as one calf per year per cow but, due to natural processes (e.g. failure to conceive), was seldom attained. During the various production cycles, cow-calf producers tried to minimise the costs linked to intermediate consumptions (mostly work time, depreciation of buildings, medical treatments, and animal feed) and to optimise their incomes (weanling price, depending on weight and conformation): "*I am a cow-calf producer, by 8 months [of age], they must have had the maximum growth rate*." (CC 1^{C})
- Then middlemen, mostly livestock traders, were responsible for matching the demand of fatteners with the offer from cow-calf producers. These middlemen bought and collected weanlings from farms or other market places and organised them into batches to sell to the fatteners:

  "*Batches are not necessarily homogenous, that's why there are sorting centres*. (…) *Sometimes, weanlings stay longer [than one day at the sorting centre] because we have to find buyers*." (MM 1^{C})

  Middlemen tried to maximise their returns and to minimise their intermediate consumptions (fuel consumption, animal feed, depreciation of their buildings, and work time).
- Finally, the fatteners were responsible for fattening these animals, aged from 6 to 9 months to a maximum age of 24 months. Their main aim was to keep their barns as full as possible all year long by grouping the animals into batches of at least 8 animals and fattening them. Fatteners attempted to maximise the difference between the buying price for weanlings and the selling price for young bulls, minimise the costs (work time, depreciation of their buildings, intermediate consumptions, such as animal feed, and medical treatments), and reduce the time involved in the fattening procedure:

  "*I think we are not that bad, but we also want to simplify. With the size [of our farm], it turns out to be complicated to make too many [different] feed rations*". (BF 11^{W})

The aim of fatteners was to have daily weight gains that were as high as possible:

"*We try to keep them as little as possible and to get as much [money] as possible*". (F 2^{W})

[30] Source: Institut de l'élevage, 2015. Economie de l'élevage. Institut de l'élevage. Dossier viande bovine française. 461

[31] Source: Institut de l'élevage, 2016. Economie de l'élevage. Institut de l'élevage. Dossier marché mondial. 468

3.2.2. Major material flows in the young bulls' value chain: from weanlings to young bulls

The general material flows in the young bulls' value chain consisted of the following steps: (i) the calves were born and raised in a cow-calf unit until 6 to 9 months old; (ii) they were then sold to a middleman and could be traded, sometimes several times, to different intermediaries; (iii) finally, the calves were raised in a fattening unit until the age of slaughter (at approximately 18 months and before 24 months old) (Figure 5). One exception concerned the breeder-fattener farmers where weanlings were reared and fattened. However, even in this farming system, some farmers explained that they bought in weanlings to make up the batches so as to optimally fill their barns.

All stakeholders admitted the existence of serious coordination issues along the value chain. On the one hand, weanlings were irregularly available on the market and supply varied on a weekly and seasonal basis. These variations depended on the season chosen for mating and the selling decisions of cow-calf producers, which depended on the age and body condition of the weanlings. According to their system and farm size, some farmers synchronised the calving period and were thus able to sell homogenous batches of weanlings (more than 10 weanlings of the same weight). But most often, they sold smaller batches or heterogeneous batches (weanlings of heterogeneous weight): "*For the same batch with [weanlings] of the same age, I sometimes have an 80 or 100 kg discrepancy*" (CC 1^{C}). Other farmers sold weanlings in small batches (from 1 to 9 weanlings): "They *leave in small groups*" (Cow-calf producer 6^{W}).

In contrast, the fatteners produced young bulls all year long and had a fixed number of places in their barn. They almost always asked for homogenous batches in terms of live body weight and conformation as this facilitated subsequent management: "*He* [*middleman employee] does N batches of 10 to 15 homogenous weanlings each week (…). Like that at the finishing time, everybody leaves together*". (MM 1^{C}) In addition, and depending on their preference, fatteners asked for light or heavy weanlings and might also have a preference for a particular breed.

The role of middlemen was thus of paramount importance to match the cow-calf producers' irregular supply with the regular demand of the fattener. To be able to sell weanling batches of homogeneous weight to the fatteners, middlemen had to buy and mix weanlings from different cow-calf producing farms.

To coordinate weanling transfers from the cow-calf farm to the fattening farm, we observed different possible physical flows, ranging from the simplest to the most complicated. Transfers of weanlings could be done directly from the cow-calf producing farm to the fattening farm or weanlings could be transported from the cow-calf producing farm through different intermediary steps before being sold to the fattener (Figure 3). Some even longer and more complicated schemes were observed, for instance with two stints in livestock markets. This occurred when the batch or the weanling did not find a place at a fatteners' barn:

> "*We already have purchase orders, and after, I might "provoke the market" and buy animals without knowing at the moment of the purchase where I will sell them. I call colleagues to try to sell them, that's pure trade. (…) When trends are a bit tougher, sometimes we are forced to store them*". (MM 10^{W})

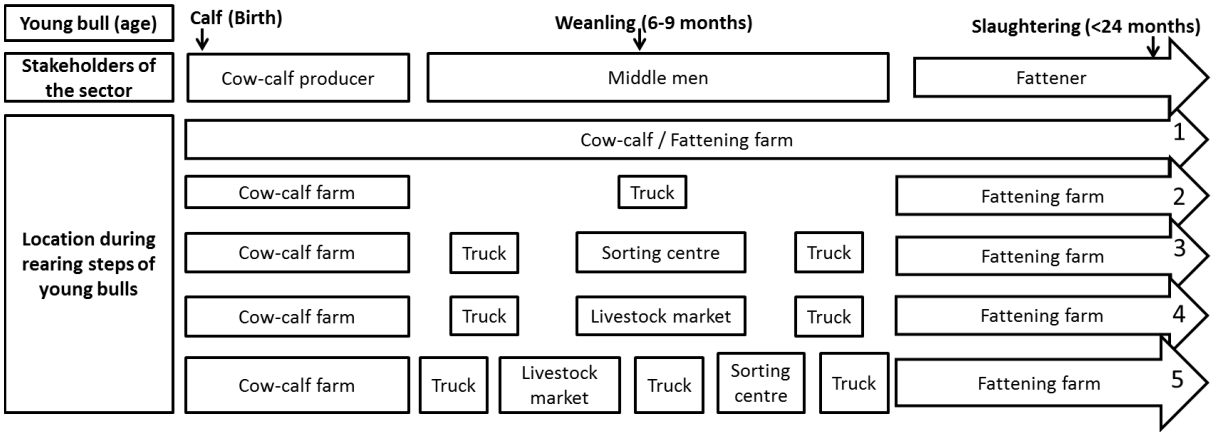


Figure 5: The major physical flows of male beef cattle in the young bulls' value chain

Two physical locations, namely the livestock markets and sorting centres, played an important role in the logistic organisation of the young bulls' value chain.

Livestock markets were places facilitating transactions between stakeholders where different bovines (age, breed, health status) were mixed or grouped close together. Cattle remained from half a day to one day on livestock markets. They were brought directly by the cow-calf producer or through a provision agreement by a carrier or a middleman.

Sorting centres were places for the grouping of cattle and their redistribution into batches. Almost all middlemen had their own sorting centre. Depending on the middleman's customer base, cattle of different origin, age and breed were grouped in neighbouring boxes. Usually, cattle stayed from one day to one week in the sorting centres. Middlemen tried to minimise the length of stay of the cattle to reduce the associated costs:

> "*We organise the collection depending on the sales concluded. (…) Everything comes through here [sorting centre] (…). Everything linked to exportations is brought here, we sort them and we send them the same day to Italy. (…) We sort them out depending on their weight, breed, quality, sex, GMO [Genetically Modified Organism] or not GMO [fed]".* (MM 2^{C})

All the major physical flows varied considerably over time. Cow-calf producers (fatteners) could sell (buy) weanlings by choosing one of the four major flows described (lines 2, 3, 4 and 5), for a single period or for one type of animal or for a better opportunity at a specific moment:

> "*We have a portion of loyal customers, otherwise it's door-to-door selling all the time. (…) Loyal customers, they are very few. (…) They want a price, and make several people come by [to propose to buy animals]*". (MM 2^{C})
>
> "*Among a batch, I will maybe sell 4 to 5 [weanlings] to another middleman (…) but only to make him happy*". (BF 12^{W})
>
> "*Animals, when we know there is something [wrong], we bring them to the livestock market. It's without guaranty, the price is not always [good]… but we sell without guaranty*". (CC 2^{C})

3.2.3. Major monetary flows in the young bulls' value chain

Monetary flows were dependent on the different physical flows.

Simple transfer in a truck corresponded to two different situations: (i) transportation was handled by a middleman who had bought weanlings, which corresponded to two commercial agreements: first the cow-calf producer with the middleman, and then the middleman with the fattener; (ii) transportation was handled by a carrier. In that case, the transaction was done directly between the cow-calf producer and the fattener. The carrier was paid by the fattener for the transport service.

In the case of more complex transfers, different monetary flows and ownership transfers were observed: (i) weanling ownership changed from cow-calf producer to middleman during the intermediate phase. In this case, weanlings could be sold by the middleman on the livestock market or be transferred through a sorting centre. Most middlemen used sorting centres. Sorting centres did not play an economic role in the conclusion of transactions, but had a logistic role as they allowed control of the different flows of animals linked to the commercial activity of middlemen; (ii) cow-calf producers kept weanling ownership and came directly to the market to sell or buy animals, or could delegate this mission to middlemen. In the case of delegation, middlemen were responsible for concluding the transactions on the livestock market and kept a margin from the transaction, but had no property rights regarding the weanlings.

Livestock markets and sorting centres thus had different functions: livestock markets were places allowing the interaction of supply and demand, whereas sorting centres ensured good flow management.

3.2.4. Major information flows in the young bulls' value chain

The transmission of information about market prices was relatively good. Livestock markets established prices on a weekly basis and this information was transmitted to middlemen and farmers through the press or internet. It was then used by most stakeholders to estimate weanling prices for subsequent transactions.

On the contrary, technical information about the weanlings (weight, past diseases, vaccination, former treatments, farm of origin, former feeding regime, lengths of transfers, etc.) was not made available in the value chain. The current vertical coordination of the value chain revealed a huge lack of information circulation between stakeholders in three out of the four major physical flows described (Figure 5). This poor circulation of information involved both downstream and upstream flows in the value chain (Figure 6).

First regarding downstream flows, information transmission from the cow-calf producers to the fatteners was lacking: "*We don't even know the background of animals*". (MM 1^{C}) The fatteners bought weanlings about which they had no information (Figure 3). The loss of information regarding past diseases, disease prevention, vaccination, etc. was significant and immediate from the first intermediary onwards. Information was not even considered by middlemen.

> "*I do not sell vaccinated animals at a higher price, they don't even ask [if they are vaccinated]*". (CC 2^{C})
>
> "*I would be ready to buy already vaccinated weanlings, but one should tell me*". (BF 7^{C})

The only information flow in the value chain was indicated on the green card, the official identity document of the weanling. This document provided information about the weanlings' age and notifiable disease testing. But this information was not taken into consideration for conclusion of the transaction: the fattener placed an order regarding the number and weights of weanlings required and the middleman was responsible for sorting the animals. The fattener only received information about the animals on their arrival in the fattening unit.

Second, regarding the upstream flows, no information was transmitted about the future of the cow-calf producers' weanlings, their destination, or their subsequent performance:

> "*Once it's gone [weanlings], we don't know anything afterwards*". (BF 8^{C})
>
> "*I don't know the fatteners. Destination of animals, this is no longer my responsibility*". (CC 3^{C})

Finally, as a result of this poor information circulation, most cow-calf producers and fatteners worked as if they were independent from each other. Most cow-calf producers had no interest in the future performance of their weanlings:

> "*99 out of 100 cow-calf producers see them [weanlings] get on the truck, (…) after they don't give a damn about what happens afterwards*". (CC 1^{C})
>
> "*Every man for himself, that's the spirit, some of them are pure cow-calf producers, other pure fatteners, it's like cats and dogs*". (BF 6^{C})
>
> "*If there are problems at the fatteners (…) it's the least of their concerns [cow-calf producers]*." (MM 2^{C})

Cow-calf producers based their evaluation of weanling performance, before selling to fatteners, on daily growth rate. They did not pay any attention to the possible consequences of their rearing methods on future fattening of weanlings: "*The more they [weanlings] are pushed, the more they are fragile*". (MM 1^{C})

There were two exceptions, where the vertical coordination patterns allowed an effective transmission of information in both upstream and downstream directions.

The first exception was linked to the vertical organisation of the physical flows: (i) when fattening was done in the same farm as cow-calf production, (ii) when cow-calf producers sold directly to the fattener. In these cases, the communication and transmission of information was facilitated as there was no intermediary.

The second exception was linked to the individual willingness of a middleman to pass on information to improve the supply from the cow-calf producers and better respond to the demand of the fatteners:

> "*There are some farmers, I give them the results of the young bulls they sell me when they were weanlings, ten months afterwards, when they are dead. (…) I call them [my clients] to tell them that their weanlings were not good. They have to take the good and the bad. That's how we progress*." (MM 5^{W})

In these two cases, coordination between the cow-calf producer and the fattener was fully or partially re-established. Each stakeholder was integrated into the dynamics of the value chain, the cow-calf producer saw himself as a producer of future young bulls and not only of weanlings. This seemed to be appreciated:

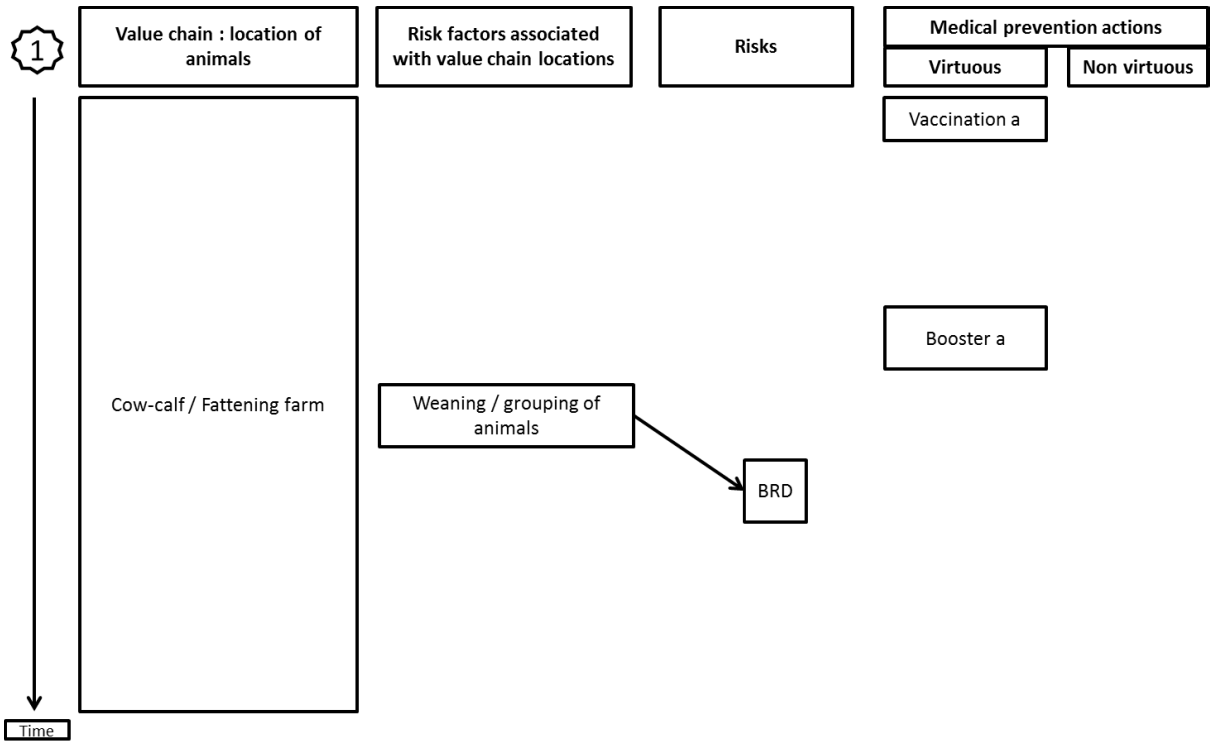
> "*The fattening, we love to see an animal evolving at home*". (BF 7^{C})
>
> "*I give them the results (…) I put them in this farm, they did this and this as a result. They are found of it.*" (MM 5^{W})

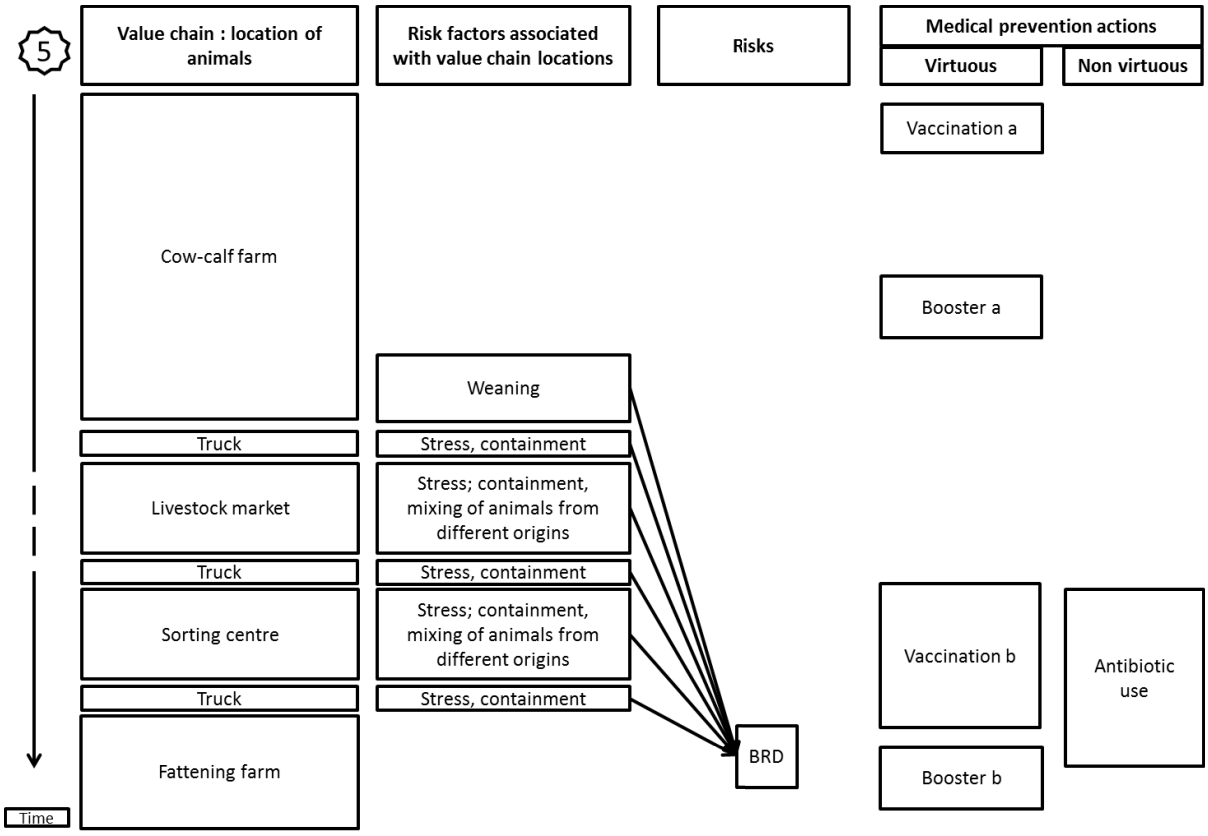
3.3. Influence of the young bulls' value chain on BRD risks and on preventive measures

3.3.1. Influence of physical flows of weanlings on the level of BRD risk

It was apparent from the vertical organisation of the young bulls' value chain that the physical flows of weanlings influenced the risk of developing BRD during the first weeks of fattening. As the complexity of this vertical organisation increased, the risk of BRD also increased. The best option to reduce this risk was to fatten weanlings in the same farm where they were born because they were then only subjected to the stress associated with weaning (change in feeding practices and rearing

environment) (Figure 3, Figure 4). In the case of direct transfer from a cow-calf producing farm to a fattening unit, weanlings were subjected to an additional stress linked to transportation (Figure 3). However, for all the other flows of weanlings (Figure 3), the stress situations and microbial exchanges, and thus the risk of developing BRD, were strongly increased (Figure 4). For complex transfers of weanlings, the constitution of homogenous batches based on weight necessitated the mixing of weanlings from different farms of provenance (Figure 5). This increased microbial exchange. Transportation from the cow-calf fattening farm to the sorting site, and then to the fattening unit took longer than direct transfers, and thus increased stress. These further increased microbial exchanges and the increased stress led to higher risks of BRD (Annex, Table 16). Two “node” locations, the sorting centres and the livestock markets, increased the risk of BRD even further. In those locations, the spatial organisation was supposed to minimize contacts between cattle of different origins and stress. However, proximity between the animals was unavoidable. The longer the transportation and the greater the mixing of animals, the greater the risk of BRD occurrence at the beginning of the fattening period (Annex, Table 16).





Vaccination a: early vaccination against BRD, best option to protect the weanling during the fattening period
Vaccination b: late vaccination against BRD, if implemented just before the beginning of the fattening period, protection is not optimal for the most critical period (3 first weeks of fattening)

Figure 6: Two detailed value chain patterns and their consequences on health risk and medical preventive measures – Pattern (1) Weanlings born and fattened in the same farm; Pattern (5) Weanlings sold through livestock market and batched in sorting centre

Most stakeholders, in the value chain, were aware of the risks generated by the current organisation of the physical flows of weanlings:

> Cow-calf producers: "*I know they [weanlings] have respiratory problems at the fatteners' farm, especially when they purchase animals from different farms. (…) That's an animal that has undergone stress*". (CC 4^{C})
>
> Middlemen: "*To really have no problems, to limit antibiotics, there should be complete batches [of weanlings], to bring animals directly from the cow-calf producer to the fattener. (…) If it [weanling] goes through a middleman to go to a fattener, that's even worse*". (MM 2^{C})
>
> Fatteners: "*Because I see the difference, I purchase [weanlings] directly [from the cow-calf producing farm]… I never sting [them with antibiotics]*". (F 4^{W})
>
> Cow-calf producers and fatteners: "*I get feedback from someone who does some fattening activities, and all the animals that come by the livestock market, they have an injection of Trademark1*[32]*, that's systematic. Otherwise, ¾ have the flu. Maybe fatteners should come to buy animals directly from us*". (BF 2^{C})

[32] Trademark 1: long-acting antibiotic

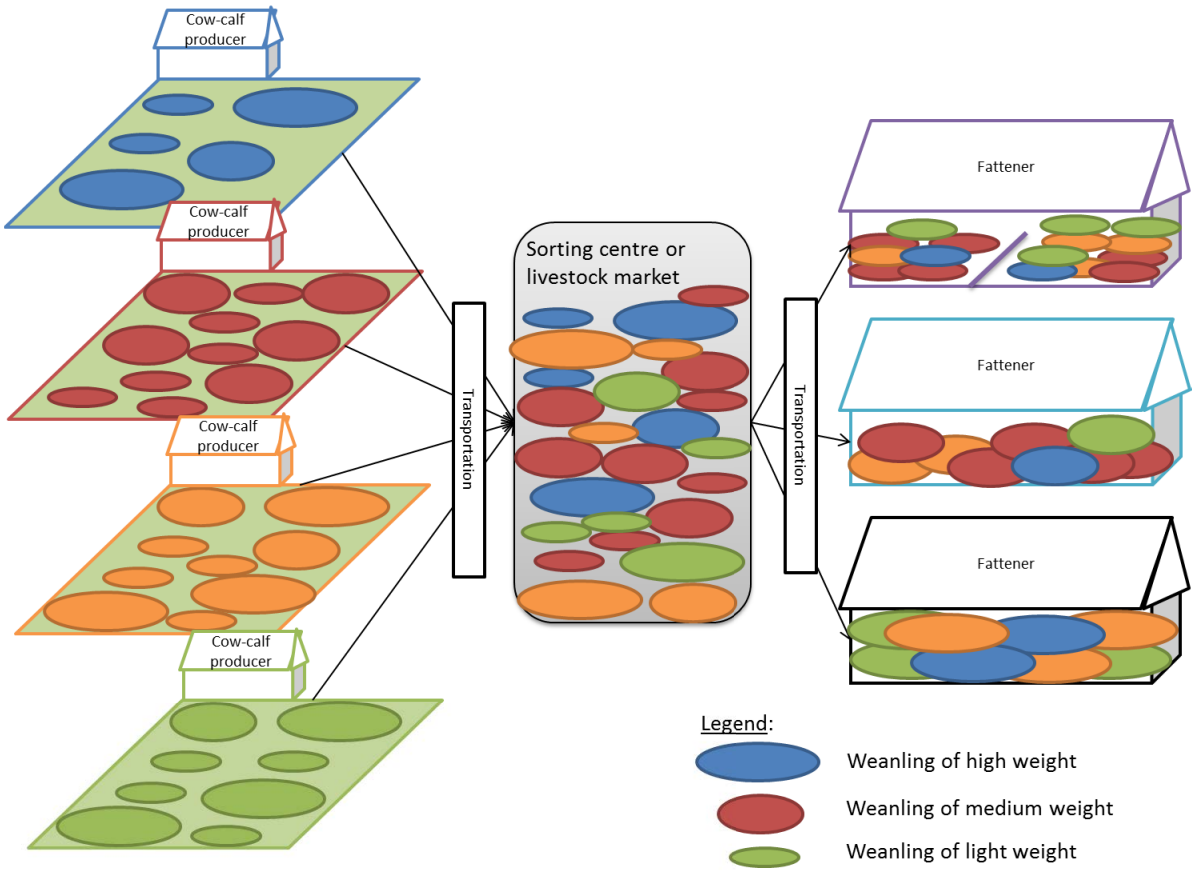


Figure 7: Complex transfers of weanlings to constitute batches with weanlings of homogenous weight, but diverse farm of provenance

However, despite the general awareness, most stakeholders did not modify their commercial practices and did not seem to take health issues into account in their commercial transactions. Middlemen and fatteners neglected all factors that determine BRD risks and exclusively focussed on weight when ordering and sorting weanlings. Fatteners were very rarely concerned by the practices implemented to constitute batches or by the number of farms providing the weanlings in a batch. This could be linked to logistical constraints and to fatteners' restraints:

> "*Otherwise, it should be tolerated to have heterogeneous batches. We sometimes do it. One should tolerate having large and small [weanlings], from 250 to 500kg. The fattener remakes batches at home. Afterwards, he spreads the departure of animals. They are not all ready to do this*". (MM 2[C])

3.3.2. Influence of information and monetary flows on the implementation of preventive measures against BRD

Only those preventive measures linked to the intermediary phase of weanlings' transfers, and which had a long-term effect, were considered. The rearing method and the internal environment in barns, etc., were not taken into account. Thus, two different kinds of preventive measures against BRD were instigated at the beginning of the fattening period.

First, there were zootechnical and hygienic measures: limitation of stress, limitation of microbial exchanges, appropriate transitional diet at weaning, etc. Those preventive measures were the easiest to implement when weanlings were produced and fattened on the same farm, and in the case of direct transfer from a cow-calf producing farm to a fattening unit. First, because both vertical coordination

methods limited stress and microbial exchanges (Figure 7). Second, there is a need for information about the animals' diet prior to weaning so that an appropriate transitional diet can be provided. The transfer of information about the previous diet was evident for the system in which calves were produced and fattened on the same farm, and was easy and quasi systematic in the case of direct transfers.

However, in the case of more complex transfers (Figure 4, lines 3, 4 and 5), there was a huge, if not total, loss of information about the previous diet, or the length and intermediary steps of transfers. As the fatteners were unaware of the length and intermediary steps of the transfers, they could not take this element into consideration when placing their order. As fatteners described their criteria for ordering weanling batches, they rarely mentioned the length and intermediary steps of transfers as a way to limit BRD risks.

Second, medical preventive measures such as early vaccination and preventive antibiotic use just before the fattening period were sometimes implemented. The systematic and preventive use of antibiotics is to be banned for public health reasons linked to antimicrobial resistance. However, the systematic and preventive use of antibiotics did not require any coordination between stakeholders as only one injection was needed. As fatteners did not know the level of stress and microbial exchange to which the weanlings had been exposed, they often chose to administer a systematic and preventive injection of antibiotics. This could easily be done by the middleman or by the fattener under veterinarian prescription. The manipulation of animals for transportation and antibiotic injections could be done at minimal cost and effort. This treatment protocol was common in the case of long and complex weanlings' transfers (figure 4), but very rare in the case of direct transfers or in the case of cow-calf producing and fattening systems. On the contrary, the implementation of an effective vaccination protocol required coordination between the cow-calf producer and the fattener. The first vaccine injection had to be administered in the cow-calf producers' farm to confer the highest possible protection at the beginning of fattening (Figure 5, Vaccination a, booster a). Late vaccination during transfers of the animals, or at the beginning of fattening, was possible but less effective (Figure 5, Vaccination b, booster b). Proper early vaccination protocols were usually implemented in cow-calf and fattening systems and in the case of direct transfers: "*Cow-calf producers and fatteners (…) are used to vaccinating in their farms*". (MM 1^{C}) However, in more complex vertical flows (figure 4, lines 3, 4 and 5), fatteners rarely had any information about the vaccination programs instigated by the cow-calf producer against BRD disease: "T*hey don't ask if they are vaccinated or not. They should check. They don't ask us*". (BF 8^{C}) As there has never been any record of this information, animals vaccinated against BRD can be mixed in batches that include non-vaccinated animals. "*It's one of the few sectors where there is that little traceability. Everything is done orally"*. (BF 3^{C})

In addition, in most systems, and linked to the lack of information transmissions, there was no added value for the cow-calf producer in the case of early vaccination against BRD:

> "*I don't sell weanlings at a higher price, because they systematically sting again [for vaccination protocol]*". (BF 8^{C})
>
> "*For all exported animals, we should work with the fatteners; we could avoid antibiotic injections (…). For instance, [we could] administer a booster a short time before they leave (…), but it must be compensated*". (BF 2^{C})
>
> "*If cow-calf producers don't take the leap of vaccination, that's because we don't pay them enough*". (MM 2^{C})

Finally, the whole value chain was mostly functioning without an effective transmission of information. However, the systematic use of antibiotics erased the technical dependence of the fatteners on the upstream portion of the value chain, and ensured the increased risk of BRD development.

3.3.3. Attempts to improve coordination and lower BRD risk in the young bulls' value chain

Two major initiatives, one proposed by a POC[33], the other by a PONC[34], had attempted to improve information flow and added value for the cow-calf producers and fatteners. Their aim was to guarantee the implementation of a rigorous weanling vaccination program against BRD during the early stages in cow-calf production (Figure 5, Vaccination a, booster a). They developed internal certification systems that allowed the circulation of information from the cow-calf producer to the fattener whatever the coordination pattern. The price of weanlings was increased to cover the costs of vaccination: the cow-calf producers got a higher price and the fatteners invested more in the weanlings he purchased.
However, these initiatives only covered a negligible proportion of the value chain flow of weanlings. Cow-calf producers expressed practical restraints to implementing vaccination, such as the time taken to handle the weanlings:

> "*The problem is that it needs additional manipulation. This is a problem for us: a practical problem*". (CC 4^{C})
>
> "*We should do it [vaccination] 3 weeks before [weanlings leave the farm]. I am not ready to do it. It's a very big burden. Vaccination, it's time and it's risks. What bothers me the most is the time. Cows might kill too, that's a fact. There are risks and one has to take them into consideration. We limit the manipulation of animals*". (CC 5^{C})

In addition, these two initiatives only modified the vaccination parameter, but had little influence on other risk factors, such as stress and mixing of animals. In addition, during our field observations, we noticed that the vaccination certificate did not modify the vertical flow of animals, which could remain very complex.

One other personal initiative from a private middleman was also intended to improve vertical coordination of the flows of weanlings, the value added and information:

> "*I give 25€ more to every person able to prove, by a confirmation from the veterinarian, that they did the vaccination protocol. (…) My 10 best farms, I know them, we might pay 30€ more for their animals. (…) I do prefer to give 40 or 50€ more to people who do everything right. Sometimes, over 20 weanlings, 5 are smaller. I say never mind, we had better leave the 5 weanlings as they are coming from the same farm. (…) Some middlemen don't care about that. (…) When I sell, I say: this batch is more expensive, but it has been stung [for the vaccination protocol]. There is never any remark*." (MM 5^{W})

However, this middleman worked in a niche market with the biggest fatteners of Northern France and the Netherlands.

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[33] POC = Production Organisations of Commercial nature. Include cooperatives and producers' groups. They buy and sell cattle.

[34] PONC = Production Organisations of Non-Commercial nature. Have an interface role by gathering farmers and middlemen in their association. Do not buy or sell cattle.

4. Discussion

4.1. Risks of BRD related to the value chain

The organisation of the French young bulls' value chain had a strong influence on BRD risks and the implementation of BRD prevention measures. As the physical flows of weanlings became more complex, the risk of BRD was increased, due to 1) the number of transfers of animals and, as a consequence, microbial exchanges; 2) the length of transfers, which increases stress, and impairs the animal's immune status and ability to limit the clinical effects of BRD. The increased complexity of the value chain also negatively affected the information circulation between stakeholders. The poor circulation of information in complex situations impeded the implementation of virtuous prevention measures and the reduction of antibiotic use. It also limited the possibility of developing a price premium quotation for weanlings less likely to develop BRD.

BRD risk was neglected by stakeholders and controlled by systematic and preventive antibiotic injections. The value chain was fragmented and institutional attempts to improve vertical coordination of the young bulls' value chain only concerned a very marginal fraction of this chain.

Most interviewees were located in Western and Central France, two major regions for weanlings' and/or young bulls' production. We tried to complete our data collection by interviewing stakeholders with a national vision of the value chain, and by field observations. We met a large diversity of stakeholders and the information collected attained saturation, suggesting that our sample was large enough to allow a comprehensive analysis of the value chain.

4.2. Restraints in the young bulls' value chain limiting the improvement of health practices

Analysis of the young bulls' value chain revealed that, in most cases, the fattener supported the high risk of BRD disease, which led to economic losses. However, he was only partly responsible for the BRD risk and for the implementation of preventive measures, because both risk and preventive measures were mainly linked to the former complex flows of weanlings required to constitute the fattening batches and to the practices of previous stakeholders in the value chain. Major restraints for the mitigation of BRD risks were identified.

First, the complex flows of weanlings and the loss of information along the young bulls' value chain was linked to a lack of vertical coordination between stakeholders. There were very few contractual agreements or commercial alliances, and spot markets remained an important commercial route. This was also noted in the Canadian beef industry (Brocklebank and Hobbs, 2004) and could be linked to the geographic dispersion of cow-calf producers and fatteners (Brocklebank and Hobbs, 2004). This hypothesis was corroborated, in our study, by the fact that two out of the three initiatives to improve the vertical coordination identified on-field were developed in Western France, a region with both cow-calf producers and fatteners. However, it also appeared to improve vertical coordination in Central France, where there are very few fattening units.

Second, the production of a given sector in a value chain is usually driven by consumer demand (Chen and Paulraj, 2004). However, when the intermediary step in the value chain was examined i.e. the sale of weanlings from cow-calf producer to fattener, almost the exact opposite was observed. Weanlings could be sold whatever their characteristics and quality because of the numerous outlets in France, Italy, and Spain. The demand from these different outlets varied on a large scale, which created little pressure on cow-calf producers and middlemen to improve their practices (e.g. vaccination or logistic coordination).

Finally, the lack of effective information transmission led to negligence with respect to BRD risks and BRD preventive measures. Very little consideration was given to the demands of fatteners, due to the lack of information transmission. This limited the possible valuation, through a price premium, of any improvement in preventive practices implemented by the cow-calf producers or fatteners.

4.3. Possibilities for improved efficiency in the young bulls' value chain

From a biological point of view (Annex 1), the best way to manage weanlings in order to reduce the risk of BRD and antibiotic use just before and during the fattening period would be:

- To reduce the number and length of transfers;
- To reduce the mixing of animals: during different transfers and within a given batch;
- To implement early vaccination at the cow-calf producers to ensure optimal protection of the animals in early life and at the beginning of the fattening period.

In order to implement those measures and reduce antibiotic use, the information flows between stakeholders in the value chain need to be vastly improved. First, cow-calf producers should be able to pass on information about an early vaccination protocol whatever the intermediate steps in the weanlings' flow. This should enable them to benefit from a price premium or improved market access if they supply weanlings that are better protected against BRD.

Middlemen should play a central role in information transmission (Brocklebank and Hobbs, 2004). They could also change their paradigm to better incorporate the risk of BRD associated with logistics. They could abandon the use of homogeneous weanling weight as a paramount criterion when constituting batches, and instead use the uniqueness of farms or origin. Having a less strict criterion regarding the homogeneity of weanling weight in a given batch could limit the lengths and number of intermediate steps before the fattening farm.

Finally, fatteners need to know the level of risk for a given batch of weanlings to better assess their quality. They could subsequently implement an appropriate prevention strategy and, in the best case avoid the systematic and preventive use of antibiotics.

The improvement of vertical coordination for economic and health purposes could be linked. Better vertical coordination in the young bulls' value chain might also improve the added value measured at the cow-calf producer's and at the fattening stage. Because Western France has cow-calf producers and fatteners in the same area, this region could serve as a trial site for new initiatives to improve vertical coordination and reduce animal transfers and mixing.

5. Conclusion

The geographic, logistic, and economic organisation of the young bulls' value chain has a paramount influence on the risks of BRD and preventive measures. To improve the latter, actions should thus focus primarily on suitable levers to improve the physical, information and monetary flows already existing in the young bulls' value chain.

A formal ban on preventive antibiotic use could be implemented by the French government and constitute a further restraint. This would threaten the current organisation of the young bulls' value chain and future profitability of this sector, thus compounding the need to improve BRD risk management in the young bulls' value chain.

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Annex

Table 16: Risk factors with an influence on BRD morbidity or mortality at the beginning of the fattening period

Factors	Risk factor observed	Number of observations (n animals)	Significant influence on BRD*	Detail of influence on BRD morbidity	Bibliographical source
Factors relative to weanlings before the fattening period					
Weight	Weight at the beginning of fattening	20 136	Morbidity	BRD risk significantly decreases with the weight	(Sanderson et al., 2008)
		288 388	Morbidity		(Cernicchiaro et al., 2012a)
Delay between weaning and transportation to fattening unit	0-1 scale: weaned or not weaned before the beginning of fattening	2 544	Morbidity	Weaning weanlings 10 or more days before the beginning of the fattening reduces BRD risk	(Faber et al., 1999)
	0-2 scale: weaned the day of fattening, 45 days before or 45 days before and vaccination	509	Morbidity		(Step et al., 2008)
BRD disease before weaning	0-2 scale: no previous BRD, 2 out of 8 calves with previous BRD, 5 out of 8 calves with previous BRD	240	None	Some contrasted results, but trend: having BRD before weaning increases BRD risk	(Bach et al., 2011)
Vaccination	0-2 scale of vaccination protocol	12 313	Morbidity	Vaccination significantly diminishes mortality, morbidity and treatment costs	(Joanne E Macartney et al., 2003)
		451	Morbidity		(John G Kirkpatrick et al., 2008)
		698	Morbidity		(Assié et al., 2009)
		16581 (herds)	Morbidity		(Gay and Barnouin, 2009)
Factors relative to intermediary phase (transportation, batching phase)					
Period of the year for the beginning of fattening	Month of the year	58 885	Mortality	Autumn and winter significantly increase BRD risk during batching of animals	(Ribble et al., 1995a)
		16 581	Morbidity		(Gay and Barnouin, 2009)
	Seasons of the year	14 601	Morbidity		(Cernicchiaro et al., 2012a)
Transportation	Distance of transfers (km)	45 253	None	Duration of transportation significantly increases BRD risk	(Ribble et al., 1995c)
		20 136	Morbidity		(Sanderson et al., 2008)
		14 601	None		(Cernicchiaro et al., 2012b)
	01-1 scale: duration of transfers <6h, >6h	35 131	None		(Hay et al., 2014)
Number of farms of origin in a batch	Number of farms of provenance	45 253	None	The increased heterogeneity of provenance in a batch significantly increases BRD risk	(Ribble et al., 1995b)
		20 136	Morbidity		(Sanderson et al., 2008)
		35 131	Morbidity		(Hay et al., 2014)

* Significant influence: $p<0.05$

Chapitre 2B : Intégration vertical et mesures de contrôle sanitaire dans la filière viande de jeune bovin de boucherie française

Note d'avancement : Ce chapitre de thèse a été soumis à Managerial and Decision Economics le 29 novembre 2017. Les reviewers ont rendu leurs retours le 18 mars 2018 avec des corrections majeures. Le papier a été resoumis le 21 juin 2018 dans la version ci-dessous.

Abstract

The organisation of the French young beef bull sector is complex. The more the animals are mixed and transported over long distances, the more likely they are to develop bovine respiratory disease (BRD). We aimed to distinguish the different governance schemes within the young bull sector. We then examined how such schemes might influence public health issues (BRD risk management, antibiotic use) and detected numerous vertical integration patterns. The "health issues" parameter was only rarely considered in transactions and was usually neglected by stakeholders. When vertical integration was strong (weak), the risk of BRD was low (high), which thus reflected an indirect effect on prevention measures and antibiotic use.

Key words

Vertical integration –Young bull sector –– Animal health control measures – Reduction of antibiotics use

JEL Codes D23, L14, Q13

1. Introduction

Bovine respiratory disease (BRD) is widespread in the young bull sector. Up to 80% of French young bull herds can develop the disease (Timsit et al., 2013). BRD triggers clinical signs in young bulls such as delayed growth and even death at the beginning of the fattening period[35] (Hay et al., 2016b). Systematic preventive antibiotic treatments are frequently prescribed to control BRD and prevent economic losses. However, antibiotic efficiency in the young bull sector is tending to decrease, due to the general overuse of antibiotics (Gautier-Bouchardon et al., 2014). This biological phenomenon is extensive and of growing concern worldwide (Laxminarayan et al., 2013; OECD, 2014). Reducing antibiotic use, to limit the spread of antimicrobial resistance, is thus of paramount importance for public health. Systematic preventive antibiotic treatments should therefore be stopped. However, public regulators and the sector's stakeholders need to know how to instigate a positive transition in the use of antibiotics to control BRD.

A new regulation in France could possibly prohibit any systematic preventive use of antibiotics. This regulation represents a risk for fatteners who would be directly and strongly impacted. Calf production (in farms raising cow-calves) occurs separately from the fattening of young bulls (in fattening units).

[35] Here, "young bulls" refers to 24-month old male beef bovines

This implies intermediary weanlings transactions[36] and increases the risk factors of BRD development (confinement, transport, stress, mixing of weanlings…). Middlemen[37] play a key role because they ensure the matching of supply and demand. Most cattle producers and middlemen are independent with few long-term contracts (less than 20% of the sector (Marty et al., 2015)). This lack of vertical integration considerably reduces the sharing of information between stakeholders and differs from the situation in other animal production sectors where market institutions with commercial long-term contractual agreements or even stronger vertical integration (e.g. pork production; broiler production) (Antoine et al., 2014) have been developed (Hendrikse, 2007). Many different types of vertical integration governance co-exist, ranging from spot market (livestock market) to vertical integration (breeder-fattener producers). This paper aims at exploring the link, if any, between the mode of vertical coordination and the probability of developing BRD disease by analysing the characteristics of the vertical organisation schemes operating in the young bull sector and how these might affect antibiotic use.

We first focussed on the different governance schemes observed during weanling marketing, to see how these could influence health issues and antibiotic use in young bulls. Our study is based on the Firm Boundaries literature initiated by Coase (1937) which has greatly influenced research trends in organisation economics. We then discuss the benefits and costs of improving vertical coordination schemes in relation to animal health. Vertical integration raises the issue of whether a given transaction should occur within or between two firms. Gibbons (2005) discussed the shared features, differences and complementarities of some of the proposed theories. The transaction cost theory mainly focuses on vertical integration as a way of avoiding ex-post haggling issues. Two other theories focus on ex-ante incentive alignments. In the property rights theory, efficient ex-ante bargaining determines each party's surplus share depending on asset ownership. The ex-ante investment decision is thus determined by the integration decision. The incentive-system theory orientates toward the multi-task incentive problem by providing incentives to employees[38]. Our aim was first to better understand the various organisation schemes in the agricultural sector, based on the firm boundary literature and, second, to interview economic actors in the young bull sector to see how the vertical governance patterns existing in this sector might influence BRD development and antibiotic use.

The semi-structured interviews revealed clear variations in the vertical integration patterns between cattle producers, depending on the stage of production (cow-calf producer or fattener) or on their specific assets. Animal health is mainly linked to quality issues, but the definition of quality by different stakeholders in the supply chain can vary considerably. Quality based on animal health can only be assessed if information about the weanlings' length of transportation, commingling within the batch, previous vaccination protocol) is transmitted along the supply chain. The vertical integration patterns in the young bull sector seem to influence both the transmission of information about BRD risk, and the BRD risk itself. This raises issues about how to implement better animal health management when communication of the required information is asymmetrical.

[36] Weanling refers to male beef calf between 5 to 9 months old.
[37] Middlemen is a generic term which includes all livestock traders in the sector.
[38] See Gibbons (2005) for a more detailed review.

This paper is divided into four sections. Section 2 reviews the literature on vertical coordination in the agricultural sector; Section 3 describes the general study design; Section 4 presents the results and discussion; Section 5 concludes.

2. Towards vertical integration in the agricultural sector?

Lafontaine and Slade (2007) reviewed empirical findings about the types of transactions that occur within a firm and the consequences of vertical integration decisions. They showed that specific human assets, specific physical assets, dedicated assets, geographic specificity and temporal specificity all had significant influence on increased vertical integration in a wide variety of industrial sectors. Complexity, which often refers to the heterogeneity of inputs or products, and/or uncertainty in addition to specific assets tends to encourage more ex-post renegotiation and opportunism. Empirical studies have revealed more mixed effects of complexity and uncertainty on the vertical governance patterns. We compare the results of empirical studies in agriculture with those detailed in this literature review.
We first present the influence of assets specificity on vertical integration, then the influence of uncertainty and risks on vertical integration, and finally the influence of complexity, quality and information asymmetry on vertical integration.

2.1. Positive influence of assets specificity on vertical integration in agriculture

The findings reported in the literature on the influence of assets specificity on vertical integration include human assets, physical assets, geographical specificity, temporal specificity, and dedicated assets.

Human assets consist of farmers' knowledge and skills (Ortmann and King, 2007). In the industrial sector, human assets are considered to have mostly a significant and positive influence on vertical integration (Lafontaine and Slade, 2007). Similar conclusions have been drawn in the agricultural sector with two studies showing a positive and significant effect (Fraser, 2005; Traversac et al., 2011). However, even if there is a positive, significant link between the farmers' level of education, or between the farmers' years of experience and vertical integration, the human assets in agriculture can also be used in other activities (Traversac et al., 2011). This could be particularly relevant in the French agricultural context where most farms exist in crop-livestock farming systems. The human asset specificity also depends on the farming activity and, for example, is greater for technical production sectors such as dairying than for poultry rearing.

Physical assets are of specific nature if they cannot be redeployed to alternative uses without losing productive value. In agriculture, specific assets are mostly related to investments in farm buildings. In industrial sectors, physical specific assets are usually considered to have a positive and significant influence on vertical integration (Lafontaine and Slade, 2007). Similar findings have been described for the agricultural sector with one study showing a positive, significant effect towards more upstream vertical integration (Boger, 2001) and other studies a positive effect towards more downstream vertical integration, significant or non-significant depending on the variable considered (Fernandez-Olmos et al., 2009; Pascucci et al., 2012). However, physical specific investments vary a lot between production sectors. For instance, a milking parlour is more specific than a poultry barn. Investments can also have a positive influence on vertical organisation even if they are not specific.

There is geographic(al) specificity if transport costs are high compared to the price of a given product. An increase in geographic specificity should increase the level of vertical integration. However, Lafontaine and Slade (2007) mentioned only one article that demonstrated a positive and significant effect of geographic specificity on vertical integration, in the coal and electricity sector. In their literature review, another paper showed a positive effect (inputs in the chemical products sector), and one showed a negative effect (manufacturing plants sector), but both effects were non-significant. To our knowledge, only one study has explicitly addressed the effects of geographic specificity on vertical integration in the agricultural sector and describes a positive effect (Pascucci et al., 2012). In the agricultural sector, transport costs can be high, and legal constraints might also add a limit to the long transport of live animals (duration, space, etc.). However, costs and legal constraints are highly dependent on the sector considered. For instance, transport costs and legal constraints are much higher for transporting horses than for transporting corn.

The temporal specificity of transactions has been introduced recently in the TCE and is a particularity of the agricultural sector (Ortmann and King, 2007). This element is relevant to sectors working with perishable products (e.g. fruits, meat, etc.), and takes the hold-up risk linked to temporal constraints into account. If one stakeholder in the transaction faces temporal constraints, the other might take the opportunity to renegotiate the transaction deal. More temporal specificity is thus in favour of vertical integration, both in the industrial sector (Lafontaine and Slade, 2007) and in the agricultural sector with two studies demonstrating significant positive effects (Fraser, 2005; Goodhue et al., 2003). However, temporal specificity can vary a lot depending on the agricultural product. This parameter is for instance more important in the poultry sector, where the production cycle is short (62 days) and poultry characteristics are highly standardised (size, weight), than in the corn production sector.

Dedicated assets are investments made for a particular supplier or buyer, which have no or less value outside this specific commercial relationship. Dedicated assets are conducive to improved vertical integration in the industrial sector (Lafontaine and Slade, 2007). In the agricultural sector one article also reported a significant positive effect (Fernandez-Olmos et al., 2009).

2.2. Paramount but contrasted influence of uncertainty and risks on vertical integration in the agricultural sector

Uncertainty and risks are high in agriculture (Hardaker, 2015). Uncertainty is linked to the characteristics of the exchanged products. Uncertainty cannot be measured or evaluated, whereas risk evaluates a possible loss. In agriculture, the risk for a given farm has been divided into five main types: production or yield risk (e.g. animal disease), human or personal risk (e.g. workplace accident), price or market risk (e.g. fluctuations in prices), financial risk (e.g. investment burden too high), and institutional risk (e.g. changes in regulations) (Hardaker, 2015).

The uncertainty of transactions can be linked to the behaviour of stakeholders or to the environment of the transactions, such as market fluctuations. Most empirical studies in diverse industrial and agricultural sectors revealed a significant positive effect of behavioural uncertainty on the level of vertical integration (Fernandez-Olmos et al., 2009; Lafontaine and Slade, 2007). However, two empirical articles showed a negative but non-significant effect of uncertainty in the industrial sector (Lafontaine and Slade, 2007), and one article showed a negative and significant effect of behavioural uncertainty on long-term relationships, and thus on vertical integration (Coronado et al., 2010). In this

case, the authors explained that stakeholders did not want to limit themselves with long-term contractual agreements. However, Coronado et al. (2010) did find a positive and significant influence of environmental uncertainty on vertical integration. In their meta-analysis, Chen et al. (2004) found that uncertainty in the manufacturing firms sector could sometimes support less vertical integration. In an uncertain context, there would be fewer monetary risks in having many marketing channels for selling a single product (Chen et al., 2004), which would favour spot markets. This reluctance to develop long-term relationships can be enhanced as uncertain contexts often have negative effects on trust. However, trust is a very important element when developing long-term relationships (Geyskens et al., 1998). The level of uncertainty associated with human behaviour is dependent on the bargaining power between stakeholders and on a possible hold-up by one of the stakeholders. In agricultural sectors, this can vary considerably depending on the type of production and general organisation of the sector.

Uncertainty is also linked to environmental uncertainty (market fluctuation (price and volume), climate, etc.). Environmental uncertainty associated with meteorological changes is important in agriculture, especially as the products are of biological nature and susceptible to diseases and weather conditions. This uncertainty is higher than in most industrial sectors. The market fluctuation uncertainty depends on seasonal variations that can be predicted, but also on international prices changes that are partly unpredictable. As the environmental uncertainty level increases, the effects on vertical integration in agricultural and industrial sectors are positive (Lafontaine and Slade, 2007) .

When the exchanges involve live animals, uncertainty is of paramount importance. Indeed, the future potential growth of animals is uncertain and is dependent on past, present and future events, such as a disease.

An increased level of risk is in favour of vertical integration, both in the industrial and agricultural sectors (Hernandez-Espallardo et al., 2012; Lafontaine and Slade, 2007). This effect is positive and significant in the agricultural sector.

The risk linked to production in the agricultural sector is high and intrinsic to the nature of the products: animal and plant products might suffer from a disease outbreak, either due to external contamination, or because of an internal disease. Both elements should lead to the development of vertical integration in the agricultural sector.

In agriculture, the farmers' market risk is increasing due to greater price fluctuations. Market fluctuations depend on the boosted globalisation of markets and industrialisation. International markets vary a lot on a monthly and yearly basis, thereby increasing the risks incurred by farmers (Meuwissen et al., 2001).

The financial risk can be considered as a trade-off between investments and the market risks sector (Traversac et al., 2011). The importance of specific assets in agriculture combined with the importance of market risks should be in favour of vertical integration because market fluctuations endanger the returns on investments (Fernandez-Olmos et al., 2009). However, financial risk also varies considerably on an individual basis, depending on the farming system and linked investments.

2.3. Positive but varying influence of complexity, quality and information asymmetry on vertical integration in the agricultural sector

In agriculture, value creation through product differentiation is a crucial issue. Horizontal differentiation of products is linked to the co-existence on markets of a wide variety of the same types of products, but presenting different characteristics.

As the horizontal differentiation of products increases, complexity increases too. In a given sector, complexity is linked to difficulties in handling a wide number of intermediate production steps and routine organisation to produce a product (Mesquita and Brush, 2008). Complexity can also be approximated by the heterogeneity of a given product (Lafontaine and Slade, 2007). Most of the empirical studies (8) in various industrial sectors revealed a significant positive effect of complexity on vertical integration. One study, however, showed a significant negative effect, and another demonstrated a U-shaped effect (Lafontaine and Slade, 2007). Complexity (as well as uncertainty) both complicate the building of complete long-term contracts and their reinforcement over time (Lafontaine and Slade, 2007). As complexity (and uncertainty) increase, the incompleteness of long-term contractual agreements also increases. This could explain the contrasted influence of complexity on vertical integration. We did not find any empirical analysis of the effect of complexity on vertical integration in the agricultural sector. We can assume, however, that such complexity might vary a lot depending on the sector. For example, both cereal and poultry production are usually highly standardised. In contrast, the diversity of animals in the beef sector is large and depends on the breed, age, weight, etc.

The vertical differentiation of products depends on the succession of stakeholders involved in achieving high quality products in the value chain. Product quality is therefore a very important characteristic in TCE as it interacts with vertical integration choices (Goodhue et al., 2003). Quality refers to the level of desirable characteristics of a product. The definition of quality usually enjoys a consensus among stakeholders, who agree to pay a premium for quality. Goodhue et al. showed that the level of product quality has a significant positive influence on vertical integration in the agricultural sector. Fernandez-Olmos et al. demonstrated a significant positive influence of quality for high added value products, but a negative non-significant influence of quality for low added value products (Fernandez-Olmos et al., 2009). Fraser reported a non-significant negative effect (Fraser, 2005). The measurability of product quality in agriculture varies across sectors. For example, animal weight could be a good proxy for estimating hog quality (Boger, 2001), but is not sufficient. Non-observable or measurable attributes such as meat quality are only estimated after the transaction. In addition, quality in the agricultural sector is also dependent on random effects (Boger, 2001; Hernandez-Espallardo et al., 2012). Random effects (disease, feed nutritional values and environmental conditions, for example) are of particular importance when exchanging live products, such as animals.

As quality interacts with the vertical integration of stakeholders, information flows along the value chain are essential to trace and control for quality attributes. If the quality is difficult to measure, having premium prices for quality might be costly to implement and control (Goodhue et al., 2003). In this case, the system would tend to favour more vertical integration and long-term relationships to insure the level of quality (Goodhue et al., 2003; Raynaud et al., 2005). If quality is difficult to measure, an asymmetry of information might occur which can lead to adverse selection effects (Akerlof, 1970). Coronado et al. (2010) showed that the efficiency of the value chain and products quality were increased by improved information exchange in the agricultural sector.

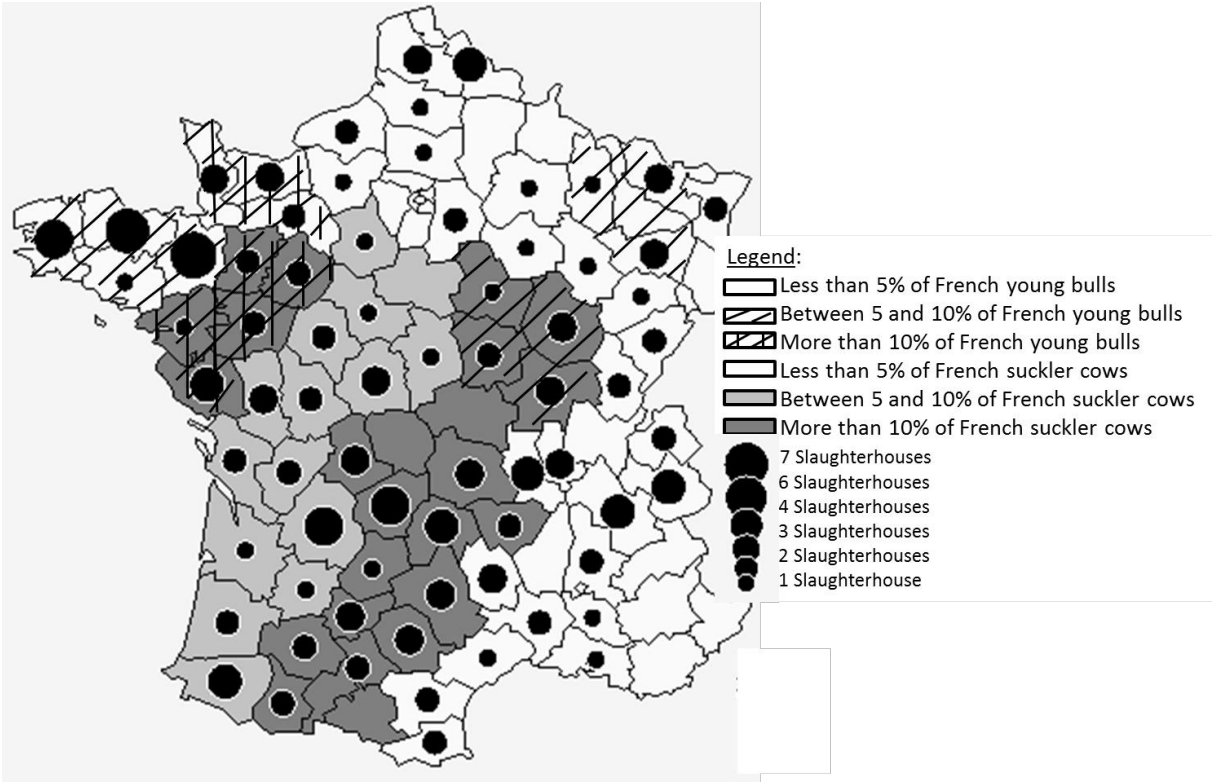
3. General study design

3.1. General context of the French young beef bulls sector

The young bull sector is dedicated to beef production. When estimated in Livestock units (LU), France is ranked first in Europe (E-27) for raising young bulls (4.1 million beef cows)[39].

The young bull sector produces two kinds of animals: weanlings (male beef calves between 6 to 8 months old) and young bulls (male beef less than 24 months old). Half the weanlings are exported, mostly to Italy (74% in volume) and Spain (12% in volume)[40]. The other half is fattened in France. However, the majority of these young bulls is not destined for French consumers because of the latter's preference for redder meat. Most young bull meat is exported to Italy, Germany, Spain and Greece. There is competition for price and volume on the markets for both weanlings and young bulls, but no possibility for a quality premium.

Approximately 93 000 farms have more than 5 suckling cows in France[41]. Many different stakeholders are involved in the sector because they raise, sell or fatten weanlings (Timsit et al., 2011). Coordination in this sector is poor and is not changing. The cattle producers are independent and own their animals. This differs from other meat production sectors (poultry, pork), where the importance of the spot market has decreased considerably (Hendrikse, 2007) and the main stakeholders are coordinated within cooperatives and investor-owned firms (S. James et al., 2011). The coexistence of spot markets and long-term contracts is a characteristic of the bovine sector (Hendrikse, 2007).The use of long-term contracts is particularly rare (less than 20%) in the young bull sector (Marty et al., 2015).



[39] Idele, Dépliant Chiffres clés 2016.
[40] Idele, Dépliant Chiffres clés 2016.
[41] Idele, Dépliant Chiffres clés 2016.

Figure 8: Distribution of cow-calf producing units, young bulls farms and slaughterhouses in France (Source: Idele, Chiffres clés, 2016)

Table 17: Distribution of major stakeholders upstream in the young bulls sector (Source: Idele, Chiffres clés, 2016)

Cow-calf producer and fattener	Cow-calf producer	Intermediaries*		Fattener
		Independent middlemen business	Producers' organisation	
11 900	49 700	1300	117	12 700

*Number of intermediaries is underestimated because independent middlemen businesses often employ more than one middleman, and producers' organisations always employ more than one middleman

Different systems of vertical integration coexist in the young bull sector. First, young bulls might be raised until slaughter in the same farm (cow-calf and fattening system Figure 2, line ①). This production system is found in 11 900 farms (Table 17) and, because the cow-calf producing phase is integrated by the fatteners and corresponds to perfect vertical integration, it was used as our baseline. Second, young bulls might be produced at a cow-calf producer unit and then sold at 7 to 9 months (weanlings) to a fattener. There are 49 700 cow-calf producing farms, mostly located in Central France, and 12 700 fattening farms in Western and Eastern France (Figure 8, Table 17). The transaction between cow-calf producer and fattener can be done without intermediaries (Figure 9 line ②). However, in most cases, the transaction involves a middleman. Middlemen play a paramount role as they match the cow-calf producers' offer with the fatteners' demand. This demand is quite regular and the fattening process more standardised. Batches of 8 to 12 weanlings are required for fattening so buyers look for weanlings with the same body condition and size. In doing so, they can fatten all their weanlings during the same period and optimise the occupation of their buildings more easily. However, the cow-calf producers' supply is more irregular, depending on the season and varying on a weekly basis. First, cow mating is naturally seasonal and the weanlings market tends to be saturated in autumn. Second, most cows are still mated by natural servicing. Synchronised breeding programs are therefore difficult to implement. Consequently, cow-calf producers rarely sell ten weanlings at the same sale, but more often propose 2 to 3 weanlings with similar characteristics (age, weight, and size). Most commercial structures have a sorting centre for gathering weanlings and reorganising the batches. Middlemen can handle the logistic issues thanks to these sorting centres.

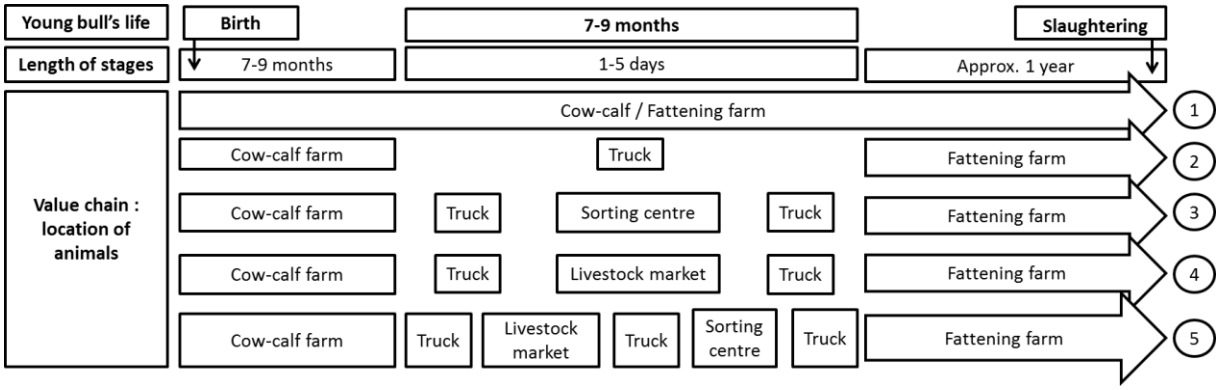


Figure 9: Existing vertical commercial routes in the young bulls sectors from cow-calf production to fattening (source: authors' elaboration)

The differences between the producers' supply and the fatteners' demand explain the logistic issues in this sector and the role played by middlemen. To match the demand of fatteners with the supply from cow-calf producers, middlemen buy up various weanlings and subsequently attempt to fit this demand. They have several weanling suppliers: cow-calf producers, livestock markets and other middlemen. There are 47 livestock markets in France[42]. Depending on the demand, they are sometimes left with unsold weanlings. They may then sell these again to livestock markets or to other middlemen. This "matching process" occurs on a weekly basis and explains the diversity of stakeholders (Timsit et al., 2011) and the complexity of the different commercial routes (Figure 9, lines ③, ④, and ⑤). Very few weanlings are sold under long-term contractual agreement.

3.2. Selection of interviewees, and analytical method

We chose a qualitative method because of the great complexity of the young bull sector and the lack of precise knowledge about its functioning. The semi-structured interview approach is designed to describe a wide range of possible circumstances regarding a certain field, rather than to evaluate a question in a quantitative and representative way (Kvale, 1996; Sivertsson and Tell, 2015). This qualitative method allows a wide range of topics to be taken into account.

Qualitative semi-structured interviews were carried out with cattle producers (24) and other major stakeholders in the young beef bull sector (30), such as the bosses of middlemen or the managers of meat producers' unions (Appendix 1 for more details). Stakeholders were located in the two main production regions of Central and Western France. Field observations were also carried out (6). All these elements were then combined to describe the determinants of transaction costs and to construct and interpret a diagram of the existing vertical integration patterns.

The length of the interview (approximately two hours) was conducive to more authentic discussion, even if an ex-post re-organisation of personal histories is always possible (Brinkmann and S. Kvale, 2015). Interviews were based on four main questions: (i) general presentation of personal career and professional structure, (ii) everyday interaction with other stakeholders in the sector, (iii) practices regarding health management and antibiotic use, (iv) understanding of current changes, fears and motivation linked to future prospects.

A grid was drawn up to analyse the different interviews. When the interviewees were cattle producers, their descriptions of the different determinants of transaction costs (specificity of assets, market risks, complexity, uncertainty, information availability, etc.), and which vertical integration pattern they chose, were directly apparent.

When the interviewees were stakeholders, their descriptions of the sector regarding the different determinants of transaction costs, and their global depictions of the vertical integration patterns in the sector, were examined.

A more specific analysis of how the interviewees considered animal health and BRD issues was also carried out and integrated into our analysis of governance schemes. By combining these different elements, we were able to construct a general picture of the observed diversity of transaction governance, and its influence on animal health management.

[42] Source: FMBV

4. Results

The governance schemes in the young bull sector exhibit several main patterns, ranging from highly to poorly integrated systems: (i) total vertical integration, (ii) written long-term contractual agreement, renewable on a yearly basis or for a longer period, (iii) oral commitments also called relational contracts, and (iv) spot markets.

The types of coordination differ between cow-calf and fattener farms. Almost all cow-calf producers sell their weanlings through less coordinated marketing channels such as spot markets (livestock markets and/or middlemen with no long-term contracts). Two exceptions are breeder-fattener producers, and cow-calf producers who sell their products directly to a fattener through relational contracts. Fatteners can implement any of these coordination patterns.

4.1. Quality and information asymmetry at the core of vertical integration patterns

The major issues in the sector seemed to be information asymmetry and quality. The information asymmetries were strong and apparently linked to poor vertical integration. Measurements of quality by stakeholders can vary considerably and, depending on the criterion, be difficult to assess. Both issues (information and quality) are jointly evolving. Most transactions for the transfer of weanlings from cow-calf producers to fatteners, involve middlemen. Their role in matching the offer by cow-calf producers with the demand by fatteners is paramount. The cow-calf producers' offer mainly consists of small batches of weanlings (1 to 10), whereas the fattener's demand is more standardised i.e. batches of 10 to 15 weanlings of the same weight. Quality attributes for transactions include purchase attributes, observable before purchase (weight, age, homogeneity of batches), and credence attributes, linked to health status and non-observable even after purchase (length of transportation before fattening, commingling, vaccination protocol implemented). Direct sell (or direct supply) is often too costly and time consuming for cattle producers. Middle men therefore gather weanlings from different cow-calf farms, sort them into different batches, and then send them to the fatteners depending on the demand (weanling weight, age). As the weanlings are transported and mixed, this process therefore has consequences on the weanlings' BRD risk and the possibilities of managing this risk.

4.1.1. Influence of information asymmetries on animal health attributes

One important hypothesis, based on the interviews and underlying the following analysis, is that cow-calf producers and fatteners develop different farming systems, in different geographic areas, under different constraints, and in different economic environments, etc. which result in different transaction costs.

Cow-calf producers mostly sell on spot markets and have no long-term contractual agreement. The observed low level of vertical integration was mostly influenced by the complexity of the weanlings' market. Cow-calf producers have limited specific assets and no price premium for credence attributes of quality and complexity. The whole picture is thus conducive to spot markets. The two exceptions are where cow-calf producers sell weanlings through relational contracts or through a written long-term contract. In certain forms of relational or written long-term contracts, the transactions are associated with a price premium for a quality attribute such as the early vaccination of young bulls. The investments in a vaccination protocol (biomedical material, worktime, etc.) are compensated in this price premium through a more coordinated form of transaction. In the case of a relational contract, we observed a quasi-direct contact between the cow-calf producer and the fattener. The relationship

is initiated either by the cow-calf producer or the fattener, and information asymmetry is reduced to a minimum. In the case of written long-term contracts, the relationship is initiated by middlemen. Information asymmetries are reduced to allow the valuation of a given quality attribute, but information asymmetry regarding credence attributes is still large and commonly neglected by stakeholders.
Vertical integration might be affected by uncertainty and risk but cow-calf producers can often mitigate such risks because weanlings are not the only type of product sold by the farm. In addition, they receive substantial financial support from the Common Agricultural Policy (CAP), which can be as high as 33% of the farm income.[43] Financial support is linked to the geographic location (systems with a natural handicap), or the nature of production (support for extensive systems, support for suckler cows, etc.). This tempers the risks linked to market fluctuations.

Fatteners sell under all forms of vertical integration, from spot market to perfect vertical integration, in the case of cow-calf and fattening farms, sometimes using different forms of vertical integration simultaneously. This diversity of levels of vertical integration is mostly influenced by the enormous information asymmetry observed within the sector. Information asymmetry diminishes as the level of vertical integration increases. Information asymmetry is non-existent in the case of total integration, and considerably diminished in the case of a direct agreement between a cow-calf producer and a fattener. Nevertheless, some information is lost even in the case of a long-term written contractual agreement. The information (vaccination, animal feed, past diseases, etc.), exists but is not transmitted. Some cow-calf producers did implement a proper vaccination protocol to protect animals against BRD at the beginning of the fattening period, but the information was not demanded by or transmitted to middlemen. In all cases, the greatest asymmetry and loss of information coincided with the intervention of middlemen. They are furthermore of paramount importance in dealing with the geographic distribution of cattle producers and with the complexity of the weanling offer.
Other transaction costs also influence the fatteners' choice of vertical integration level. These depend on the characteristics of individual assets, such as the level of temporal specificity (e.g. temporal specificity might be higher in the case of reduced animal feed stock, or maximised use of the fattening unit), the level of dedicated assets (e.g. after the construction of a new fattening barn), and the uncertainty and risk linked to market fluctuations. As the costs of all these factors increase for fatteners, the level of vertical integration also increases. For example, certain forms of written long-term contracts allow both the dedicated assets (through cash-flow advance) and the market risks (agreement on prices, investments), etc. to be taken into account. Fatteners often mitigate the market risk by developing different agricultural activities so that fattening only accounts for part of their revenue.

4.1.2. Stakeholders diversely define quality in the young bull sector

This horizontal and vertical differentiation of the young bull sector affects vertical integration. Horizontal differentiation deals more with the complexity of the sector. The weanlings sold on the market are very diverse, depending on different attributes such as breed, weight, and notifiable disease status. Vertical differentiation has more to do with quality and information asymmetry.

[43] Prices and margins observatory (*Observatoire de la formation des prix et des marges*), 2015.

The weanling market exhibits great horizontal differentiation. This offer diversity, considered as a high level of complexity, mirrors the diversity of the demand. For example, most French fatteners tend to demand 'light' weanlings, whereas most Italian fatteners prefer heavier weanlings. Weanlings can be sold and bought on the market between 6 and 12 months of age. A cow-calf producer can extend the period prior to selling at minimal cost as, during that period, weanlings graze and eat little expensive feed. Some French fatteners ask for officially-certified disease-free animals, others do not require any certification of this nature. There is no official price premium on the quotation linked to these characteristics and the system tends to be based on individual preferences. This broad horizontal differentiation introduces a high level of complexity into the weanling market. This might have a negative effect on the level of coordination, as cow-calf producers have numerous options for selling their weanlings. This has rarely been reported in the literature as vertical integration usually increases with high level of complexity. However, in the young bull sector, the level of complexity is mitigated by the considerable outside opportunities offered to cow-calf producers and the low level of additional cost to keep weanlings for longer on the farm. A wide variety of marketing channels exists. Cow-calf producers (fatteners) can sell (buy) animals through middlemen, livestock markets, or directly to fatteners (cow-calf producers). And those channels are not exclusive.

Vertical differentiation involves the different stakeholders in a vertical value chain and is linked to the levels of quality and associated with price premiums. However, our observations of the weanlings' market and the stakeholders' interviews revealed 1) very diverse criteria associated with a definition of quality, furthermore difficult to observe *ex-ante*, 2) no price premium associated with the quality of young bulls, some examples apart, but accounting for a negligible volume. For example, some middlemen value the vaccination against BRD implemented by cow-calf producers before shipping of weanlings and manage to get a premium when selling such weanlings to fatteners.

The quality of the animals exchanged in the young bull sector (weanlings or batches) is not easily measured. Indeed, as young bulls are live products that are to undergo fattening, their quality depends on their ability to grow quickly at minimum cost. Weanlings' characteristics (past disease events, animal feed, etc.) at a given time *t* determine their future and good performances at a given time *t+1*. However, these characteristics are often non-observable.

The choice of attributes to approximate "quality" varied a lot depending on the stakeholders' point of view (cow-calf producer, middleman, fattener, or veterinarian) (Table 18). Cow-calf producers choose criteria that minimise the costs of producing and selling weanlings. Middlemen and fatteners prefer criteria that reflect batch homogeneity. Their aim will be to buy or sell the whole batch at the same time, with no young bulls left in half-empty barns until they reach the optimal weight for slaughter. Except for regulatory constraints and official vaccination (Table 18), all stakeholders, except veterinarians, neglect health and logistical criteria such as the number of farms of origin and the duration of transportation. Because they focus on attributes associated with homogeneous batch size, middlemen and fatteners neglect health characteristics (e.g. vaccination against BRD) as well as logistical characteristics. This choice might have the opposite effect to the one expected as it leads to size heterogeneity within the batches during the fattening period. This effect is reduced when the batches include weanlings of heterogeneous size at the beginning of fattening but come from the same cow-calf producing unit. In this case, size heterogeneity might be reduced during the fattening period. In addition, the quality criteria that are currently chosen to constitute weanlings batches increase the risk of developing BRD (Ackermann et al., 2010; Assié et al., 2009; Sanderson et al., 2008), and thus are conducive to the systematic and preventive use of antibiotics.

Table 18: Different stakeholders' points of view, collected during semi-structured interviews, regarding the preferred and usual criterion to define the quality of weanlings (W) or weanlings' batch (B)

Stakeholders' points of view on quality attributes required*	Cow-calf producer	Middle men	Fattener	Veterinarian
Zootechnical characteristics				
Uniformity (size) of batches		**B**	**B**	
Breed	**W**	W - B	W - B	
Weight	**W**	**W - B**	**W - B**	W - B
Potential daily weight gain		W - B	W - B	W - B
Beef conformation		W - B	W - B	
Logistical characteristic				
Farm of origin		W		
Number of farms of origin				**B**
Number of transitional intermediaries				**W - B**
Duration of transportation				**W - B**
Health characteristics				
Official vaccination	**W**	**W - B**	B	W - B
Past disease events				B
Health prevention (antibiotics)		W - B	B	W - B
Health prevention (vaccination against BRD pathogens)		W - B	W - B	**W - B**
Health prevention (Anthelmintic treatments)		W - B	W - B	**W - B**

*Highlighted boxes correspond to the opinion of stakeholders regarding the most important points to define quality or desirable attributes of weanlings or weanling batches.

When cow-calf producers sell weanlings, there is rarely a price premium (except for some long-term or relational contracts), even though the market prices can differ depending on the breed (up to 20%, but usually less than 10%). Despite the apparent price uniformity and the disparate quality criterion, a mixed formal and informal system of quality recognition has been developed on markets (and adapted according to the cow-calf producer, middlemen and fatteners' criteria). Each week, livestock markets provide a formal quotation for weanlings depending on their breed, age and weight which serves as a benchmark for price negotiations during the transactions. An informal system then allows a price discussion based on weanling appearance, age, batch uniformity, and other criteria cited in Table 18. However, despite this mixed formal and informal price fixation, there is no clear price premium for the quality criteria. This does not encourage cow-calf producers to improve the quality of their weanlings.

4.1.3. Information asymmetry and quality

Both the lack of vertical integration and valuation of the quality of weanlings or weanling batches are strongly linked to the information asymmetry. The level of information transfer within the sector decreases abruptly downstream from the cow-calf producers. The French and European regulatory frameworks impose a traceability for live animals, but the information reported on the ID papers is limited to notifiable diseases and the ID number of the farm of origin.

The cow-calf producer has information on each animal's health status (official and personal records of disease events and on-farm medical treatments), its age and weight. The first intermediary can be aware of those events if he knows the cow-calf producer well enough. But as soon as the weanling is sold by the cow-calf producer, the information transferred is only the one written on the two official

documents i.e. (i) the passport, just indicates the identity of the animal (identification number, farm of origin, age) and (ii) the back of the passport or green card, just indicates the health status of the last farm which housed the animal (but only for notifiable diseases) and all the past owners of the animal. Both documents are compulsory for every transaction. The weight of the weanling is also roughly estimated by stakeholders or precisely measured with a balance. The age/weight ratio provides a rough idea of the good health (present and/or past) of the weanling. Then, at each subsequent transaction, there is a loss of information linked to a loss of efficiency.
However, the development of an efficient upstream-to-downstream information flow within the sector is hindered by two major limitations. First, when fatteners conclude the transaction to buy weanlings, they only have access to information about weight, but none of the above-mentioned elements. Second, the above-mentioned elements available ex-post (written on official documents and weight) are not precise enough to predict the animal's subsequent performance or the risk of it developing BRD. Factors such as logistical or health characteristics need to be considered to reduce this risk.
The information asymmetry issue increases the difficulty of collecting information about animal quality and properly highlighting the quality attributes of weanlings in transaction negotiations.

Two exceptions were reported. Both used additional criteria to define quality and endorsed quality with a price premium (given to cow-calf producers and paid by fatteners). The first one took the implementation of a BRD vaccination protocol into account and compensated this investment through a price premium. This was formalised in a long-term written contract offered by a cooperative. The second one took the vaccination protocol, the farm of origin and the number of farms of origin into account. This was not formalised but established through an oral long-term contract by middlemen for a niche fattening market (Holland, Belgium, Northern France).

4.2. Influence of vertical governances on animal health issues and systematic preventive antibiotic use

Stakeholders in the young bull sector need to coordinate their actions if they are to be more productive than if working alone. Indeed, although the performances of young bulls during the fattening period depend on the fatteners' know-how, they also depend on the way the weanlings were raised. A weanling's history, from birth to the beginning of fattening, will include (i) ease of birth, feeding practices, vaccination, disease events (diarrhoea, BRD, etc.) at the cow-calf producer's farm and (ii) duration of transportation, number of mixes of weanlings, number of intermediaries during the transfers involving middlemen. We define these points as the quality attributes of weanlings. Thus, in the current situation, the vertical organisation of the young bull sector is making the fattener technically interdependent on upstream portions of the sector.

Animal quality is best taken into consideration in the most integrated vertical integration system (Figure 9 line ①), as there is no transporting, no mixing of weanlings and no intermediary. In most of the other vertical integration systems, the risks of BRD are increased due to animal transportation and mixing (Figure 9 lines ②, ③, ④, and ⑤). When the risks of BRD are examined, the technical interdependency of the fattener is particularly strong (Table 19). Indeed, the distribution of risk between the various stakeholders is very unequal. The risk of BRD development only affects the fatteners. However, numerous mixings of weanlings are involved in the present upstream vertical organisation of the young bull sector. Mixing of weanlings and long transportations promote bovine

respiratory diseases (BRD) because they permit microbial exchanges and involve confinement and stress (eg. Ackermann et al., 2010; Assié et al., 2009; Sanderson et al., 2008). The longer the exchanges, the greater the risks of BRD development. Microbial exchanges are particularly rife in sorting centres and livestock markets. In fattening units, the greater the number of cow-calf farms providing the weanlings in a given batch, the greater the risk of developing clinical BRD. If exchanges of weanlings and transport over long distances are involved, the risk of BRD development can be as high as 85%.

The cost of BRD can be a huge burden for fatteners (reduction in yields, death of weanlings, etc.). To control the important risk of BRD development at minimum cost, fatteners systematically administer a preventive antibiotics treatment just before the riskiest period, i.e. the first fifteen days of fattening (Figure 10). The systematic preventive use of antibiotics is easily implemented and the cost-benefit ratio is good. Antibiotics thus have a particular economic role in the vertical organisation of the young bull sector, as they almost erase the technical dependency of fatteners on the upstream portion of this sector.

However, from a public health point of view, the systematic preventive use of antibiotics needs to be reduced. Regarding the economics of public goods, antibiotics are considered as "impure" goods as they have both private and public value (Smale et al., 2004). When fatteners use antibiotics, they do it for a private purpose: to prevent the development of BRD or to heal the weanlings. They expect the antibiotic treatment to be efficient and to generate profit in the short-term. But at the same time, as fatteners use antibiotics, they are also eroding future antibiotic efficiency. Indeed, antibiotic use generates antibiotic resistance in the treated animal, on the farm and on a larger scale. Thus antibiotic resistance and antibiotic use have a public value, an insurance that future generations will have a useful and protective tool for managing animal and human health (Smale et al., 2004). So, regarding the issue of antibiotic use, fatteners face a social dilemma as their personal interest is opposed to the collective interest (Abele et al., 2010).

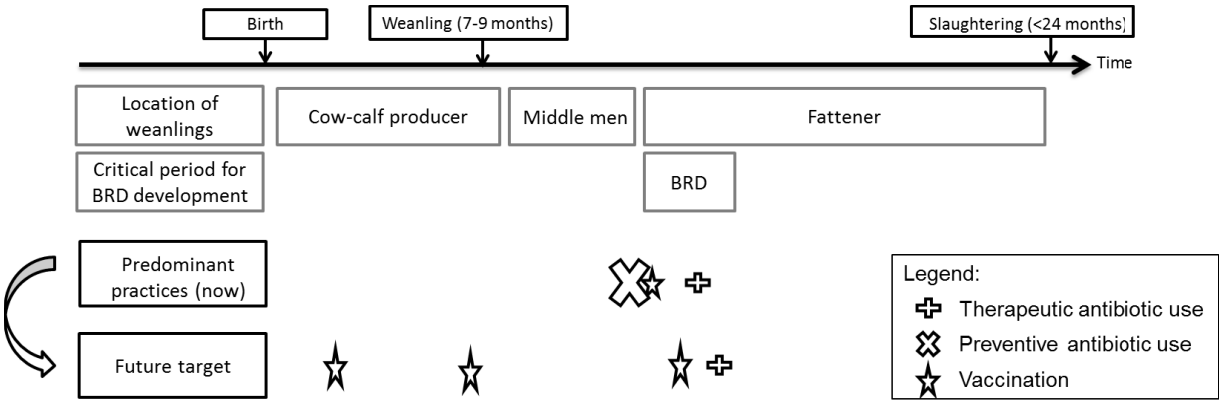


Figure 10: Principal strategies in medical control of BRD linked to the vertical integration in the young bulls' sector (source: author's elaboration)

Table 19 shows that the vertical integration pattern influences the quality attributes of weanling batches. Zootechnical batch characteristics might vary regardless of this vertical integration pattern. Conversely, logistical, and health characteristics are more strongly impacted in the case of high or low levels of vertical integration. The most efficient situation is one in which there is no transfer and the weanlings are fattened in the cow-calf producing farm (Figure 9, line ①). However, if this is not possible (limited size of the farm, limited animal feed producing capacities, geographic area, etc.), the

second-best option is the one involving direct transfers from the cow-calf producer to the fattener (Figure 9, line ②).

As the quality attributes of weanling batches influence the level of BRD risk and the possible measures required to prevent BRD, the level of vertical integration also indirectly influences the level of BRD risk and the choice of medical preventive measures (Table 19). The quality of weanling batches is globally improved for most integrated transactions (vertical integration, and direct transfers of weanlings). In these situations, the risk of BRD therefore decreases, which makes the systematic and preventive use of antibiotics less necessary.

Table 19: Quality attributes of weanling batches and their effects on BRD risk and the systematic preventive use of antibiotics depending on vertical integration patterns (source: authors' elaboration)

	Spot market	**Oral commitment (direct) to farmer**	**Oral commitment to middle men**	**Written contract**	**Vertical integration (cow-calf producer and fattener)**
Quality attributes of weanling batches					
Zootechnical characteristics	Medium or Good				
Logistical characteristics	Bad	Good	Bad or medium		Very good
Health characteristics	Bad	Medium to good	Bad or medium		Very good
Consequences of quality attributes on BRD risk and systematic, preventive use of antibiotics					
BRD Risk	Very high	Medium to small	Medium to high		Small
Systematic and preventive antibiotic use	Very likely	Unlikely	Likely		Very unlikely

In addition, in most cases, as the level of vertical integration increases, the efficient transmission of information between stakeholders also increases. This in turn increases the likelihood of valuation and the implementation of good vaccine protocols to protect weanlings at the beginning of the fattening period. The most integrated system (Figure 9, line ①) is again the best system for information transmission as the same person is usually doing both the cow-calf producing and fattening phases. In the case of a high level of vertical integration, this is an additional element that allows the reduction of systematic and preventive antibiotic use. However, the best two vertical integration patterns for reducing systematic and preventive antibiotic use, (namely Figure 9 line ①: perfect integration, or Figure 9 line ②: direct weanlings' transfer) are rarely observed in the field due to the complexity of the sector, and because the upstream and downstream portions of the sector are physically and geographically separated. Information transmission can be observed in the case of oral commitment or even oral commitment to middlemen. However, this only exists in a few situations when middlemen take the health attributes of weanlings into consideration. There are no official systems to implement the traceability of weanlings' origin or control of weanling vaccination. Some private initiatives have developed guaranties, but only for a limited volume of transactions.

5. Discussion and conclusion

We describe here the context of the existence of multiple vertical integration patterns in the French mature young bull sector and their influence on BRD risk management in weanlings. Our analysis shows that the level of vertical organisation has a direct influence on BRD risks and antibiotic use at the beginning of the fattening period. From a technical point of view, the risk of BRD and at the same time, the systematic preventive use of antibiotics could be diminished by implementing early vaccination, less animal mixing, and reducing the duration of transfers (Figure 10). From an economic point of view, this improvement could be linked to better information transmission and to quality valuation in the different governance of transactions. This tends to confirm an empirical study by Paulraj et al. (2008), which revealed a positive correlation between good information exchange and performance. However, our interview-based hypothesis needs to be further tested on a larger scale.

Our findings are coherent with the economics literature on firm boundary. The complexity of the weanlings' market and the orientation of cow-calf producers toward spot markets accords with empirical studies (Coronado et al., 2010). Cow-calf producers are not constrained by long-term contractual agreements. This enables them to sell weanlings through numerous marketing channels and to mitigate market risks (Chen et al., 2004). The behavioural uncertainty of cow-calf producers might also have negative effects on trust, which can be crucial when developing long-term relationships (Geyskens et al., 1998).

The lack of information transmission between stakeholders in the supply chain, and the absence of quality-based price premiums does not encourage an improvement of quality and investment by cow-calf producers. Product quality is either poorly defined or ignored in transactions. This is further enhanced by the fact that improvement of weanling quality upstream in the sector is not promoted by the demand broadcast by the fatteners. As a consequence, the cow-calf producers compete over volumes and prices, and less coordinated patterns are logically preferred (Boger, 2001). However, with short-term relationships are less likely to lead to a good collaborative transmission of information (Paulraj et al., 2008). Improving the system of information transfer in the young bull sector could therefore serve as an important lever to improve economic performance and to meet public health requirements. The public authorities could also set up systems to guarantee the implementation of preventive practices to control BRD, such as early vaccination. At present, the green card provides a minimum level of information regarding the weanling but could also include additional items and more extensive data. A good level of traceability is already being developed in the agronomic food sector.

The vertical governance apparent in the young bull sector shows that BRD risks are high at the beginning of the fattening period which often leads to a systematic and preventive use of antibiotics by the fatteners. However, this vertical integration and the associated technical practices could be threatened by an institutional policy. Indeed, the French Ministry of Agriculture has already introduced a national plan known as "EcoAntibio". During the first phase (2012-2017), and amongst other things, the French government enforced a stronger regulation of antibiotic use to accompany antibiotic reduction. During the second phase of the plan (2017-2021), an additional regulation could possibly ban the systematic and preventive use of antibiotics. This would threaten fatteners who use antibiotics in this way to protect weanlings against the very likely risk of BRD linked to weanling transfers and mixing upstream in the sector. In the present system, a ban on preventive and systematic antibiotic use could seriously burden the fatteners' income and the whole vertical governance in general. In the case of such a regulation, this vertical governance needs to be rethought by the entire sector. For

example, the improvement of information regarding batch quality could be very important and linked to price premiums, for which the fatteners could agree to pay. Having better information about batch quality could also reduce the risk and uncertainty linked to health issues.

Appendix 1

Table 20: Semi-structured interviews and field observations

Profession	Number, of interviews / field observations	Depending institution
Semi-structured interviews		
Cow-calf producer* **	7	Cooperative and independent
Breeder-fattener* **	12	Cooperative and independent
Fattener* **	5	Cooperative and independent
Middle men* **	10	Cooperative and independent
Farm advisors*	4	Cooperative
Veterinarians* **	8	Cooperative and liberal
Middle men superiors*	3	POC and PONC
Chamber of Agriculture*	1	-
Meat producers' Union*	1	-
Slaughterhouse director*	1	-
Senior Official**	2	French Ministry of Agriculture
Field observations		
Specialized fattening units*	4 (one day)	-
Livestock Market* **	2 (one day each)	-
Sorting centre*	2 (2 hours each)	Cooperative

Regions considered: *Western France; ** National; ***Western France and Central France

Appendix 2

Table 21: Observed transaction costs of cow-calf producers on the most commonly observed vertical integration governance

Transaction costs observed (Cow-calf producers)	Influence of observed transaction costs on levels of vertical integration*	Most commonly observed vertical integration patterns and associated transaction costs	
		Spot market	Oral commitment (direct) to farmer
Human specific assets	0	All levels of education and experience	
Physical specific assets	0	Few investments or higher investments	
Geographic specificity	0	Central France and Western France	Western France
Temporal specificity	0	Very low	
Dedicated assets	1^{+}	Very low	Moderate (e.g. vaccination)
Uncertainty - Risk	1^{+}	Moderate	
Complexity	2^{-}	Very high	High
Asymmetry of information	0	High	Reduced to a minimum

* 0: *Ceteris paribus*, no influence on vertical governance; 1: *Ceteris paribus*, influence ($^{+}$positive or $^{-}$negative) on vertical governance depending on individual characteristics; 2: *Ceteris paribus*, influence ($^{+}$positive or $^{-}$negative) on vertical governance

Table 22: Observed transaction costs of fatteners on the most commonly observed vertical integration governance

Transaction costs observed (Fatteners)	**Influence of observed transaction costs on levels of vertical integration***	**Most commonly observed vertical integration patterns and associated transaction costs**				
		Spot market	Oral commitment (direct) to farmer	Oral commitment to middle men	Written contract	Integration
Human specific assets	0	All levels of education and experience				
Physical specific assets	0	Little or higher investments	Little or higher investments	Little or higher investments	High investments	Little or higher investments
Geographic specificity	0	Central France and Western France	Western France	Central France and Western France	Central France and Western France	Central France and Western France
Temporal specificity	1^{+}	Low	Low to moderate			Low
Dedicated assets	1^{+}	High				Moderate
Uncertainty - Risk	1^{+}	Moderate (fattening, additional activity)	High (fattening, additional but important activity)		High (fattening, major activity)	High (no plural activity)
Complexity	1^{+}	Moderate				
Asymmetry of information	2^{-}	high	Very Low	Low to moderate	Low to moderate	Null

* 0: *Ceteris paribus*, no influence on vertical governance; 1: *Ceteris paribus*, influence ($^{+}$positive or $^{-}$negative) on vertical governance depending on individual characteristics; 2: *Ceteris paribus*, influence ($^{+}$positive or $^{-}$negative) on vertical governance

Chapitre 3 : Fonctionnement économique de filière, verrous et leviers liés à la compatibilité avec les standards

Après avoir analysé, sous deux angles méthodologiques différents, l'organisation verticale de la filière jeunes bovins de boucherie, ce dernier chapitre complète notre analyse des verrous à l'adoption d'innovations de gestion sanitaire des troupeaux – ici la réduction d'usage d'antibiotiques – par une analyse quantitative des facteurs d'influence dans les choix de pratiques sanitaires des éleveurs et par une étude de cas d'innovations de niches.

Dans le chapitre 3A, l'analyse économétrique de données d'enquête auprès d'éleveurs naisseurs (82), engraisseurs (52) et naisseurs-engraisseurs (74) a permis de partiellement valider l'hypothèse d'un lien entre la gouvernance des transactions, la transmission de l'information, la valorisation des attributs de la qualité et les pratiques de maîtrise des risques de maladies respiratoires par les éleveurs. Seuls les modes de gouvernance les plus extrêmes (marché spot d'un côté, intégration verticale et transfert direct de l'autre) semblent être en faveur respectivement d'une dégradation ou d'une amélioration de la transmission de l'information et de la prise en compte d'attributs non visibles de la qualité lors des transactions. En revanche, les formes de gouvernance des transactions intermédiaires semblent être caractérisées par un faible niveau d'information transmis et une non valorisation des attributs non visibles de la qualité. Les pratiques de gestion de la santé des broutards (vaccination et antibiothérapie) semblent être davantage influencées par des caractéristiques d'élevages et d'éleveurs (taille des exploitations, aversion au risque) que par la gouvernance des transactions.
La gouvernance des transactions actuelle constitue donc un verrouillage à une amélioration des pratiques d'antibiothérapie. Cependant, même les modes de gouvernance des transactions plus coordonnés ne semblent pas permettre une amélioration des pratiques de gestion. La sensibilisation des acteurs aux enjeux de l'utilisation d'antibiotiques et de l'antibiorésistance reste un élément central. Par ailleurs, l'analyse de cas d'étude de modes de gouvernance permettant une amélioration des pratiques d'utilisation d'antibiotiques pourrait permettre de proposer des leviers pour manager des changements de pratiques à l'échelle de la filière.

Dans le chapitre 3B, l'analyse des informations collectées lors d'entretiens semi-directifs avec des acteurs des filières de viande de jeunes bovins de boucherie en France (56) et au Canada (16) a permis d'envisager des leviers pour engager une transition vers un régime sociotechnique moins basé sur l'utilisation prophylactique d'antibiotiques. Les filières canadienne et française présentent des caractéristiques d'organisation communes, qui permettent d'envisager des leviers d'action pour une réduction d'utilisation d'antibiotique s'inspirant d'observation de cas d'étude dans ces deux pays. Les cas d'étude issus des observations de terrain concernent encore un volume mineur des transactions de bovins et sont à l'initiative de diverses instances (éleveurs, groupements de producteurs, entreprises de négoce privées) ; ils constituent des niches d'innovation. Ces pratiques innovantes ont en commun de rétablir un lien immatériel entre les éleveurs naisseurs et les éleveurs engraisseurs. Les premiers reçoivent un retour d'information, et souvent de valeur ajoutée, sur une amélioration de la qualité des animaux qu'ils mettent en marché (préparation des animaux, performances en engraissement). Les seconds disposent de plus d'informations sur les broutards qu'ils achètent (critères non visibles de la qualité), et cherchent souvent à minimiser les risques liés au transfert des

broutards (durée du transport, nombre de mélanges). Ils valorisent le plus souvent la qualité des animaux qu'ils achètent en payant un prix supérieur à l'éleveur naisseur ou au négociant.
Afin d'élargir l'adoption de ces pratiques innovantes, les systèmes de traçabilité existant et autres supports informatiques pourraient favoriser une meilleure transmission des informations et une meilleure gestion des pratiques sanitaires. Par ailleurs, le levier législatif pourrait également être un instrument puissant pour amener à un changement de pratiques rapide. Cependant, l'équilibre des filières française et canadienne pourrait être fortement impacté, ces mesures sont donc à activer prudemment.

Chapitre 3A : Gouvernance des transactions et transmission d'information : implications pour les pratiques de gestion de la santé animale dans la filière viande de jeunes bovins de boucherie française

Note d'avancement : Ce chapitre, dont le travail est encore en cours, devra être soumis à une revue d'économie encore non déterminée.

Abstract

Antimicrobial resistance is a global issue and a reduction in antibiotic use is necessary to address the growth of antimicrobial resistance. In the French young beef bulls' sector, however, antibiotics are often used to control the risk of bovine respiratory diseases (BRD) at the beginning of the fattening period. The level of BRD risk depends on management practices implemented before animals enter feedlots (transportation, commingling, vaccination). Information transmission on health management practices used at earlier stages of the value chain by cow-calf producers could thus allow a more accurate evaluation of the level of BRD risk, and reduce systematic and preventive antibiotic use. Information transmission may be correlated with the structure of the beef value chain, including the type of vertical coordination. Decisions on antibiotic use could also be correlated with the characteristics of cattle producers and types of farms. The paper uses data from a quantitative survey of 225 French beef cattle producers to examine the extent to which the value chain governance structures and cattle producers' and farm characteristics are correlated with health management practices. Few governance structures allow proper information transmission regarding health management practices, and there does not appear to be a relationship between the governance structure within the value chain and the use of improved health management practices. Characteristics of farms (size, involvement in other livestock/crop activities) and of cattle producers (risk aversion, education) could be correlated with systematic and preventive antibiotic use. There is scope for the development of strategies to support better BRD management practices.

Keywords

Information transmission; credence attributes; antibiotic; bovine respiratory diseases, value chain, transaction costs.

1. Introduction

Antimicrobial resistance is a global issue (Laxminarayan et al., 2013). To limit further spread of antimicrobial resistance, antibiotic use should be reduced to minimum for animal and human health control. In France as in other beef meat producing countries (*e.g.* Canada, Ireland) (Anonymous, 2008), most young bulls are raised until maximum 12 months in cow-calf producing units; then they are fattened in feedlots and slaughtered before the age of 24 months. Young bulls are at risk of developing bovine respiratory disease (BRD) at the beginning of the fattening period. In North America, to control that risk in similar situation, more than 40% of feedlots implement a systematic and preventive

injection of antibiotics (Sneeringer et al., 2015). Systematic and preventive antibiotic use, also called prophylactic use, is problematic due to growing challenges from antimicrobial resistance. Other preventive measures such as vaccination and zootechnical management of herds are considered preferable, with antibiotics limited to medicinal purposes.

Two major sets of parameters could influence the fatteners' decision to use antibiotics to prevent, or only to control BRD, in the case of an outbreak. First, the level of BRD risk depends on the production steps preceding the beginning of the fattening period, such as transportation from the cow-calf to the feedlot or the commingling of weanlings (young bulls of 6 to 9 months) to constitute homogenous batches (in terms of animal size and weight). The longer the transportation and the higher the number of transfers through livestock markets, the higher the commingling, and the higher the BRD risk for young bulls (Cernicchiaro et al., 2012b; Hay et al., 2014; C. S. S. Ribble et al., 1995; Sanderson et al., 2008). In addition, vaccine protocols provide a good but only partial protection against BRD pathogens. The effects are fully efficient and optimal only if (i) vaccination has been implemented at the cow-calf farm some weeks before shipping weanlings, and (ii) vaccination protocol is pursued at the feedlot (Gay and Barnouin, 2009; J G Kirkpatrick et al., 2008). A more limited vaccination protocol can be implemented at the beginning of the fattening period with a reduced effectiveness compared to the optimal protocol. The level of BRD risk depends on these elements - transport (partially linked to farm of origin), past diseases, commingling, vaccination protocol, preventive injection of antibiotics - which can be considered as credence attributes for the buyer (i.e. attributes that cannot be observed or verified even after purchase without precise and reliable information (Brocklebank et al., 2008)). By extension, the level of BRD risk in a batch of weanlings is considered as a credence attribute for the buyer. The information transmission, as well as quality of the products exchanged, are expected to be influenced by the governance structure for transactions between cow-calf producers and feedlots (Coronado et al., 2010). Governance structure of transactions has been described as a continuum existing between two extremes: spot market and vertical integration (Bijman, 2006). In between, hybrids forms of governance structures, such as oral agreements or written contracts exist. However, empirical evidence is mixed regarding the extent to which different governance structures facilitate specific quality requirements or management practices within supply chains(Brocklebank et al., 2008; Fernandez-Olmos et al., 2009; Fraser, 2005; Goodhue et al., 2003). The governance of transactions and information transmission through the value chain between the cow-calf producer and the fattener could thus influence the practices implemented by downstream fatteners to mitigate BRD risk. To our knowledge, the analysis of the influence of supply chain relationships on stakeholders' animal health management decisions issue is original.

Second, the level of BRD risk exposure may not be a central focus of herd management within the complex decision-making environment for fatteners. First, cattle producers' practices can also be influenced by their production system (level of intensification, such as labour productivity (units of agricultural product produced per full-time equivalent) and agronomic intensification). The production system impacts the organisation of daily labour on farms, including health management practices (Visschers et al., 2014). Production systems also influence the availability of financial resources, and can thus impact the choice between different health management practices (Speksnijder et al., 2015). Second, farmers' knowledge of and perceptions regarding the importance of specific issues also influence their willingness to implement a change in their practices (Friedman et al., 2007). Farmers'

knowledge, level of education and skills, and generally attitudes toward risk, could thus influence BRD risk management practices (van den Borne et al., 2014b).

The aim of this study is to understand the elements that influence cattle producers' decisions to implement health management practices (optimal or limited vaccination protocol or systematic preventive antibiotic use) in the French young beef bulls' value chain. The paper presents a theoretical framework and derives a set of hypotheses drawing upon insights from transaction costs economics (TCE) as well as elements of production systems and cattle producers' characteristics that could influence health management practices. The data used for the analysis were obtained from a survey of cow-calf producers and fatteners in France, based on an online and telephone questionnaire, administered from April to October 2017. Data are analysed using cluster analysis, multinomial and binomial logit models to test the theoretical predictions.

The paper is organised as follows: section 2 presents a theoretical framework based on TCE positing a relationship between governance structure within the beef value chain, information transmission and quality. Second the expected effect of production systems and cattle producers' characteristics on health management practices is examined. Section 3 presents the study design, the sample selection and description of the data. Section 4 reports the empirical results from the cluster analysis and the multinomial logit regression analysis. Section 5 discusses and concludes the analysis with a consideration of implications for improved health management practices with respect to reducing BRD risks.

2. A framework to understand factors influencing weanlings' health management practices

This section develops a framework identifying the factors that could be correlated with health management practices implemented by cow-calf producers and fatteners to control BRD risk.

A first set of hypothesis is based on the relationship between vertical governance of transactions, information transmission, and definition of quality. Governance structures within a supply chain are a continuum of different contracting schemes (Boger, 2001 adapted from Williamson, 1998). In the French young bulls sector, one can adapt this contracting scheme to the diversity of governance structures that are observed: (i) spot market, when weanlings are marketed through livestock markets, (ii) short term (one-off) transactions where cattle producers use the services of middlemen once or occasionally (iii) long-term relational contracts, where weanlings are marketed through middlemen in a multi-year relationship, without a written long-term contract, (iv) written long-term contracts, (v) direct transfers of weanlings between a cow-calf producer and a fattener, (vi) vertical integration of cow-calf and fattening farms, where the cow-calf producing phase is vertically integrated with the feedlot.

Paulraj, Lado and Chen (2008) showed that information transmission with commercial partners is related to the existence of a long-term relationship as the primary governance structure. In the present analysis, the focus is based on information transmitted between cow-calf producers and fatteners that is necessary to evaluate the level of BRD risk (cow-calf farm of origin, length of transportation, level of commingling, past diseases, past antibiotic or vaccination use).

Quality refers to the level of desirable attributes of a product. The quality of products could significantly and positively be associated with the way in which transactions occur i.e. the governance structure within the value chain(Goodhue et al., 2003). However this association could vary depending on the importance of added value of products exchanged (Fernandez-Olmos et al., 2009). Quality attributes are defined into different categories (Brocklebank et al., 2008): (i) search attributes can be easily evaluated before purchase (e.g. weight and shape of an animal or carcass (Boger, 2001)), (ii) experience attributes can only be determined after purchase (e.g. performance during fattening), (iii) credence attributes present much more challenging measurement issues since they cannot be evaluated even after purchase (e.g. level of BRD risk, approximated by vaccination protocols implemented or comingling of animals at earlier stages of the supply chain, etc.). In the context of the present analysis, the credence attributes of interest describe the preference of fatteners for weanlings with a lower level of BRD risk. Evaluating credence attributes, in this case BRD risks, requires information transmission within the supply chain. In addition, information transmission could positively affect the quality of products exchanged (Coronado et al., 2010).

Hypothesis 1: Considering the diversity of governance of transactions in the young beef bulls sector, the type of governance structure is correlated with the level of information transmission regarding BRD risks and with the type of quality attribute (search vs credence) preferred by cattle producers.

Hypothesis 1a: Increased coordination in governance structures is correlated with the level of information transmission.
Hypothesis 1b: Increased coordination in governance structures is correlated with buyers' preference for information on credence attributes when purchasing weanlings.
Hypothesis 1c: The level of information transmission is correlated with buyers' preference for information on credence attributes when purchasing weanlings
Hypothesis 1d: Increased coordination in governance structures is inversely correlated with buyers' preference for search attributes when purchasing weanlings.

A second set of hypothesis is based on the potential link between weanlings' health management practices implemented by cattle producers, the level of information transmission, and the preference for search or credence attributes for transactions.
Dairy farmers could use antibiotics in response to the level of risk they perceive using diverse elements (individual, herd) to evaluate the risk (Vaarst et al., 2002). In addition, pig farmers were more prone to evaluate different health management options when the perceived risk was lower (Callens et al., 2012). The level of BRD risks (transportation, commingling, vaccination) and the extent of information transmission regarding BRD risk should thus influence fatteners' choice of health management practices (vaccination, prophylactic antibiotic use).

Hypothesis 2: The implementation of weanlings' health management strategies from the best (optimum vaccination protocol, low level of risks linked to weaning and transportation, no prophylactic antibiotics) to the worst (no vaccination, high level of risks linked to weaning and transportation, prophylactic antibiotic use) should be correlated with the level of information transmission regarding BRD risks, and the type of quality attribute (search vs credence) preferred by cattle producers.

Hypothesis 2a: The level of information transmission should be correlated with improved weanlings' health management practices (optimal vaccination protocol and no prophylactic antibiotic use).
Hypothesis 2b: Credence attributes taken into account to estimate BRD risks should be correlated with improved weanlings' health management practices.
Hypothesis 2c: Search attributes taken into account should be inversely correlated with improved weanlings' medical health management practices.

A third set of hypotheses is based on the potentially existing link between farm characteristics (size, diversification,…), and farmers' characteristics (risk aversion, level of education,…), and the implementation of diverse health management practices for weanlings. *Ceteris paribus*, cattle producers' implementation of prudent BRD management practices also depend on their production system and on their socio-economic characteristics. Indeed, veterinarians estimate that financial burdens and time restrictions could be two major limitations to farmers implementing their recommendations (David C. Speksnijder et al., 2015). The level of intensification impacts the organisation of labour on the farm and the work load (Visschers et al., 2014). Farm size and the diversification of the farm's activity could thus affect the implementation of an optimal vaccination protocol, implying a first injection by cow-calf producers, and affect he prophylactic antibiotic use by fatteners. In addition, farmers' knowledge and skills could also influence the adoption of management practices for reducing BRD risk (van den Borne et al., 2014a). Risk aversion is also an element that positively influences preventive antibiotic use (Ge et al., 2014; Visschers et al., 2014).

Hypothesis 3: The implementation of weanlings' health management strategies from the best (optimum vaccination protocol, low level of risks linked to weaning and transportation, no prophylactic antibiotics) to the worst (no vaccination, high level of risks linked to weaning and transportation, prophylactic antibiotic use) should be correlated with farm and farmers' characteristics.

Hypothesis 3a: Farm size and diversification of farm activities should evolve in disproportion with prudent BRD management practices (early vaccination, no prophylactic antibiotic use).
Hypothesis 3b: Cattle producers with higher levels of education should be correlated with more prudent BRD management practices (optimal vaccination protocol and no prophylactic antibiotic use).
Hypothesis 3c: Fatteners who are more risk averse should be correlated with more prophylactic antibiotic use.

3. General study design

A qualitative exploration of this agricultural sector was first implemented by conducting qualitative interviews with stakeholders in the value chain (54 interviews) and field observation in major French producing areas (6 observations) to describe the general organisation of the young bulls' value chain in France (Table A1 in the Appendix). Based on the diversity of governance structures observed, the way weanlings' health management was taken into consideration by stakeholders was explored. The quantitative survey was developed and some questions were adapted to the types of cattle producers of interest for this research, namely: cow-calf producers (n=96), fatteners (n=54), or breeder-fattener producers (i.e. vertically integrated operations engaging in both cow-calf production and fattening of young bulls) (n=75). The questionnaire was divided into four sections: (i) determinants of choices when selling (or buying) weanlings, (ii) description of the cow-calf (or fattening) activity, (iii) elements

regarding the farm operation, (iv) characteristics of the interviewee/farmer[44]. Before field implementation the questionnaire was tested with two cattle producers of each category, with the duration of the questionnaire, difficulties and redundancies noted and then corrected. The survey required between 25 and 40 minutes to complete.

3.1. Sample selection

The sampling strategy deliberately did not intend to be fully representative of the proportions of existing governance structures. The sample was selected in order to have sufficient data for each type of cattle operation so as to be able to make comparisons and to analyse each category of cattle producers. The survey was initially designed to be administered online, however, due to difficulties in collecting data (outlined below), several methods of contacting cattle producers were used. The survey was eventually administrated by e-mail and by telephone.

A first source of contact for identifying cattle producers was the French network of Animal Health Protection Groups (AHPG, Groupements de Défense sanitaire GDS), with which most French beef cattle producers are affiliated. AHPG were asked to send the survey to their cattle producer members by e-mail. Cattle producers thus completed the survey by themselves. Forty out of 90 AHPG departmental offices were contacted in the major French regions producing cow-calves or young bulls[45]. Approximately 10% of AHPG sent the survey and a second relaunch to their affiliated cattle producer members (i.e. the same e-mail as the initial message to encourage responses from cattle producers three weeks after the first message). Others declined or ignored our request to assist with the survey. Through this channel the answer rate to the survey was extremely low (less than <0.01%).

Cattle producers' telephone numbers were collected via four other major sources: (i) internet ("Bienvenue à la ferme" website was the most important source[46]), (ii) 16 producers' associations, (iii) three "Chambres d'Agriculture" (local or regional public agencies supporting farmers' development, applied research and extension services), and (iv) 11 private veterinarians. Four agricultural students and one agricultural engineer collected information through telephone interviews. Through this channel, the response rate to the survey was close to fifty percent.

A total of 225 cattle producers completed the survey form April to October 2017: 96 cow calf producers, 54 fatteners, and 75 vertically integrated breeder-fattener producers. Of these, 13 breeder-fattener producers were buying weanlings for fattening, they were thus considered as fatteners in the analysis. Not all cattle producers completed the entire survey (some questions were not compulsory). After excluding incomplete responses, a final sample size of 82 cow-calf producers and 65 fatteners were included in the models. In the models, no significant difference was observed between vertically integrated breeder-fattener producers buying weanlings for fattening, and specialized fatteners.

[44] A copy of the survey (written in French) is available from the authors upon request.

[45] Regions where AHPG were contacted include: Centre Val de Loire; Bourgogne Franche-Comté; Nouvelle Aquitaine; Auvergne-Rhône-Alpes; Pays de la Loire; Occitanie; Normandie. In all contacted regions, the survey was transmitted to the farmers in at least one department, except in Pays de la Loire and Normandie, where such confirmation was not given.
A department is a French sub-division of a Region.

[46] This website (http://www.bienvenue-a-la-ferme.com/) gives the contact (including telephone number) of farmers interested in selling their products through short marketing cycles, or interested in welcoming hosts to their farms.

3.2. Variable descriptions

To test the hypothesis developed, key variables had to be quantified (Table 24). Only variables included in the model are presented, however, all other variables are described in Table A2 in the Appendix.

First, to describe the implementation by cattle producers of sanitary prevention measures, two different ordinal variables were used (Figure 11). First VACCIN describes the vaccination strategy used by cattle producers. For cow-calf producers and breeder-fattener producers VACCIN has two levels which describes whether vaccination against BRD has been implemented before shipping (or weaning) (optimum vaccination protocol) or not (no vaccination). For fatteners VACCIN is a three level variable which describes whether a vaccination protocol has been implemented in the optimal way (vaccination at the cow-calf farm before the stressful period of weaning and transfer, booster implemented by the fattener), or in a limited way (just before or at arrival in the feedlot), or never implemented by the fattener. Second, ANTIBIO describes if a prophylactic antibiotic injection is implemented never, sometimes, or always just before the fattening period.

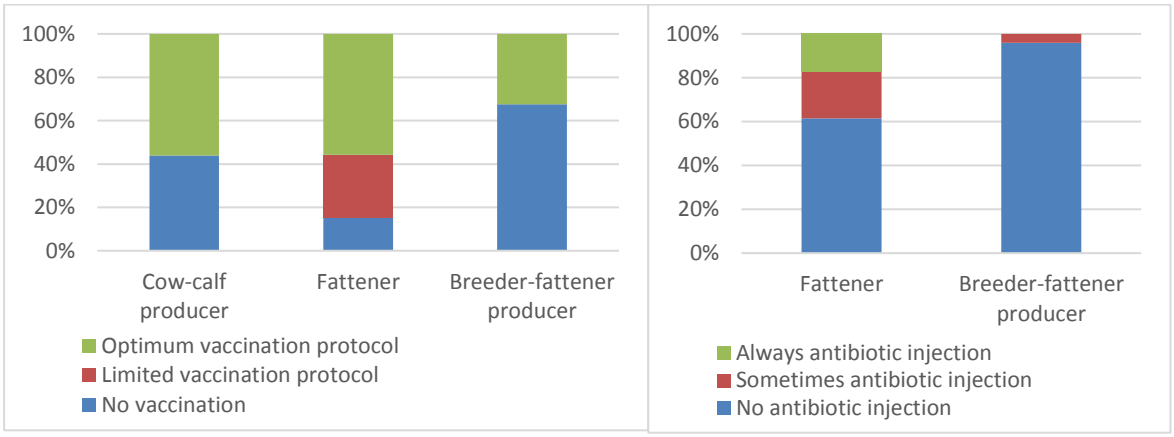


Figure 11: Implementation of vaccination protocols (VACCIN), and of prophylactic antibiotic injection by cattle producers (ANTIBIO) (Percentage of respondents). (Cow-calf producers, n=82; Fatteners, n=52; Breeder-fattener producers, n=74)

Second the governance of transactions was captured by two variables. The variable COORD describes the dominant (most frequently or largest volume) governance structure chosen by cattle producers, in particular the type of buyer (seller) (Table 23). Direct transfers of weanlings from cow-calf farm to feedlot (fattener) corresponds to the mostly highly coordinated governance structure (after vertically integrated cow-calf and fattening production) as no middlemen are involved and the system is close to the vertically integrated form of governance structure. The number of middlemen cattle producers worked with was considered as an indicator of degree of vertical coordination: the higher the number of middlemen, the less coordinated. The variable CONTRACT describes the dominant (most frequently used) contractual arrangement (Table 23). “Spot market” encompassed when the cattle producers (i) sold/bought cattle through a livestock market, or (ii) had no contractual agreement and worked for one year with one or more middlemen with no long term commitment, or (iii) had no contractual agreement and worked for less than one year with one or more middlemen. Spot market was coded as 0 for the CONTRACT variable. Oral informal contract and formal contract were coded as 1 and 2 respectively. Both COORD and CONTRACT variables are based on the dominant commercial practices of cattle producers considering the quantity of weanlings transacted. Some cattle producers are using

more than one type of governance structure, but our analysis could not capture this level of detail. Table 23 presents a cross-tabulation of the COORD and CONTRACT variables.

Table 23: Cross tabulation of COORD, level of dominant governance structure chosen by cattle producers (type of buyer/seller) for the transaction of weanlings, and CONTRACT, form of contract chosen by cattle producers (type of buyer/seller) for the transaction of weanlings. (Cow-calf producers, n=82; Fatteners, n=52; Breeder-fattener producers, n=74)

Number of cattle producers	**COORD**					
CONTRACT	**Livestock market**	**1 single middle man**	**2 or more middle men**	**Direct with farmer**	**no sell/purchase**	**Total**
Cow-calf producer	**4**	**47**	**27**	**4**		**82**
Formal contract		2				2
Relational contract	3	45	26	4		78
No contract	1		1			2
Fattener		**37**	**11**	**4**		**52**
Formal contract		19				19
Mixed system		1	5	3		9
Relational contract		16	5	1		22
No contract		1	1			2
Breeder-Fattener producer	**1**	**5**	**1**	**6**	**61**	**74**
Formal contract				1	1	2
Mixed system			1	2		3
Relational contract	1	4		3		8
No contract		1			60	61
Total	**5**	**89**	**39**	**14**	**61**	**208**

In a third step, the information transmitted between the cow-calf producer and the fattener was described. The type of information which cow-calf producers indicated they received (from the fattener or the middlemen) included: INFODESTIN (information on the destination farm), INFOPERF (information on weanlings' performances during fattening such as weight daily gain, occurrence of BRD, carcass yield at slaughter). The type of information, which fatteners indicated they received from cow-calf producers, describes the BRD risk level and prior health management protocols which are credence attributes for the buyer: INFONUMFARMS (information on number of farms of origin), INFOSOURCE (identification of farm of origin), INFODIS (information on past diseases), INFOVAC (information on past vaccination), INFOATB (information on past antibiotic injection). These variables capture the level of information cattle producers had on a batch.

Next, in order to describe the weanling attributes that are search attributes for the buyer, AGECHOICE, HOMOGCHOICE, and PRICECHOICE, described respectively if the age of weanlings, homogeneity of batches, or price were important criteria for them (Figure 12). CREDENCE was used to describe if

credence attributes were important criteria for fatteners, specifically, prior vaccination of weanlings, few farms of origin, and/or short transportation distances. This variable existed only for fatteners.

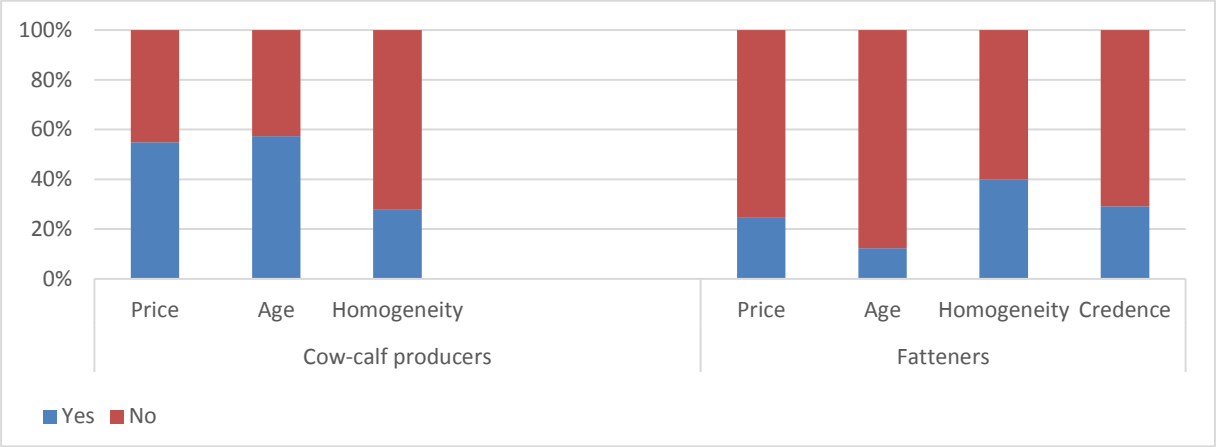


Figure 12: Search and credence attributes (PRICECHOICE, HOMOGCHOICE, PRICECHOICE, CREDENCE) important for cow-calf producers (n=82) or fatteners (n=65) (percentage of respondents).

Finally, cattle producers' characteristics were considered. GENDER describes if the cattle producer is female or male. The variable EDUC describes the farmer's level of education using a five point scale from 0 (no diploma) to 4 (Masters' degree or more, or equivalent)[47]. The variable OTHERPROF describes if the cattle producer has another professional activity. Two variables were created as proxies for cattle producers' technical management of the herd (i) COSTS describes if the cattle producer calculates the production costs of the farming activity, (ii) MORTALITY describes the level of mortality of calves or weanlings as a percentage. Mortality rate is expected to be higher for calves before weaning than for weanlings during fattening. As a consequence, it should be compared among cow-calf producers (mortality rates: mean 14.9% +/- 4.2%), and among fatteners (mortality rates: mean 3.3% +/- 3.0%).

In the agriculture sector, risk factors have been defined into five main types: production or yield risk, including animal disease; human or personal risk, linked to workplace accidents; risk linked to fluctuations in market prices; financial risk linked to investment burden; and institutional risk linked to a change in regulation (Hardaker, 2015). In the survey, the risk perception of cattle producers was evaluated with five different variables[48]. Two of them were included in the model as potential indicators of the degree of risk aversion for an individual cattle producer: ACCIDRISK and REGRISK reported if the cattle producers perceived respectively human risk and institutional risk as one of two major risks on their farm. Two other variables complemented the evaluation of cattle producers' risk perception, evaluating cattle producers' attitudes toward risk and risk mitigation (risk aversion): (i) CAP, specifically evaluated the cattle producers' attitude regarding the importance of the Common Agricultural Policy subsidies in their income. Income support via the CAP could mitigate the risk linked

[47] 0=No Diploma; 1=Certificate of General Education or equivalent; 2=High School Diploma or equivalent; 3=Bachelors' Degree or equivalent; 4=Master's degree or more or equivalent

[48] The survey question was: "What are the two risks that you fear most for the sustainability of your farm?" Five different options corresponded to the different risks, among which: ACCIDRISK "a work accident for me or one of my business partner", and REGRISK "New regulatory constraint (among which CAP), impairing the level of subsidies I get or the organisation of my farm".

to cow-calf producing or the fattening activity; (ii) FLUCTU reported cattle producers' attitude towards market fluctuation (significance of variation of weanlings' price fluctuation on market).

Finally, farm characteristics were described using two variables: (i) SCALE if cattle producers had a scale to weigh animals, because this is an investment that eases handling of weanlings, (ii) SIZE describing the size of the beef herd (for cow-calf producers: number of calvings per year; for fatteners: capacity of the fattening facility). Table 24 describes the variables used in the analysis.

Table 24: Variables used for the empirical analysis

Variable	Description	Units
Weanlings' medical health management practices		
VACCIN[3]	Vaccination implemented against BRD (0=no vaccination, 1=limited vaccination protocol (only implemented by the fattener), 2= vaccination protocol implemented by the cow-calf producer and booster by the fattener)	0, 1, 2 ordinal
ANTIBIO[2]	Preventive antibiotic injection implemented (0=never, 1=sometimes, 2=always)	0, 1, 2 ordinal
Governance of transactions		
COORD	Type of dominant governance structure (1=livestock market, 2=2 or more middlemen, 3=Single middlemen, 4=Direct transaction between cow-calf producer and fattener)	1, 2, 3, 4 ordinal
CONTRACT	Type of dominant contractual arrangement (0=spot market, 1=oral informal contract, 2=formal contract)	0, 1, 2 ordinal
Attributes to estimate BRD risk and information transmission		
INFODESTIN[1]	Cow-calf producers' knowledge on the farm of destination (0=no, 1=yes)	0, 1 nominal
INFOPERF[1]	Cow-calf producers' knowledge on weanlings' performance during fattening(0=no, 1=yes)	0, 1 nominal
INFONUMFARMS[2]	Fatteners' knowledge on weanlings' farm of origin (0=no, 1=yes)	0, 1 nominal
INFOSOURCE[2]	Fatteners' knowledge on number of farms of origin in a weanlings' batch (0=no, 1=yes)	0, 1 nominal
INFODIS[2]	Fatteners' knowledge on previous weanlings diseases (0=no, 1=yes)	0, 1 nominal
INFOVAC[2]	Fatteners' knowledge on implementation of vaccination protocol on weanlings (0=no, 1=yes)	0, 1 nominal
INFOATB[2]	Fatteners' knowledge on implementation of antibiotic preventive injection on weanlings (0=no, 1=yes)	0, 1 nominal
Search and credence attributes for cattle producers		
AGECHOICE	Cattle producers' choice for weanlings based on age (0=no, 1=yes)	0, 1 nominal
HOMOGCHOICE	Cattle producers' choice for weanlings based on homogeneity of batches (0=no, 1=yes)	0, 1 nominal
PRICECHOICE	Cattle producers' choice for weanlings based on price (0=no, 1=yes)	0, 1 nominal
CREDENCE[2]	Cattle producers' choice for weanlings based on credence attributes (0=no, 1=yes)	0, 1 nominal
Cattle producers' characteristics		
GENDER	Gender of the farmer (1=male, 2=female)	1, 2 nominal
EDUC	Level of education (0=no diploma, 1=Certificate of General Education, 2=High School Diploma, 3=Bachelor's Degree, 4=Master's Degree or more)	0-4, ordinal
OTHERPROF	Other professional occupation (0=no, 1=yes)	0, 1 nominal
COSTS	If cattle producers measure their production costs (0=no, 1=yes)	0, 1 nominal

FLUCTU	Cattle producers' perception on weanling's market price fluctuations (1=low, 2=moderate low, 3=medium, 4=high, 5=very high)	1-5, ordinal
ACCIDRISK	Cattle producers' perception of the uncertainty linked to professional accident (0=no, 1=yes, one of the two major risk perceived)	0, 1 nominal
REGRISK	Cattle producers' perception of the uncertainty linked to possible change of regulation (0=no, 1=yes, one of the two major risk perceived)	0, 1 nominal
CAP	Cattle producers' perception of the importance of the CAP in their income (1=null, 2=negligible, 3=medium, 4=important, 5=essential)	1=5, ordinal
Farm characteristics		
SCALE	Scaling system to weight weanlings (0=no, 1=yes)	0, 1 nominal
RESTRAIN	Restraining system to manipulate weanlings (0=no, 1=yes)	0, 1 nominal
SIZE[3]	Size of the herd	Number of head

[1] Only cow-calf producers answered this question.

[2] Only fatteners answered this question.

[3] Variable is the same, but measurement is different between cow-calf producers and fatteners: VACCIN: [0=no vaccination, 2=vaccination protocol against BRD] for cow-calf producers, [0=no vaccination, 1=limited vaccination protocol, 2=optimal vaccination protocol] for fatteners; SIZE: [number of cows] for cow-calf producers, [number of fattening places] for fatteners.

4. Empirical analysis

4.1. Statistical methods

This section is divided into two parts. First, hypotheses 1 and 2 are tested empirically using a cluster analysis describing transaction governance structure, information transmission, quality attributes and health management practices. Then the third set of hypotheses are tested empirically using multinomial and binomial logit models. These models link fatteners and farm characteristics with health management practices implemented for BRD risk control.

The first analysis developed profiles of farmer types according to their use of health management practices associated with vertical coordination levels, weanling search attributes that were important to the farmers and information transmission along the value chain. The analysis proceeded in five steps. First, individuals with missing data were excluded from the sample: 82 cow-calf producers and 65 fatteners remained. Second two separate multiple correspondence analysis (MCA) were carried out in R (R Core Team, 2016) on cow-calf producers and on fatteners, to identify clusters of cattle producers according to a set of variables that was common to both samples of farmers (Rault and Hennessy, 2016).. These variables include health management practices used for weanlings (VACCIN); governance of transactions (COORD, CONTRACT); and search attributes (AGECHOICE, HOMOGCHOICE, PRICECHOICE). These variables respectively correspond to generic health prevention practices, to the organisation of the value chain, and to information on the animals being transacted. In addition, some additional variables which were specific to each sample were included in the MCA:

- For cow-calf producers (n=82): information transmission (INFODESTIN, INFOPERF);
- For fatteners (n=65): weanling health management practices (ANTIBIO); information transmission (INFONUMFARMS, INFOSOURCE, INFODIS, INFOVAC, INFOATB); credence attributes (CREDENCE).

Then the Ward hierarchical clustering method was applied to distinguish groups of cattle producers having the closest characteristics (Husson et al., 2010). The final classification was adjusted by applying the K means algorithm[49]. A four-cluster grouping was chosen for the cow-calf producers, and a three-cluster grouping was chosen for the fatteners. Finally, to confirm the relevance of the clustering, a Random Forest test was implemented on the different clusters (Pal, 2005). Results are discussed in section 4.2

The second analysis aimed at quantifying the risk of implementing different preventive protocols (vaccination or prophylactic antibiotic use) depending on the characteristics of the farm and farmer. Logit multivariate regression models were used. This approach was chosen as the analysis included qualitative variables, and most frequently binary variables. The analysis proceeded in five steps. First, observations with missing data were removed, leaving 82 cow-calf producers and 65 fatteners. Second, univariate analyses were performed with each independent variable having potentially relevant interactions with dependent variables. Due to the non-linear effect of association between SIZE and dependent variables, SIZE was categorised into three or four classes. Categories were built according

[49] The K means algorithm aims at partitioning a set of data into clusters, each observation having the nearest mean. The algorithm allows convergence to a local optimum.

to quantiles. Some observations concerned too few fatteners (EDUC, FLUCTU, and CAP), they were thus grouped together to obtain enough fatteners in each group for the models. Variables were selected for multivariate analysis if they contributed to the model at a 20% significance level (Rault and Hennessy, 2016). Third, covariates were tested between all independent variables (Chi-square or exact Fischer test). Variables having strong and relevant interactions (p-value<0.05) were tested in different multivariate models. If models implemented with different correlated independent variables gave different outputs, they were presented; otherwise, outputs of models implemented with different correlated independent variables gave similar output. Fourth, remaining variables were offered to the model. Variables were selected in the model by backward stepwise selection until all variables significantly (p-value<0.05) contributed to the model. The best model was evaluated using AIC comparison (Ref.). Finally, marginal effects (for binomial models), and Average Marginal Effects (AME) for the multinomial model were calculated (Williams, 2012).

4.2. Governance of transactions, information transmission and health management practices

Hypothesis 1 regarding the positive correlation between the level of coordination in governance, the level of information transmission regarding BRD risks, and the type of quality attribute (search vs credence) preferred by cattle producers is partially confirmed.

Results of the cluster analysis for cow-calf producers and fatteners are presented in Tables 25 and 26 and exhibit a similar pattern, with good predictive results as shown by the random forest test. Details of the underlying quantitative models are provided in the Appendix (Tables A3-A6) Analysis seems to confirm a positive correlation between the level of coordination and the level of information transmission only for the most extreme level of coordination: direct transfer from cow-calf producer to fattener (*Hypothesis 1a*). In all other types of coordination, information transmission is most of the time non-existent or limited (Relational group of fatteners, table 26).

The same conclusion pertains to *Hypothesis 1b*: there is a positive correlation between the preference for credence attributes by fatteners and the level of coordination in governance only for direct transfers (table 26).

Fatteners from the "Informed" group tend to use a single middleman or transact directly with cow-calf produces, they are well informed about prior production practices and exhibit preference for credence attributes. In contrast, fatteners from the "Formal" cluster are not well informed about prior animal health management practices, the source of animals or the distance travelled and do not place importance on credence attributes in their demand for weanlings. Preference of fatteners for credence attributes and good information transmission between the cow-calf and fattening stages are thus correlated, which validates *hypothesis 1c*.

Hypothesis 1d is thus confirmed for one form of vertical coordination: direct transfer of weanlings from cow-calf to fattener producers.

Table 25: Cow calf producer clusters (Quantitative details Tables A3 and A4)

Variables	Modality of variables which distinguish clusters within each other's (p-value<0.05)				Accuracy (Random forest, average)
	"Independent" (n=2)	"Relational" (n=65)	"Formal" (n=2)	"Direct" (n=13)	0.94

COORD* **	-	-	-	Direct transfers	
CONTRACT* **	No contract	Oral informal contract	Written contract	-	
INFODESTIN* **	-	No	-	Yes	
INFOPERF* **	-	No	-	Yes	

*** p-value<0.01 as testing the influence of the variables in clusters' differentiation

Table 26: Fattener Clusters (Quantitative details Tables A5 and A6)

Variables	Modality of variables which distinguish clusters within each other's (p-value<0.05)				Accuracy (Random forest, average)
	"Independent" (n=14)	"Relational" (n=13)	"Formal" (n=27)	"Informed" (n=11)	
COORD* **	Livestock market or 2 or more middlemen	Single middleman	Single middleman	Single middleman or direct transaction	
CONTRACT* **	Oral informal contract	-	Formal	-	
VACCIN* **	No vaccination	Heterogeneous practices	Optimum	-	0.91
ANTIBIO	-	Sometimes	Always	-	
INFONUMFARMS* **	-	Yes	No	Yes	
INFOSOURCE* **	No	Yes	No	Yes	
INFODIS* **	-	-	No	Yes	
INFOVAC* **	-	-	No	Yes	
INFOATB* **	-	-	-	Yes	
AGECHOICE* **	-	Yes	No	-	
PRICECHOICE	-	-	No	-	
CREDENCE **	-	-	No	Yes	

**p-value<0.05; *** p-value<0.01 as testing the influence of the variables in clusters' differentiation

The cluster analysis provides *only partial support to hypothesis 2 that implies a positive correlation between health management practices, level of information and preference for credence attributes.*

For cow-calf producers (Table 25), the level of information transmission does not influence the implementation of vaccination protocol. Health management practices do not even appear in the cluster analysis as they were not significantly different across clusters. For cow-calf producers, results thus give no support to *hypothesis 2*.

For fatteners, results are mixed and only partially validate *hypothesis 2a*. First "Independent" fatteners seem to have relatively little information about the prior history of the calves they purchase but still do not implement any kind of vaccination protocol. Second, fatteners from the "Relational" cluster seem to implement more vaccination protocols (optimum or limited) than in the general population

of the study. They also sometimes implement prophylactic antibiotic injections and have information on some aspects of the calves they purchase (number and location of source farms) but not other aspects (distance travelled, prior use of vaccination and antibiotics). Third, fatteners from the "Formal" cluster have no information about prior production practices and calves' history, but declare that they implement the optimal vaccination protocol. However, the latter necessitates a first vaccination injection at the cow-calf farm, and thus information from the cow-calf farming step would be necessary to validate that this occurred. In addition, they always implement a prophylactic antibiotic injection. Fourth, fatteners from the "Informed" cluster have the best level of information about the calves they purchase, but their vaccination practices and antibiotic use is no different from the general population of the study.

Hypothesis 2b and *2c* cannot be validated. There is no correlation between the preference for search or credence attribute and the implementation of health management practices.

4.3. Links between fatteners' and farm characteristics, and implementation of health management practices to reduce BRD risk

For the control of BRD at the beginning of the fattening period, cow-calf producers are only involved in the prevention process when they implement a vaccination protocol against BRD. The first model was thus a binomial logit model with the dependent variable VACCIN and the explanatory variables GENDER, EDUC, COSTS, ACCIDENRISK, SCALE, SIZE. A backward stepwise process was used to select the variables (Table 27).

Table 27: Multivariate analysis: Marginal effects of variables linked with weanlings' vaccination implemented against BRD by cow-calf producers (n=82)

Variables	Items	Number or individuals	Marginal effects
GENDER	Man	65	Reference
	Woman	9	-0.40***
EDUC	No diploma, or certificate of general education	8	Reference
	High school diploma	44	0.46*
	Bachelor's degree or master's degree or more	30	0.50**
COSTS	No	38	Reference
	Yes	44	0.13
ACCIDRISK	No	57	Reference
	Yes	25	-0.24*
SIZE (number of cows)	]0;45]	17	Reference
	]45;70]	17	0.17
	]70;100]	18	0.45***
	>100	17	0.38***

*p<0.1; **p<0.05; ***p<0.01

Hypothesis 3 seem to be partially validated as some fatteners and farm characteristics are correlated with the implementation of health management protocols.

Bigger cow-calf farms tend to implement more vaccination protocols. This gives support to *hypothesis 3a*.
The level of education as well as the calculation of production costs by cow-calf producers are both positively correlated with a higher tendency to implement an optimal vaccination protocol. Cow-calf producers showing more technical management skills are more likely to implement optimal vaccination protocols. This gives support to *hypothesis 3b*.
Cow-calf producers exhibiting more risk aversion are less likely to implement vaccination protocols. This contradicts *hypothesis 3c,* although the analysis may be capturing a different type of risk aversion.

To explore factors influencing the implementation of vaccination protocols by fatteners, a multinomial logistic model is estimated where the dependent variable is VACCIN and the explanatory variables refer to cattle producers' characteristics (i.e. variables GENDER, EDUC, EXPE, COST, FLUCTU, CAP, SIZE, SCALE, and RESTRAIN). After the backward stepwise selection, EDUC, FLUCTU, CAP, and SCALE remained in the final model. Average Marginal Effects (AME) were then calculated (Table 28).

Table 28: Multivariate analysis: Marginal effects of variables linked with weanlings' vaccination implemented against BRD for the entrance in feedlots (fatteners' point of view)

Variables	Items	Number or individuals	No vaccination	Limited vaccination	Optimum vaccination
EDUC	No diploma, or certificate of general education, high school diploma	41	Reference	Reference	Reference
	Bachelor's degree or master's degree or more	24	0.11	0.19	-0.30
SCALE	No	23	Reference	Reference	Reference
	Yes	42	-0.21	0.07	0.14
FLUCTU	Low or moderate low	29	Reference	Reference	Reference
	Medium	18	-0.29	0.25	0.04
	High or very high	18	-0.25	0.40	-0.15
CAP	Null or negligible	11	Reference	Reference	Reference
	Medium	11	-0.23	0.42	-0.20
	Important or essential	43	-0.05	-0.10	0.16

*p<0.1; **p<0.05; ***p<0.01

Results show that farms having a scaling system are more prone to implement limited or optimum vaccination protocol.

To explore factors influencing the implementation of prophylactic antibiotic use by fatteners, a binomial logistic model was used with the dependent variable specified as ANTIBIO and the following explanatory variables: GENDER, EDUC, OTHERPROF, MORTALITY, FLUCTU, REGRISK, SIZE, SCALE, and

RESTRAIN. After the backward stepwise selection, EDUC, OTHERPROF, FLUCTU, REGRISK, SIZE, and SCALE remained in the final model (Table 29).

Table 29: Marginal effects of variables linked with prophylactic antibiotic use against BRD when weanlings enter feedlots (fatteners' point of view), using two different models (n=65)

			Multivariate analysis	
Variables	Items	Number or individuals	Marginal effects	p-value
EDUC	No diploma, certificate of general education, or high school diploma	41	Reference	
	Bachelor's degree or master's degree	24	0.30*	0.070
SCALE	No	23	Reference	
	Yes	42	0.20*	0.072
REGRISK	No	36	Reference	
	Yes	29	-0.27**	0.022
FLUCTU	Low or moderate low	29	Reference	
	Medium	18	-0.26**	0.011
	High or very high	18	0.19	0.29
OTHERPROF	No	27	Reference	
	Yes	38	-0.37**	0.013
SIZE (number of fattening places)	]0;112]	21	Reference	
	]112;223]	21	0.57***	0.0017
	>223	21	0.32	0.14

*p<0.1; **p<0.05; ***p<0.01

Larger farms are more prone to use prophylactic antibiotic, but the effect is nonlinear (partial support for *hypothesis 3a*).

More prophylactic antibiotic use for more educated fatteners. In addition, farmers having another professional activity could use less antibiotics. (No support for *hypothesis 3b*)

More risk adverse fatteners are less prone to use prophylactic antibiotic. (No support for *hypothesis 3c*)

5. Discussion

5.1. Information transmission and possibilities to improve animal health management practices for BRD

Raising awareness of the importance of information transmission for better mitigation of BRD risks could be of paramount importance for all stakeholders in the value chain. Middlemen are involved in most governance structures within beef value chains and they seem to act as a barrier to information flow between the cow-calf producers and the fatteners. For most transactions (except for direct transfers from the cow-calf to the fattener), no information regarding the farms of provenance, the commingling of weanlings, or the prior implementation of a vaccination protocol is available for the

fattener. Fatteners thus do not have the opportunity to evaluate the level of BRD risk of the batches they purchase, and thus to adapt their health management practices to reduce BRD risks, for instance refraining from prophylactic use of antibiotics if the actual BRD risk is low.

As there is no information transmission on health-related credence attributes to the fattener, there are no possibilities to reward producers for these attributes. Cow-calf producers thus have no incentives to implement optimal vaccination protocols, which adds costs and is time consuming. Incentivising cow-calf producers to implement vaccination against BRD could be a lever to improve the rate of vaccinated weanlings and reduce prophylactic antibiotic use (Ochieng' and Hobbs, 2016). However, this would be useful only if fatteners had accurate information on previous vaccination protocols and thus the level of BRD risk in their intake of weanlings, and adapted their prophylactic antibiotic use. Nevertheless, even in lower BRD risk situations when there is direct transfer of weanlings and good information transmission about prior health management practices within the value chain, fatteners' animal health practices are not significantly better than other fatteners. This could be explained by the fact that animal health issues are one of the most important sources of stress for farmers and they may not wish to take any chances in this regard (Visschers et al., 2014). Fatteners may thus wish to take steps to ensure the minimum level of risk and continue to use antibiotics in a prophylactic manner even in lower-risk situations. The economic impacts of BRD are extremely large and constitute a high risk for feedlots (Delabouglise et al., 2017). In addition, antibiotics can be seen as an easy and secure way to control diseases (Vaarst et al., 2006). Finally, training cattle producers to facilitate a change in perceptions with respect to antibiotic resistance issues could be important, especially as farmers' perceptions influence their practices (e.g. Friedman *et al.*, 2007). Veterinarians, who are a major source of information for antibiotic use, could have a key role to play in this regard (Russell and Bewley, 2013).

5.2. Cattle producers' and farms' characteristics and possibilities to improve animal health management practices for BRD

In the sample, cow-calf producers with bigger farms and investment in market-oriented equipment (a weighing scale) are more willing to implement a vaccination protocol against BRD. This could be related to the organisation of the work on farm and the possibility to more easily handle weanlings for vaccination. In addition, it has been shown that larger farms are more prone to take advice from a veterinarian (Russell and Bewley, 2013), thus veterinarian advice is likely to have an important role in the adoption of optimal vaccination protocols. On the contrary, in the sample, larger feedlots are more likely to implement prophylactic antibiotic use. This could be linked to time limitations and preventative risk management strategies for fatteners that face bigger financial risks (Visschers et al., 2014). This could also be linked to biological and logistical reasons: larger feedlots could be sourcing weanlings that are likely to come from a variety of sources, with higher levels of comingling, and therefore, higher risks of exposure to BRD. Diversified farming operations with other farming activities in addition to the feedlot could also limit the implementation of more desirable prevention measures because of time limitations, such as implementing optimal animal health management practices in the beef fattening side of the business incurring a higher opportunity cost.

In the sample, the risk perception of fatteners also influences antibiotic use, which is consistent with other studies (Ge et al., 2014). Fatteners' who perceive work accidents as a major risk could be more risk averse in general, and thus use more prophylactic antibiotics (Visschers et al., 2014). On the

contrary, fatteners perceiving a risk of a change in regulations could be more attuned to the impact of regulations on their farm business, and therefore more aware of increased legal restrictions regarding antibiotic use as they are less likely to utilise prophylactic antibiotics. Legal restrictions in France have been increased since the beginning of the first national plan for antibiotic reduction (EcoAntibio 2012-2017), and further restrictions on prophylactic use of antibiotics are likely to occur.

5.3. Limitations

Some limitations of our analysis should be addressed. First the selection of cattle producers was difficult and thus two different methods of data collection were used (internet and telephone), with 5 different "data collectors". This could induce bias in the quality of data collection. In addition, telephone collection of data allowed interactions and questions could thus be explained and answers adapted depending on the oral interaction. In addition, the selection of cattle producers was not random as technical institutes, cooperatives and middlemen provided contacts. Second, evaluating cattle producers' health management practices based on self-assessments by survey respondents is challenging. For instance, some fatteners state that they buy weanlings that have received the primary vaccination against BRD at the cow-calf farm; however, at the same time, they declare having no information on previous vaccination protocols implemented before purchase. The proportion of prophylactic antibiotic use (34%) seems to be low compared to the rough estimation from experts in the value chain (>60%). This could be due to imperfect knowledge of farmers regarding antibiotic use (Moreno, 2014). In addition, in the beef sector as in other sectors, the poor knowledge of farmers regarding veterinary medicines and their use is nurtured by marketing techniques such as the regular replacement of branded medicine names. This could possibly increase the confusion when cattle producers report their practices. Results of this analysis should be interpreted in the light of these limitations.

6. Conclusion

The quantitative analysis aimed at understanding elements influencing cattle producers' decisions to implement health management practices in the French young beef bulls value chain. The structure of supply chain relationships (transaction governance structure) and information transmission on health-related credence attributes, including the adoption of optimal health management practices for weanlings, were expected to be related. Health management practices were also expected to be influenced by the nature of the farm operation, and farmer characteristics, particularly their level of education and their risk perceptions and attitudes.

Only one kind of governance structure, direct transfer of weanlings from cow-calf to feedlot facilities, seemed to be related with transmission of information about credence attributes in the survey sample. The availability of information about credence attributes such as prior production and animal health management practices, the origin of cattle, the degree of comingling, seemed to be non-existent in other governance structures, as middlemen were involved and therefore the relationship between cow-calf producers and fatteners was less direct. The adoption of improved health management practices was instead influenced by the type of farming operation and the characteristics of the cattle producers. Larger and more diversified farms used more prophylactic methods (vaccination and prophylactic antibiotic use). If fatteners perceive that a regulatory change with respect to the use of

antibiotics in the beef sector is likely, this may incentivize proactive steps towards more prudent antibiotic use.

Economic levers could thus be targeted in the value chain to improve vertical coordination and information flows between stakeholders and to better reward credence attributes that would be related to a lower level of BRD risk, such as vaccination of weanlings by cow calf producers. To reduce prophylactic use of antibiotics, communication on antibiotic resistance issues as well as the effectiveness of prudent risk mitigation strategies could improve practices. Further research into understanding the economics of different production practices, such as the costs of cow calf producers undertaking optimal vaccination protocols and the premiums that would be necessary through the supply chain to incentivize the adoption of those protocols could help public policy and private actors to meet public health protection objectives.

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Appendix

Table A1: Semi-structured interviews and field observations

Profession	Number, of interviews / field observations	Depending institution
Semi-structured interviews		
Cow-calf producer* **	7	Cooperative and independent
Breeder-fattener* **	12	Cooperative and independent
Fattener* **	5	Cooperative and independent
Middlemen* **	10	Cooperative and independent
Farm advisors*	4	Cooperative
Veterinarians* **	8	Cooperative and liberal
Middlemen superiors*	3	POC and PONC
Chamber of Agriculture*	1	-
Meat producers' Union*	1	-
Slaughterhouse director*	1	-
Senior Official**	2	French Ministry of Agriculture
Field observations		
Specialized fattening units*	4 (one day)	-
Livestock Market* **	2 (one day each)	-
Sorting centre*	2 (2 hours each)	Cooperative

Regions considered: *Western France; ** National; ***Western France and Central France

Table A2: Variable eliminated from the final model as they were unrelated with the dependent variables (implementation of vaccination protocol, and implementation of antibiotic injection in the logistic regression models).

Variable	Description	Units
Farmers' characteristics		
AGE	Age of the farmer	years
EXPE	Number of years of work experience as a cow-calf producer, a fattener or a cow-calf and young bulls producer	Years
INSTAL	Number of years since settlement	years
MORTALITY	Mortality rate	Percentage
INVESTRISK	Farmers' perception of the uncertainty linked to market investment burden (0=no, 1=yes, one of the two major risk perceived)	0, 1 nominal
PRICERISK	Farmers' perception of the uncertainty linked to market price fluctuations (0=no, 1=yes, one of the two major risk perceived)	0, 1 nominal
SANIRISK	Farmers' perception of the uncertainty linked to animal health risks (0=no, 1=yes, one of the two major risk perceived)	0, 1 nominal
Farm characteristics		
RESTRAINT	Restraint tools for animal manipulation (0=no, 1=yes)	0, 1 nominal
REGION	French region where the farm is settled	nominal
BREED	Major breed raised in the farm (0=Charolais, 1=Limousin, 2=Blonde d'Aquitaine, 3=other)	0,-3, nominal
ACTIVE	Number of active members in the farm	Number
OTHERFARM	Other farming activity (more than 50ha cereal fields, other animal farming)	number

HOG	Hog farming activity in the farm (0=no, 1=yes)	0, 1 nominal

Table A3. Cow-calf producer clusters with similar governance structures, level of information transmission and health management practices

Variables		Mod/Cla (%)	Global (%)	p-value
Cluster "Independent" (n=2)				
CONTRACT	Spot market	100	2	0.00030
	Oral informal contract	0	95	0.0018
Cluster "Formal contracting (n=2)				
CONTRACT	Oral informal contract	0	95	0.0018
	Formal contract	100	2	0.00030
Cluster "Relational" (n=65)				
COORD	Direct transaction	0	5	1.4e-3
CONTRACT	Spot market	0	2	4.1e-2
	Oral informal contract	100	95	1.4e-3
	Formal contract	0	2	4.1e-2
INFODESTIN	No	97	83	6.0e-9
	Yes	3	17	6.0e-9
INFOPERF	No	98	87	9.2e-8
	Yes	1	13	9.2e-8
Cluster "Informed"(n=13)				
COORD	Livestock market or 2 or more middlemen	8	38	1.32e-2
	Direct transaction	31	5	4.09e-04
INFODESTIN	No	8	83	1.39e-11
	Yes	92	17	1.39e-11
INFOPERF	No	23	87	1.42e-9
	Yes	77	13	1.42e-9

*p<0.1; **p<0.05; ***p<0.01

Table A4. Matrix from the Random Forest test implemented on the clusters (Cow-calf producers)

	Independent	Formal contracting	Relational	Informed	Accuracy (average)
Independent	2.1	0	0	0	0.94
Formal contracting	0	2.1	0	0	
Relational	0	0	74.9	4.1	
Informed	0	0	2.1	14.9	

Table A5. Fatteners clusters with similar governance structures, level of information transmission and health management practices

Variables		Mod/Cla (%)	Global (%)	p-value
Cluster "Formal" (n=27)				
VACCIN	No vaccination	7	22	2.1e-2
	Optimum vaccination protocol	78	55	2.5e-3
ANTIBIO	Always	26	14	2.5e-2

COORD	Livestock market or 2 or more middlemen	0	20	3.3e-4
	Single middleman	100	65	6.8e-8
	Direct transaction	0	15	2.6e-3
CONTRACT	Formal contract	52	32	6.0e-3
INFONUMFARMS	No	100	65	6.8e-8
	Yes	0	35	6.8e-8
INFOSOURCE	No	100	60	2.7e-9
	Yes	0	40	2.7e-9
INFODIS	No	100	86	5.1e-3
	Yes	0	14	5.1e-3
INFOVAC	No	85	63	1.9e-3
	Yes	15	37	1.9e-3
AGECHOICE	No	100	88	9.7e-3
	Yes	0	12	9.7e-3
PRICECHOICE	No	89	75	3.6e-2
	Yes	11	25	3.6e-2
CREDENCE	No	85	71	3.4e-2
	Yes	15	29	3.4e-2
Cluster "Independent" (n=14)				
VACCIN	No vaccination	50	22	8.5e-3
	Optimum vaccination	14	55	6.2e-4
COORD	Livestock market or 2 or more middlemen	79	20	2.9e-8
	Single middleman	14	65	2.1e-5
CONTRACT	Oral informal contract	36	14	2.0e-2
	Formal contract	0	32	1.9e-3
INFOSOURCE	No	86	60	2.9e-2
	Yes	14	40	2.9e-2
Cluster "Relational" (n=13)				
VACCIN	No vaccination	0	22	2.9e-2
ANTIBIO	Sometimes	39	17	4.0e-2
COORD	Single middleman	92	65	1.9e-2
INFONUMFARMS	No	31	65	7.3e-3
	Yes	69	35	7.3e-3
INFOSOURCE	No	0	60	6.3e-7
	Yes	100	40	6.3e-7
AGECHOICE	No	62	88	6.6e-3
	Yes	38	12	6.6e-3
Cluster "Informed" (n=11)				
COORD	Single middleman	9	65	5.7e-5
	Direct transaction	82	37	1.7e-8
INFONUMFARMS	No	9	65	5.7e-5
	Yes	91	35	5.7e-5
INFOSOURCE	No	0	60	8.6e-6
	Yes	100	40	8.6e-6
INFODIS	No	36	86	1.5e-5
	Yes	64	14	1.5e-5
INFOVAC	No	0	63	2.8e-6
	Yes	100	37	2.8e-6

INFOATB	No	9	66	3.3e-5
	Yes	91	34	3.3e-5
CREDENCE	No	36	71	1.2e-2
	Yes	64	29	1.2e-2

Table A6. Matrix from the Random Forest test implemented on the clusters (Fatteners)

	Formal	Independent	Relational	Informed	Accuracy (average)
Formal	47.5	1.3	0	0	0.91
Independent	0	14.8	0.7	0.7	
Relational	0	2	14.6	2.2	
Informed	0	0.7	1.3	14.1	

Chapitre 3B : Identification de leviers pour améliorer la transmission de l'information et la gestion des risques de maladies respiratoires : comparaison des systèmes d'élevage français et canadiens

Note d'avancement : Ce chapitre, après travail supplémentaire à réaliser, devra être soumis à une revue d'économie, Food Policy par exemple.

Abstract

Reducing antibiotic use is important to limit the spread of antibiotic resistance. In France and in Canada, beef meat producing sectors are using antibiotic at the beginning of the fattening period in a systematic and preventive way to mitigate the risk of bovine respiratory diseases (BRD) in feedlots. To get rid of prophylactic antibiotic use, the risk of BRD has to be reduced. However, the level of BRD risk depends on the previous stages of the producing process (cow-calf producers and middlemen). This article thus explores initiatives to improve BRD risk management practices in the value chain. We used qualitative semi-structured interviews (70) to compare the value chains in France and in Canada. Observed similarities allow the comparison of the two systems. Initiatives existing in both countries are inspiring to discuss possible levers to implement and their limitations to improve BRD risk management.

Key words

Value chain; Young bulls; Steers; quality; information; antibiotic; case study

1. Introduction

Antibiotic resistance is a major issue for human and animal health (*e.g.* World Economic Forum, 2018). Reducing antibiotic use is a paramount target to prevent further development of antibiotic resistance. Worldwide, half of produced antibiotic are used for animal health (Laxminarayan et al., 2013), and especially for meat producing animals.

France and Canada are two important beef meat producing countries and have roughly similar value chain organisation: in most farms, meat calves are produced in extensive pasture based systems, then sold at the stage of weanlings (6-9 months) or yearlings (12 months). They are then fattened in feedlots barns, based on intensive grain and by products feeding systems. In those systems, bovine respiratory diseases (BRD) are responsible for more than 75% of diseases happening during the fattening period (Assié et al., 2009). At the beginning of the fattening period, BRD risk is so high that most farmers use preventive and systematic antibiotics to mitigate that risk (source: expert). However, nowadays, due to overuse, antibiotics efficiency is decreasing (Gautier-Bouchardon et al., 2014). In order to prevent further expansion of antibiotic resistance, antibiotic use should be reduced to the necessary minimum, which questions the systematic preventive use, also called prophylactic use.

Preventing BRD risks at the beginning of the fattening period without using prophylactic antibiotic requires significant efforts from stakeholders involved in the rearing and the marketing of weanlings (vaccination, logistic improvement, etc.). The latter stakeholders' practices (cow-calf producers and

middlemen) have an influence on the level of BRD risks, but at the end, they do not have to face the expression of the disease, which occurs at the fattening stage. Preventing BRD risks without prophylactic antibiotic use at the fattening period thus implicates all stakeholders of the value chain, and their organisation.
The main objective of this paper is to identify levers to support stakeholders to improve BRD risk management practices by avoiding prophylactic antibiotic use. A broad observation let us to assume that French and Canadian are quite similar in terms of vertical organisation of the value chain. As a consequence, analysing improvements and limitations from initiatives in both countries should be inspiring to suggest a large set of possible levers to develop.

1.1. Background: BRD risk management practices, implications for value chain coordination

In the young beef bulls value chain, major antibiotic use occurs at the beginning of the fattening period in order to prevent an important risk for BRD (Radostitis et al., 2006). However, the risk of BRD and the possible prevention measures that could avoid antibiotic use implicate upstream stages of the value chain, before the entrance of weanling (calves from 6 to 9 months) or yearlings (one-year-old calves) in feedlot operations.

From a biotechnical point of view, two major strategies can be implemented to control BRD without using prophylactic antibiotic: reducing the BRD risk by zootechnical measures; or reducing BRD risk by medical preventive measures.
First, from the cow-calf producing farms to the feedlots, weanlings (or yearlings) are transferred directly, or through sorting centres and livestock auctions. The longer the transfers and the more mixed the animals from different herds, the higher the risk of BRD. Reducing the lengths of transfers reduces animal stress and prevents a deficiency in the weanlings' immune systems. Reducing the mixing of animals for transfers and for the constitution of batches at the feedlot reduces microbial exchanges and thus the contamination risks and bacterial or viral disorders. To better control BRD risks, the most prudent practices would be:

- To choose an appropriate season for calving, and thus fattening (Cernicchiaro et al., 2012a; Gay and Barnouin, 2009),
- To prevent diseases during calf period (Bach et al., 2011),
- To do the weaning long enough before other stressful events: vaccination, transport of weanlings (Faber et al., 1999; Step et al., 2008),
- To increase the weight of weanlings at the beginning of the fattening (Sanderson et al., 2008),
- To reduce transportation duration (Cernicchiaro et al., 2012b; Hay et al., 2014; C. S. Ribble et al., 1995c; Sanderson et al., 2008),
- To reduce mixing of weanlings for batching (Hay et al., 2014; C. S. Ribble et al., 1995b),
- To reduce the number of farms of origin in a given batch (Hay et al., 2014; C. S. Ribble et al., 1995b; Sanderson et al., 2008),
- To implement proper feed transition between weaning and fattening, which is more about general good health of weanlings (Castillo-Lopez et al., 2014).

Second, one can implement a vaccination protocol to fight BRD pathogens[50]. Best vaccination protocol is when the primary injection of vaccine is performed at the cow-calf farm, at least 30 to 45 days prior shipping. This considerably increases the level of protection. Vaccination can also be implemented at the entrance in the feedlot, but it remains less effective due to the response time of the immune system. Best vaccination practices thus would be (Gay and Barnouin, 2009; John G Kirkpatrick et al., 2008; Joanne E Macartney et al., 2003):

- Early vaccination of calves, when mother immunity is no longer prevailing
- Vaccination or booster before the weaning and shipping of animals. Primary vaccination and booster implemented close enough to the fattening period to remain efficient, or primary vaccination implemented and information transmitted so that the booster can be properly implemented afterward.

Those two major strategies to improve BRD control constitute credence attributes of the quality of weanlings for the cow-calf to feedlot transaction. Those attributes are non-visible, and thus may not be evaluated at the purchase of the animals, except for a few of them (calving season, weight). To take all these characteristics into consideration, information transmission between stakeholders is crucial.

1.2. Challenges and regulatory framework for antibiotic use in France and Canada

French and Canadian regulatory frameworks for antibiotic use differ.

In Europe (EU-28), the use of antibiotics as growth promoting purpose (*i.e.* administrated at lower doses than therapeutic ones) is forbidden since 2006[51]. In Canada, this practice is still current in feedlots to increase feed intake efficiency, to help for the control of rumen acidosis, and to reduce liver abscess (e.g. Monensin).

Since April 2007 in France, the purchase of antibiotics[52] by farmers is controlled and can only be possible under the medicine prescription form veterinarians. In Canada, antibiotics are available for purchase without any prescription. However, a forthcoming new regulation tends to make the antibiotic purchase conditional to an established veterinarian-farmer relationship[53].

France and Canada sorted antibiotic depending on their importance for human health. Antibiotics from the class I are the latest antibiotics commercialized on the market, and levels of resistance are still limited. In order to protect their efficiency, the use of these antibiotics has thus to be limited. Canada also has 3 other antibiotic categories which are defined according to their importance for human use. The last category (category IV) includes antibiotics used only for animal health. These antibiotics will be possibly used without any veterinarian prescription even after December 2018. French law only considers an equivalent of the Canadian Class I antibiotics, also called “antibiotics of critical importance”. Other Canadian antibiotic categories do not have equivalents in France. Since April 2016, antibiotics of critical importance can only be used if the proof is made that no other therapeutic options are available[54]. In addition, further regulation could forbid any prophylactic use of antibiotics. More broadly in Europe, Netherlands already adopted this regulation in 2013 (Scherpenzeel et al., 2016).

[50] Pathogens are: ….

[51] Règlement (CE) N°1831/2003 du Parlement Européen et du Conseil du 22 septembre 2003 relatif aux additifs destinés à l’alimentation des animaux

[52] Décret n°2007-596 du 24 avril 2007

[53] Source: https://www.canadianveterinarians.net/valid-vcpr (available the 28th of April 2018)

[54] Décret n°2016-317 du 16 mars 2016

The paper is organized as follows: section 2. shortly describes the theoretical framework used for the analysis; section 3. describes methods used for the data collection and the analysis; section 4. presents the results, first a comparison of the French and the Canadian system to confirm the hypothesis of sufficient similarities to jointly analyse present levers in both systems, then an analysis of the levers implemented by stakeholders on field, and their limitations as expressed by stakeholders; section 5. concludes with a discussion on the levers and their limitations as well as possible ways to overpass them.

2. Theoretical framework

The theoretical framework of the value chain aims to describe complex networks of material (products) and non-material (information, value) flow in a given sector. This framework has been used to understand the importance of the organisation of sectors' networks in the dynamic of epidemic diseases (e.g. Martin *et al.*, 2011; Paul *et al.*, 2015).

In the young beef bulls'/steers' value chain, a particular focus was given on information transmission and on quality attributes of weanlings. Those two points have been shown to be of major importance to know and control the risk of BRD at the beginning of the fattening period (Poizat et al., 2018).

We also analysed the existing levers and their limitations in regard of the scientific literature on factors influencing or limiting the adoption of disease control programs (Ochieng' and Hobbs, 2016).

3. Methods

3.1. Qualitative approach and data collection

We conducted qualitative semi-structured research interviews. Qualitative semi-structure interviews allow describing a wide range of possible circumstances in a given field and understanding complex systems, including sociological and economic drivers (Kvale, 1996; David C. Speksnijder et al., 2015). Qualitative methods do not aim to be representative but to represent the diversity of existing situations. This method is preferred when information is non-existent or rare. Length of interviews are important to establish confidence and authentic discussions (Brinkmann and S. Kvale, 2015).

Interviews are held using guidelines to explore research issues. Guidelines were adapted depending on the profession of the interviewee. We focused on the organisation of the value chains and how stakeholders took weanlings' health and BRD risks into consideration. Interview guides were structured as follows: (i) general presentation of the structure (farm, association, company), (ii) everyday work and interaction with stakeholders of the value chain, (iii) practices regarding health management, antibiotic use and interaction with veterinarians, (iv) vision for the future prospects of the sector, possible improvements of vertical coordination between stakeholders.

Three interviewers, two master students in agriculture, and one veterinarian were responsible for data collection. Interviews were usually recorded and transcribed. However, four interviews with stakeholders having national positions in France could not be recorded, due to their mistrust. Moreover, only one interview in Canada could be recorded, due to technical constraints. When recording was not possible, precise notes were taken during and just after interviews in order to report interview exchanges as accurately as possible. Recording and precise notes are supposed to limit *a posteriori* interpretation.

3.2. Selection of interviewees

Selection strategy of interviewees aims at the description of a diversity of circumstances regarding the research question (Lagarde, 2006; Sivertsson and Tell, 2015). The sample selection size is difficult to establish and depends on the complexity of the explored field. However, when saturation is established (different stakeholders' points of view reaching information already collected), the sample should be considered to be large and diverse enough (Morse, 2015). To ensure the diversity of points of view we selected stakeholders with different geographic location (to a relatively lesser extent in Canada than in France, due to constraints of higher distances for the interviewers), scale of action (local, regional or national), scale of activity (from small to large farms), and nature of function (Annex). In France, farmers and farm technicians were selected in close collaboration with the French Livestock Institute and agricultural cooperatives. Veterinarians, cooperatives managers, managers of producer organisation of non-commercial nature (PONC), employees at the "Chambre d'Agriculture"[55] were also included in the sample.

In Canada, farmers, middlemen and employees at the Canadian Cattlemen's Association were selected with the help of the Saskatchewan Cattlemen's Association and the Beef Cattle Research Council.

The exhaustive analysis was based on 70 semi-structures interviews (54 in France, 16 in Canada).

3.3. Data analysis and triangulation

Transcription of data and notes taken during interviews were examined in the light of the value chain framework and the research question regarding (i) the description of existing practices for the control of BRD risks, (ii) levers to improve information transmission and valuation of vaccinated weanlings in the value chain, (iii) limitation of already existing levers to improve BRD risk management. In respect of the standard qualitative method, the analysis was enriched as the examination of new interviews moved forward (Balarajan and Reich, 2016).

In order to reduce bias, we tried as much as possible to triangulate the extractions from the interviews with (i) scientific literature about BRD risks factors and risk management, (ii) grey literature about French and Canadian young beef bulls'/steers' organisation of the production. We used technical, legislative documents as well as reports for national and provincial institutions, and conference proceedings, (iii) scientific literature to develop the analysis of the levers and limitations to improve BRD management. When information came from the interviews, no precision is given in the text, otherwise, source of information is always reported.

3.4. Limitations

There are some limitations to be addressed in this qualitative case study. First, regarding the content of interviews, guaranty unbiased collection of data from stakeholders is always challenging, especially when addressing complex issue. This could be even stronger when dealing with sensitive topic such as antibiotic use. Second, regarding the sampling method, most interviewees were located in 2 regions (Western and Central France) and 2 provinces (Saskatchewan and Alberta). The beef meet production however exists in other parts of these countries. We thus tried to complete our data collection by interviewing stakeholders having a national vision of the value chain. Second, we met a large diversity of stakeholders and the information collected attained saturation, suggesting that our sample was large enough to allow a comprehensive analysis of the value chain. Nevertheless, the sampling of

[55] Local or regional public establishment of administrative character supporting farmers' development, applied research and extension services

interviewees in Canada is small (16). The results of this exploratory qualitative case study should be interpreted in the light of these limitations.

4. Results

4.1. Comparison of the French and the Canadian young beef bulls value chain

The French and Canadian young beef bulls (or steers) value chains are composed of the same major producing steps (Figure 13) and the size of beef cows' population is roughly equivalent (4.16 million in France vs 3.83 million in Canada). The backgrounding is an optional step to be taken. The backgrounding of weanlings is more frequent in Canada than in France.

In both value chains, calving and fattening are possibly handled in the same farm, however fattening operations are frequently separated from calving operations, if not the dominant model. This fragmented organisation is based on the valuation of different soil characteristics: (i) cow-calf farms are pasture based. They often use large grazing landscape, with poor grain growing capabilities. They are thus based in regions with poor soil characteristics, but having landscape space; (ii) feedlots are silage and grain feeding based. Fattening happens on pens, and values by-products of intensive crop productions. They are mainly located in more industrialized regions where competition for soil occupation is stronger, and grain by-products available.

The backgrounding step is uncommon in France, while backgrounding cattle in Canada occurs approximately for 60% of total cattle. The pasture of yearlings may occur marginally, after backgrounding and before the finishing step. These two steps happen to be chosen according to specific market conditions. In the case of additional producing steps, there is scarcely more than 3 owners, and two following steps can be handled by the same farmer.

Export is important both for French and Canadian production[56]: (i) half of French weanlings are exported, mostly to Italy; half of Canadian weanlings are exported, mostly to the US; (ii) a large part of steers' (young bulls') meat is exported too.

In both value chains, middlemen are involved in the transaction to match the demand of the fatteners with the supply of cow-calf producers. Most transactions (if not all in Canada) are conducted without any long term formal contract. Most relationships are long term and confidence based (relational contract). Cattle might also be transacted through livestock auction markets, or directly from a cow-calf producer to a fattener. Cattle are kept relatively longer in Canadian than in French livestock markets (resp. 2 to 7 says vs. 1 day). Distance of transportation are bigger in Canada. However, in both countries the relative transportation costs are negligible compared to weanlings' and steers'/bulls' price.

Within the value chain, information transfers and adding value with credence attributes are a huge issue. From the moment weanlings leave the cow-calf farm, the only remaining information is the one included in the ear tag (Canada and France), or in the green card (identity card, in France). All the definition of quality thus relies on purchase attributes (visible attributes before purchase, such as shape, body conformation). Credence attributes (non-measurable attributes before purchase) such as health protocol or daily weight gain is unknown to the potential purchasers and thus they cannot be taken into consideration. For most stakeholders, quality is a question of homogeneity of size and

[56] Source : L'essentiel de la filière bovine. 2017. Interbev.
Canada's Beef Industry, Fast Facts. 2017. BCRC.

weight of weanlings in a same batch, which are two purchase attributes. There might however be value added and premiums for bigger batches constituted with homogenous weanlings from the same farm. Nonetheless most of time no premiums are granted for vaccinated weanlings or better prepared weanlings for fattening.

In addition, information transfers are almost inexistent from the feedlot to the cow-calf farm. If feedlots receive feedback from the packers regarding carcass yields, they do not transmit the information to the cow-calf. However, in the case of extremely poor performances of finishing, feedlots might request a ban to the middlemen to further avoid the source of purchase.

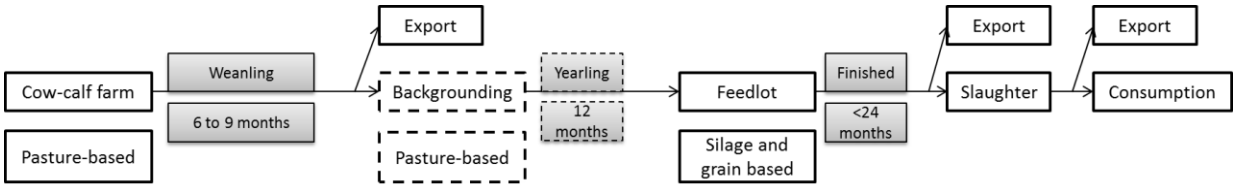

Figure 13: Value chain for Canadian and French young beef bulls or steers

Despite their similarities, French and Canadian systems differ to some extent. Here we narrow our description of these differences to the focus of our research question.

First, the size of cow-calf farms is bigger in Canada[57]. The average cow-calf is about 50 cows in France vs. 69 cows in Canada. Around 11% of cow-calf farms are composed of 100 or more cows in France while 33% of cow-calf farms consist of 122 or more cows in Canada. Regarding the smaller cow-calf operations, 68% of cow-calf farms own less than 50 cows in France while 39% of cow-calf farms have less than 47 cows in Canada.

Second, in Canada weanlings are castrated at the cow-calf farm whereas not in France. Thus are fattened in Canada whereas young bulls are in France. One of the consequences is that the Canadian conventional beef is raised with hormonal programs.

Third the farming systems are quite different regarding diverse aspects:

- Feedlots are indoors in France vs. outdoors in Canada,
- The basic size of batches for fattening is of 15 animals in France vs. 250 in Canada,
- Weanlings are fattened on a silage base in France, whereas silage and grains are used in Canada. In the latter system, high digestible grains trigger rumen acidosis and fatty toxic acids production. To control this phenomenon, antibiotics (e.g. ionophores) are used as feed additives.

Finally, one major difference is that different marketing channels exist in France and in Canada (Table 30).

In France, cattle are bought and sold: (i) directly from cow-calf producers to fatteners (pretty rare) (ii) through the mediation of a buyer. The buyer might be independent. In this case, he might act as an independent or belong to a PONC[58]. The buyer also might belong to a cooperative. From 5 to 20% of transactions are conducted with contracts (Marty et al., 2015); (iii) through livestock auction market.

In Canada, cattle are bought and sold: (i) directly from cow-calf producer to fatteners; (ii) through the mediation of a buyer. Buyers might be independent; or get a commission for transactions concluded

[57] Source: L'essentiel de la filière bovine. 2017. Interbev.
Canada's Beef Industry, Fast Facts. 2017. BCRC.

[58] PONC = Production Organisation of Non-Commercial Nature. They have an interface role by gathering farmers and middlemen in their association. They do not buy or sell cattle.

for other buyers; or be an employee of a private company (owned by cattlemen associations or private interests); (iii) through livestock markets, which are physically held or virtually held through internet. In the latter case, middlemen paid by the livestock market go to check weanlings in farms, asses the conformation quality, take pictures and videos.
Retained ownership or custom fed cattle is also common. For retained ownership, the cow-calf producer remains the owner of the weanlings and delegates the fattening part. However, even in these cases, middlemen might be involved in the transaction. Custom feed might be a synonymous for retained ownership from the feedlot point of view, but can also describe a system where investors buy weanlings in a feedlot to be fattened.

Table 30: Existing marketing channels in France and Canada

Marketing channels	France	Canada
Direct transfers (with or without order buyer)	X	X
Retained ownership/custom feed	(X)	X
Livestock auction markets	X	X
Internet livestock auction markets		X
Order buyers		X
Independent buyers	X	
Buyers from cooperatives	X	
Buyers from non-commercial organisation of production	X	

4.2. Levers and limitations existing in France or Canada to improve BRD management, from regulation to market incentives

4.2.1. Public incentives

Both French and Canadian governments implemented communication campaigns to reduce the antibiotic use (resp. National plan EcoAntibio since 2012; Federal action plan on antibiotic resistance and use in Canada since 2014), advocating for more virtuous vaccination protocols rather than antibiotic use. These programs target a quite large audience, including dairy, poultry or hog farmers. In France, they showed success with a reduction of 36,6% of the level of antibiotic exposure between 2012 and 2017 (Méheust et al., 2017). However, the impact was more limited on the beef sector. Trainings and communication campaign could thus be more focused on the beef sector. In Canada, regulation on antibiotic prescription is currently strengthened to limit access to antibiotics.
Discussions about the interdiction of the prophylactic use of antibiotics are ongoing in France. Such restriction is still at issue as the risks for the profitability of the value chain are important.

4.2.2. Market and supply chain incentives

The development of health incentives within the supply chain is to target actions aiming at (i) improving vaccination and conditioning protocols at the cow-calf farms, (ii) limiting stress during transfers, (iii) limiting the commingling of weanlings from different origins before the riskiest period for BRD. All these elements allow an improvement of weanlings' immunity and a reduction in BRD risks. However, these better management practices can only be useful if proper information is transferred to the feedlot operators so that they may adapt their preventive measures, such as

prophylactic antibiotic use depending on the level of BRD risk. Reliable information is thus of paramount importance.
Nowadays, using prophylactic antibiotics at the beginning of the fattening period is a relative cheap way to control an established and important BRD risk. Costs linked to better information transmission through the value chain about credence attributes (vaccination protocol and other BRD risks factors such as length of transfers or mixing of weanlings) should thus be reduced to minimum to be adopted by stakeholders. Initiatives to improve information transmission on credence attributes have been implemented from strong vertical integration to spot market.

Two vertical integration levels allow better information transmission and reduce BRD risks through reduced length of transfers and reduced commingling of weanlings (in market auction, sorting centre, or in the pens at the feedlot).
In Canada, the retained ownership (also called custom feed from the feedlot's point of view) allows cow-calf producers to delegate the finishing to feedlot operators. As they retain ownership, cow-calf producers are incentivised to improve vaccination protocols. During the feedlot step, cow-calf producers can choose which preventive health protocol to implement. They are thus responsible for the choice to administrate prophylactic antibiotic and they can make decisions having all the information regarding BRD risks. Retained ownership is also a way to reduce the commingling of weanlings in a given batch, and thus to reduce stress, microbial exchange and BRD risks. All those elements are in favour of reduced antibiotic use: risk is reduced and information about health management practices are transparent. A major limitation is linked to the capacity of the cow-calf farm to handle the financial risk linked to the fattening operation, and to control their cash requirement. Fattening weanlings implicates they don't get the money for the weanlings. In Canada, banks and middlemen can invest money to pay feeding bills or to make cash advances for cow-calf producers. In France, cooperatives could loan money.
In France and Canada, direct transportation of weanlings from cow-calf farms to feedlots allows the reduction of the stress linked to transportation and commingling. As intermediate steps between the cow-calf farm and the feedlot are reduced, stress linked to transportation and commingling is reduced too, and information about credence attributes is easier to get. However direct transportation is feasible only if a batch of weanlings is prepared for shipping half a truck or an entire truck. Otherwise, fatteners are not interested in small batches and transportation is too expensive.

In order to facilitate information transparency in the value chain, a Canadian veterinarian developed since 2001 a software to register farm management practices, including treatment and vaccination protocol[59]. The first intention of the software is to ease daily management of cow-calf farms. Farmers thus pay a yearly fee per cows to manage data of the farms. In addition, if members are willing to share their management information, members can track all information regarding their weanlings: (i) treatment, feed program and feed intake before weaning, (ii) treatment, feed program, performance during fattening, (iii) carcass yield and quality. All the members of the program are linked through a network, which allows (i) direct transaction and weanlings transfer, (ii) easy information sharing between two farms concluding a transaction. This system thus allows backward and forward information transmission. The customer base has been increasing up to approximately 600 farmers and 15 veterinarians. No such initiative exists in France.

[59] Available the 9th of May on: http://herdtrax.com/

The development of contracts or branded beef programs, having requirements with vaccination protocols implemented at the cow-calf farm, may help improving information transmission and the valuation of credence attributes.
In France, one cooperative designed for less than five years a contract that guaranties the vaccination of the weanlings at the entrance in the feedlot. Cow-calf producers receive a premium paid by the fattener for the increased credence quality attributes of their weanlings. In return feedlot operators do not get any premium at slaughter of the young bulls, but they benefit from the gain of performance of weanlings.
In France again the national association of the organisation of producers of non-commercial nature (OPNC), which includes buyers, cow-calf producers and feedlot operators, developed a certification program to guaranty vaccination protocol and deworming at the cow-calf farm. A premium is granted for certified weanlings. This program has been very newly implemented and results regarding the level of adhesion and trust to the program are still unknown.

In Canada, the development of internet auction markets reduces transportation length and mixing of weanlings for the sale in livestock markets. Whenever a farmer sells weanlings through the internet livestock market, a verification of the purchase attributes of the batches at sale is made by operators from the auction market. The credibility of the market is engaged for this certification. The presentation of batches at sale also improves information transmission as the name of the seller is known, and as the seller can add additional information regarding the batch management. For comparison, in traditional auction markets the only information transmitted for the sale are the age and the weight of weanlings in the batch.

Reputation of farmers and middlemen are important in the value chain. Some farmers or buyers have been banned because of wrong practices or deceit in the commercial agreement. Traceability from the cow-calf farm to the feedlot could create a link of confidence in order to value the vaccination protocols implemented by the cow-calf producers.

Table 31: Importance of different limits to implement proper preventive measures to reduce BRD prevalence at the beginning of the fattening period depending on stakeholders' point of view

	Canadian system*	French system*
Cow-calf producers		
De grouped calving systems, do not correspond to fatteners demand	+	++
Inconvenient farming systems making difficult calves manipulation (vaccination): herds on large pastures, "wild" calves	+++	++
Important workload, letting little free time to implement vaccination	++	+
Little surveillance of producing margins, reduces farmers' interest in investing in calves health	+++	++
No commercial valuation for properly vaccinated weanlings	++	+++
No feedback (information or money) for weanlings' performance during fattening, reducing involvement in improving weanlings' quality	++	+++
Opportunistic commercial behaviour	+	+
Commercialisation of weanlings, middlemen		
Supply issues, which do not allow commercial loyalty with suppliers and buyers and are in favour of the use of livestock markets	+	+
No reliable system of information transmission between the cow-calf producer and the fattener regarding health issues	+++	+++
Batching of animals submitted to logistical conditions and no animal health criterions	+++	+++
No commercial valuation of properly vaccinated weanlings	++	++
Fatteners/feedlots managers		
Demand for homogenous batches of weanlings, do not correspond to cow-calf producers supply	++	++
Lack of reliable information transmission regarding non visible attributes of weanlings' quality, no possible valuation	+++	+++
Geographical separation of cow-calf herds and feedlots	+++	++

* 0: no important restraint, +: medium important restraint, ++: important restraint.

However, all those coordination systems face four major limitations (Table 31).

First, cow-calf farms encounter logistical limits to implement vaccination. Cow-calf farmers have sometimes no facilities to manipulate weanlings, and not enough workforces to implement this time-consuming procedure. This could thus limit the impact of premium incitation. For instance, the initiative of the French cooperative is limited in volumes by the willingness of cow-calf producers to implement vaccination in exchange for a premium. Raising the level of premiums for cow-calf producers is still an issue for a large adoption of the protocol.

Second, French fatteners seem to be willing to pay a premium for vaccinated weanlings. More fatteners are willing to pay for vaccinated weanlings than cow-calf producers to vaccinate for a premium. In Canada, middlemen and fatteners seem to be more reluctant to pay a premium for vaccinated weanlings. Their preference goes to medium quality weanlings who will be manipulated

anyway to receive a treatment at the entrance of the feedlot (hormonal at least). To further improve the quality of weanlings, and thus justify a premium, some criterions could be added to the vaccination program at cow-calf. For instance weaning at a minimum delay before shipping, which reduces stress and BRD risk (Step et al., 2008). However, there is no clear protocol established to optimize this procedures, and extra costs are important for the cow-calf producers, requiring an important level of premium to compensate.

Third, the certification of efficient vaccination is an important limiting issue. In Canada, approximately a decade ago, pharmaceutical company developed a program to insure vaccination at the cow-calf farm. However, feedlot did not trust the protocol and were not willing to pay a premium. Stakeholders of the value chain argue that the guarantee of rigorous vaccination protocols (e.g. good conservation condition for vaccine, efficient administration, respect of the dose and date of administration) may require the testimony and presence of a veterinarian during the procedure, which would be very costly. This could even be impossible in Canada where veterinarian's shortage is sometimes important[60]. In France, treatment registration, bills and regular audit in cow-calf farms subscribing to a contract seem to be sufficient to guaranty the vaccination protocol. In the absence of written contracts, confidence built through the duration of business relationship could be sufficient, especially as relationship contractual agreements are common.

Finally, the volume of weanlings included in these systems to improve information transmission and valuation of credence attributes constitutes a limitation to further development. In Canada as in France, the supply of the cow-calf producers differs from the demand of fatteners: batches at sale are often smaller than batches in feedlots. As a consequence, commingling remains almost unavoidable before and/or at the feedlot. This increases BRD risk (Hay et al., 2014; Sanderson et al., 2008). In addition, for managers' convenience, prevention protocols are uniform for weanlings fattened in the same pen. This is especially true for Canadian feedlots where pens are bigger (250 weanlings *versus* 15 to 20 in France), distances longer, and thus BRD risk higher. If weanlings from farms having different prevention protocols and different level of credence attributes are mixed in a pen, there is then no longer possibilities to adapt prophylactic antibiotic use to the risk. This limitation could be mitigated if feedlots accepted to have more heterogeneous batches in terms of size and weight to limit commingling of weanlings. For instance, some feedlots in Canada only sort by weight their batches for the finishing part of the fattening, as the BRD risk is sharply decreased.

4.2.3. Other incentive

Production protocol incentives could be based on veterinarians' recommendations to use vaccination protocol against BRD pathogens. However, in Western provinces of Canada, rural areas encounter important veterinarians' shortages. In addition, cow-calf farms scarcely rely on veterinarians on regular basis: smallest farms almost don't need veterinarians, bigger farms call veterinarians for emergencies or c-sections, or once to twice a year to establish their regular health management protocol. In France, veterinarians are more involved in the management of calve health than the prevention of the weanlings' health disorders. However, the annual visit of a veterinarian to establish a health protocol for the herd is almost compulsory. These kind of advising visits, in France as in Canada, could be used to further advice cow-calf producers to vaccinate properly weanlings before the shipping to feedlots.

[60] Source: http://edmontonjournal.com/news/politics/veterinarian-shortage-looms-for-rural-alberta-after-province-nixes-agreement-critic available the 20th of April

5. Discussion and conclusion

In France and Canada, incentives to improve weanlings' health management already exist. National plans aim at reducing antibiotic use for animal health control. They are mostly based on communication campaign and reinforcement of regulations regarding antibiotic use. Both in France and Canada, some incentives could allow a reduction of antibiotic use: (i) reduction of intermediary steps to reduce BRD risks and improve information transmission between cow-calf producers and fatteners, (ii) increased transmission of weanlings' health attributes with technologic tools (internet, software), or with certification of vaccination practices.

Major observed limitations for further implementation of improved management of bovine respiratory disease in the value chain have echoes with other analysis (Ochieng' and Hobbs, 2016).

First at the cow-calf farm stage, implementing vaccination against BRD to protect weanlings for the beginning of the fattening period is of no benefits for themselves as the BRD causes no harm or loss in productivity of the weanling at that time. Farmers have no incentive (premium or penalties) to implement vaccination, which has been described by Tonsor and Schroeder (2015) as being a major reason for not adopting a vaccine.

In order cow-calf producers to adopt BRD vaccination, governments could also implement a subsidy for cow-calf producers to compensate the cost of vaccination. In France for instance, some Common Agricultural Policy (CAP) subsidies are already attributed under the respect of certain conditions such as environmental practices, but no conditions concern health management practices. However, adapted facilities, time and workforce are major limitations for cow-calf farms. Even with consequent subsidies, cow-calf producers could be unable to implement vaccination on weanlings due to workforce and time limitation. An insurance program could also encourage fatteners in reducing prophylactic antibiotic use in the case of weanlings' batches at low risk of BRD. As farmers are generally considered to be risk adverse (Meuwissen et al., 2001), this would be a lever for feedlot facilities to increase the demand for vaccinated and low risk weanlings.

Second, cow-calf producers encounter important limitations linked to the workload and time needed to implement vaccination. Having practices adapted to the field constraints is important for their adoption by farmers (Catley et al., 2012). In order to facilitate the implementation of vaccination, a third party employee could be hired to implement vaccination. This could be a service provided by a branding program, an auction market or a cooperative (in France). However, the cost should be balanced by a premium.

Third, there are important trust issues in the value chain, and giving guarantees for proper implementation of vaccination protocols is an important point. Different forms of vertical integration are able to improve information transmission from the cow-calf farm to the feedlot. Establishing contracts or branding programs is a serious help to enhance sharing of information, and the implementation of production protocols and increased quality (Coronado et al., 2010; Fraser, 2005). However, especially in Canada, contracts and breeding program seem to be inadequate, and contracts do not prevent from opportunistic behaviours (Reimer, 2006). A third party employee could be controlling the proper implementation of vaccination on the farm.

Finally, the size of the pens in the feedlots are an important limitation in Canada as metaphylaxis (treatment of the entire batch as some weanlings in a batch get sick) with antibiotic injection is too time consuming. Prevention has thus to be very efficient to ensure minimum level of risks.

Further incitation or restriction could be considered to reduce antibiotic use and prevent future spread of antibiotic resistance.

Nowadays, feedlots managers face a very important risk of morbidity and mortality due to BRD. The systematic and preventive antibiotic use is a tool having a good risk benefit ratio, due to its relative low cost comparatively to the potential avoided disease-related losses. Other preventive methods include changes in herd management which imply new practices and facilities at non trivial cost and constraints. However, new methods are generally adopted whenever the new proposed system induces significant benefits (Kennett et al., 1998).

Regulations to increase the price of antibiotics may also discourage its prophylactic use and give an incentive towards a change in practices. This is especially true as prophylactic antibiotics prevent a loss. Farmers give more importance to losses than to gains (Bocquého et al., 2014). As farmers are generally adverse to uncertainty and loss, they are mainly willing to pay for antibiotic prevention rather mitigate a risk for cheaper but less certain methods. However, a shift in the price ratio may lead farmers to modify their use of antibiotics and move from a systematic to a selective use of antibiotics, in respect of the prospect theory (Carpentier, 2017). However, increasing antibiotic price could increase feedlots production costs and impair the economy of the value chain. This would be particularly true if Canada or France are the only countries adopting such strong measure, as they respectively compete on the market with the US and Italy (resp.).

Another perspective is that the antibiotic use could be limited at the feedlot stage. Antibiotic consumption could be registered on feedlots or in veterinary practices, to:

- Use a penalty constraint depending on the level of antibiotic use (Red card system) (inspiration: Denmark in pig sector[61]), which showed positive but limited success (Bager et al., 2014),
- Publish information of veterinarian level of prescriptions, to develop a reputation based system as veterinarians are key actors to prescribe antibiotics (Russell and Bewley, 2013).

Governments could develop more focussed communication campaigns, to specifically target producers of the beef sector. However, government institutions campaign might receive limited attention from farmers as they are often seen as constraints (Heffernan et al., 2008).

Prophylactic antibiotic use in young beef bulls'/steers' value chain is still common in France and in Canada. Due to the size of the batches and the length of transport, BRD risks could be even higher in Canada. Prophylactic antibiotic use seems to remain economically beneficial. Improvement of information transmission and valuation of weanlings' quality are important elements to control for BRD risks and reduce antibiotic use. In the future, further regulation enforcement or stronger antibiotic resistance could reduce the benefits of using prophylactic antibiotics. The conjunction of reduced costs of information sharing (e.g. internet) and developing initiatives to further develop traceability, such as block chains, gives positive prospects for reduction of antibiotic use and better management.

The reputation of the entire sector is also at stake, as consumer have higher expectation regarding meat quality and production protocols. In France as in Canada, some brand certify that no antibiotic has been used at all or starting from a certain point of the production. This could further encourage farmers to improve their practices on a larger scale.

[61] Special provision for the reduction of the consumption of antibiotics in pig holding (the yellow card initiative). Ministry of Food, Agriculture and Fisheries, Danish Veterinary and Food Administration. 3 page.

Appendix 1

Table 32: Semi-structured interviews held in France

Profession	Number, of interviews / field observations	Depending institution
Semi-structured interviews		
Cow-calf producer* **	7	Cooperative and independent
Breeder-fattener* **	12	Cooperative and independent
Fattener* **	5	Cooperative and independent
Middlemen* **	10	Cooperative and independent
Farm advisors*	4	Cooperative
Veterinarians* **	8	Cooperative and liberal
Middlemen superiors*	3	POC and PONC
Chamber of Agriculture*	1	-
Meat producers' Union*	1	-
Slaughterhouse director*	1	-
Senior Official**	2	French Ministry of Agriculture
Total	54	

Regions considered: *Western France; ** National; ***Western France and Central France

Table 33: Semi-structured interviews held in Canada

Profession	Number, of interviews / field observations	Depending institution
Semi-structured interviews		
Cow-calf producer*	2	
Cow-calf and (backgrounding or feedlot or custom feed producer) producer*	3	
Feedlot*	2	
Middleman*	1	
Veterinarians* **	3	Independent, and University of Saskatchewan
Research or statistical institutions* **	5	Producers' association, statistical analysis institutions, research institutions
Total	16	

Regions considered: *Saskatchewan; ** Alberta; ***Saskatchewan and Alberta

Discussion générale

La réduction d'utilisation des antibiotiques utilisés en médecine humaine et vétérinaire est un enjeu de santé publique majeur afin de limiter le développement des bactéries antibiorésistantes. Les travaux de cette thèse ont porté sur l'étude des freins et leviers à une réduction d'utilisation des antibiotiques en élevage bovin, liés à l'organisation économique des filières, aux systèmes d'exploitation et aux actions de conseil aux éleveurs. Nous reviendrons tout d'abord sur les apports principaux de ce travail de thèse, puis nous détaillerons des réflexions sur les méthodologies employées, enfin, nous discuterons de perspectives de recherche et d'applications afin de poursuivre les efforts de recherche engagés.

1. Pistes d'amélioration de l'usage des antibiotiques au regard des connaissances produites

Nous avons fait porter l'analyse des freins et leviers à une réduction de l'utilisation des antibiotiques en élevage bovin à différents niveaux : (i) tout d'abord sur les pratiques des éleveurs et des systèmes de production, (ii) puis sur l'environnement de conseil existant pour les éleveurs, (iii) enfin, au sein des filières, afin d'explorer l'influence des formes de coordination verticale sur les pratiques observées.

1.1. Verrous et leviers à l'évolution des pratiques en exploitation de bovins

Les travaux menés en filières bovin lait et viande de jeunes bovins de boucherie (JBB) ont montré l'influence des systèmes d'exploitation, de l'environnement de conseil, et des perceptions et connaissances des éleveurs sur leurs pratiques de prévention et d'utilisation d'antibiotiques.

1.1.1. Influence des systèmes d'exploitation sur l'utilisation d'antibiotiques

Les analyses effectuées dans la thèse ont montré que dans certains systèmes d'exploitation, minoritaires, les pratiques de maîtrise des maladies et les utilisations d'antibiotiques étaient plus vertueuses qu'en situation générale (Chapitres 4 et 5). Nous avons principalement étudié l'influence des systèmes d'exploitations sur les pratiques en élevage bovin laitier, même si certains travaux effectués en filière JBB apportent également des éléments de compréhension.

En filière de lait de vache (Chapitre 6), les entretiens semi-directifs ont montré que les éleveurs produisant sous l'appellation d'Agriculture Biologique mettent tous en place un traitement sélectif des mammites au tarissement. Cette pratique semblait à l'inverse peu courante chez les autres éleveurs, ceux produisant sous l'appellation d'un autre label inclus. Le label d'Agriculture Biologique présente un des cahiers des charges les plus contraignants, interdisant notamment les usages préventifs, dont celui systématique d'antibiotiques. L'influence du système de production en Agriculture Biologique semble cependant limitée à la seule pratique interdite par le cahier des charges. En effet, pour les pratiques de traitement en cours de lactation, des mésusages ont été décrits par des éleveurs quel que soit leur système d'exploitation d'appartenance. En outre, les niveaux d'intensification du travail et de la production, indépendamment de la valorisation des produits, ne semblent pas avoir d'influence sur les pratiques des éleveurs, ce qui était pourtant une des hypothèses d'analyse.

L'existence de mésusages observés dans l'ensemble des systèmes d'exploitation pourrait s'expliquer par l'exigence des connaissances biotechniques nécessaires à la mise en place de bonnes pratiques de traitement des mammites. Le choix de la mise en place d'un traitement doit tout d'abord être ajusté selon le contexte d'intervention : gravité des signes cliniques, situation de récidive, etc. Puis selon les

signes cliniques et la bactérie potentiellement impliquée, le choix de la molécule antibiotique utilisée doit être adaptée (Barkema et al., 2006). Les vétérinaires, première source d'information sur les pratiques de traitement pour les éleveurs pourraient donc avoir un rôle dans l'accompagnement des éleveurs.

En filière viande de JB (Chapitre 5), les éleveurs naisseurs-engraisseurs présentent un type d'organisation très différent des autres systèmes naisseur ou engraisseur spécialisé. L'analyse des données du questionnaire montre les pratiques des naisseurs-engraisseurs sont significativement différentes. Ce système peut être interprété d'un point de vue économique comme l'intégration par l'engraisseur de l'étape de production des broutards. Les éleveurs naisseurs-engraisseurs vaccinaient moins et utilisaient moins d'antibiotiques de manière préventive que les éleveurs spécialisés en engraissement. Ce sont en effet des systèmes pour lesquels les risques de maladies respiratoires liés au transport, au stress et au mélange des animaux sont minimisés car les broutards sont nés et engraissés sur la même exploitation. Les pratiques des éleveurs naisseurs-engraisseurs sont donc ajustées au risque de maladies respiratoires existant au début de l'engraissement.

1.1.2. Influence des structures et techniques de production sur la gestion du risque de maladies par les éleveurs

Dans les systèmes laitiers et JB, certaines pratiques systématiques préventives d'utilisation d'antibiotiques semblent être une pratique établie, faisant référence (Chapitres 1 et 5). Par exemple, pour le traitement des mammites au tarissement, les pratiques systématiques d'utilisation d'antibiotiques ont été conseillées par les vétérinaires à partir des années 1970. Par ailleurs, au Canada, les JBB produits avec l'utilisation d'antibiotiques administrés au cours de l'engraissement sont désignés par le terme de « conventionnel », par opposition avec des systèmes de production n'utilisant pas d'antibiotiques ou d'hormones (Chapitre 7). Aujourd'hui, en filière lait de vache et JBB, la norme établie consiste en une utilisation systématique préventive d'antibiotiques à certains moments clefs risqués de la production. Au regard des connaissances acquises sur ces modèles depuis plusieurs années par les éleveurs, lever ces mesures préventives revient à prendre un risque (Chapitres 1 et 5).

En effet, lorsque pour la maîtrise d'un risque, le traitement antibiotique préventif est la référence, les éleveurs, et les vétérinaires sont alors plus averses au risque (Carpentier, 2017). La perspective d'un changement de pratiques implique alors, en théorie, une plus grande exposition au risque de pertes. Les entretiens menés auprès d'éleveurs laitiers et de JBB, de leurs vétérinaires et de leurs techniciens semblent appuyer ce point. Pour le traitement sélectif au tarissement par exemple, les éleveurs et leurs conseillers (vétérinaires et techniciens) expriment des craintes similaires quant au risque pris d'un changement de pratique (traitement sélectif au tarissement) (Chapitre 6). Toutefois une différence majeure existe entre les risques auxquels les éleveurs laitiers et les éleveurs engraisseurs font face. Les pertes liées à des mammites mal soignées sont limitées (de nouvelles infections, persistance accrue des infections) en comparaison avec les pertes engendrées par les maladies respiratoires (taux de croissances faible, perte d'un broutard).

Soutenant l'hypothèse d'éleveurs averses au risque, l'enquête quantitative réalisée en élevage de JBB (Chapitre 5) a montré une tendance à plus de médicalisation des broutards par les éleveurs ayant des exploitations de plus grande taille ou plus diversifiées. Ces éleveurs mettent alors en place les mesures de prévention utilisables à leur niveau d'action : vaccination chez les naisseurs, antibioprévention chez les engraisseurs. Ceci pourrait être lié à la charge de travail plus importante et une moindre flexibilité de l'organisation du travail des éleveurs travaillant au sein d'exploitations de plus grande taille ou plus diversifiée. En revanche, les éleveurs de JBB qui perçoivent les évolutions réglementaires à venir

comme un risque potentiel utilisent plutôt moins d'antibiotiques de manière systématique et préventive que les autres éleveurs, toutes choses égales par ailleurs (Chapitre 5). Cette tendance observée pourrait souligner le potentiel des contraintes réglementaires pour faire évoluer les pratiques des éleveurs et les amener vers un abandon des usages systématiques préventifs d'antibiotiques.

1.1.3. Le conseil et la formation : de possibles leviers pour faire évoluer les connaissances, perceptions et pratiques des éleveurs

Les différents travaux menés dans les filières lait de vache et viande de JBB ont montré que plusieurs verrous liés aux connaissances, aux perceptions et aux pratiques des éleveurs pouvaient limiter l'adoption de pratiques plus vertueuses de prévention des maladies pour un usage réduit des antibiotiques. Les éleveurs ayant des connaissances limitées sur les antibiotiques et les enjeux liés à l'antibiorésistance ainsi que les moyens de prévenir les maladies sans utilisation d'antibiotiques auraient alors peu de volonté pour changer leurs pratiques (Friedman et al., 2007; Moreno, 2014; Scherpenzeel et al., 2016; Visschers et al., 2015). Les travaux de la thèse ont montré l'importance de faire évoluer les compétences de l'ensemble des acteurs de la filière, sans distinction possible d'une population d'éleveurs dont les pratiques vertueuses permettraient un affranchissement du conseil et de la formation (Chapitres 3 et 5). Faire évoluer les connaissances et perceptions des éleveurs et autres acteurs de la filière (commerciaux en filière viande de JB, conseillers en filière lait de vache) a semblé être un levier important pour faire évoluer les pratiques (van den Borne et al., 2014b) (Chapitres 1, 2 et 5).

Un accompagnement insuffisant des éleveurs pour une meilleure prévention des maladies et une moindre utilisation d'antibiotiques ont pu être mis en évidence dans les filières lait de vache et viande de JBB (Chapitres 5 et 6). Les vétérinaires libéraux et salariés d'entreprise ne semblent bien souvent pas jouer de rôle moteur en filières viande de JBB et lait de vache pour limiter l'utilisation des antibiotiques. Ce sont pourtant des acteurs clefs de la prescription des antibiotiques. Par exemple, lorsque les avis des éleveurs et de leurs conseillers sont partagés sur l'intérêt et la faisabilité de mettre en place des pratiques sélectives au tarissement, ces pratiques sont mises en place en place (Chapitre 6). En outre, les vétérinaires semblent partager les craintes des éleveurs sur une gestion préventive des risques de maladies respiratoires sans antibiotiques. Les vétérinaires libéraux sont plutôt impliqués pour la gestion d'urgences médicales. Ils n'ont pas le temps ou les moyens de s'investir dans l'accompagnement des changements de pratiques sur le long terme. Le protocole de soin est un dispositif d'accompagnement des décisions de traitement et de gestion de la santé par les vétérinaires pour les éleveurs. Souvent vus comme une simple obligation réglementaire, ces bilans annuels devraient pouvoir être le support de discussions sur les pratiques des éleveurs et les possibilités de réduire les mésusages afin d'améliorer les pratiques d'utilisation d'antibiotiques. Un point encourageant est que les éleveurs, après avoir suivi une formation semblaient mieux comprendre l'intérêt du protocole de soin (Chapitre 8). Cependant, les résultats du chapitre 8 montrent une diminution d'utilisation de traitements systématiques au tarissement chez les éleveurs non exposés au dispositif de formation. Ceci pourrait montrer que les évolutions de pratique sont en train d'évoluer, en cohérence avec l'accompagnement des vétérinaires vers une réduction d'utilisation des antibiotiques.

Le changement de pratiques, notamment lorsqu'il nécessite de repenser un système de production, de nouveaux apprentissages et de passer d'une utilisation systématique d'un artéfact à une utilisation sélective, est un processus qui s'étale sur la durée (Vaarst et al., 2006). En élevage porcin par exemple, Fortané *et al.* (2015) ont montré que le passage d'une utilisation systématique préventive à une utilisation curative des antibiotiques nécessitait un support technique et des apprentissages au long cours, avec le soutien du vétérinaire et du technicien. Les entretiens menés auprès de vétérinaires libéraux accompagnant des éleveurs laitiers vers une moindre utilisation d'antibiotiques renforcent l'idée qu'un accompagnement au long cours, avec des essais et échecs, permet d'arriver à la mise en place de traitements sélectifs au tarissement (Chapitre 6). Il n'a cependant pas été possible de montrer que les changements de pratiques demandaient un temps long pour se mettre en place.
De plus, en filière lait de vache, un consensus existe pour définir les bonnes pratiques de prévention et de maîtrise des mammites, incluant des pratiques sélectives de traitement au tarissement. Cependant, les avis et perceptions des vétérinaires ont montré que la pression des éleveurs et leurs propres habitudes ne permettent pas une amélioration nette des pratiques de prescription (Chapitre 6). Cette différence entre les filières de monogastriques d'élevage et bovines pourrait s'expliquer d'une part par la taille plus petite des communautés des professions vétérinaires dans les filières monogastriques d'élevage par rapport aux filières bovines. Au sein des communautés de pratiques plus petites et plus uniformes de prescripteurs il serait plus facile de faire évoluer les pratiques vers une moindre prescription d'antibiotiques (Rosman, 2009). D'autre part, au contraire des filières bovines, le rôle des vétérinaires dans les filières de monogastriques d'élevage est plus tourné vers le conseil et le suivi des élevages sur le long terme que vers la gestion des urgences. Ceci pourrait expliquer le succès des efforts engagés par les vétérinaires dans les filières porcines, cunicoles et vitellines par rapport aux filières de production de lait de vache et de JBB (Pardon et al., 2012).

En élevage laitier, une étude d'intervention consistant en une action de formation et d'accompagnement a permis de montrer une amélioration des connaissances et des perceptions des éleveurs sur les questions de prévention et de traitement des mammites cliniques (usages d'antibiotiques compris) (Chapitre 8). Les améliorations observées concernent cependant les éleveurs ayant le moins de connaissances au départ. En outre, selon les profils comportementaux des éleveurs, le dispositif d'accompagnement a eu des effets différenciés sur leurs pratiques et leurs consommations d'antibiotiques. Les tendances observées montrent que les éleveurs qui travaillent dans de plus grandes structures et demandent du conseil sont plus enclins à améliorer leurs pratiques suite à la formation et au conseil que les éleveurs plus averses au risque, qui appuient leur travail sur le conseil, mais attachés à leurs habitudes ; eux-mêmes plus enclins à améliorer leurs pratiques que les éleveurs indépendants, qui utilisent plusieurs sources de conseil et susceptibles de critiquer les services techniques habituellement proposés. L'action de formation et de conseil a même été infructueuse pour cette dernière catégorie d'éleveurs, minoritaires (Chapitre 8). Ceci montre l'importance d'adapter les outils d'accompagnement aux profils des éleveurs. Différents canaux de sensibilisation et de conseil pourraient être utilisés pour parvenir à toucher l'ensemble des éleveurs en tenant compte de leurs aspirations et profils vis-à-vis du conseil. Cependant les efforts d'accompagnement doivent se potentialiser. Dans le chapitre 8, l'amélioration des connaissances et perceptions est plus marquée que l'évolution des pratiques (évolutions potentiellement sous-estimées en raison du pas de temps court dans lequel s'est déroulé l'étude). Ceci souligne l'importance et la complémentarité de la formation et de l'accompagnement des éleveurs sur le long terme pour permettre des changements de pratiques.

Accompagnement et formation des éleveurs ont un coût qui peut constituer une limite aux suivis de long terme (Friedman et al., 2007). Le développement de la facturation par les vétérinaires libéraux de leur temps de conseil et de leur expertise est encore limité en France. En élevage laitier, les vétérinaires expliquent réagir aux sollicitations d'urgence sans disposer du temps nécessaire et du soutien des éleveurs pour développer leur offre de suivi et de conseil (Chapitre 6). Les vétérinaires pourraient également utiliser les visites d'urgence pour sensibiliser les éleveurs sur la durée. Cependant l'étude d'intervention auprès d'éleveurs de bovins laitiers a montré des résultats encourageants sur les classes virtuelles (Chapitre 8). Permettant une organisation flexible (pas de déplacement, heure des sessions modulables, puis visionnage possible après la classe, courte durée), les éleveurs ont pu s'adapter pour être présents et participer, plus facilement que pour des classes organisées en présentiel. Ces outils pourraient être des véhicules de formation touchant une plus large population d'éleveurs, le manque de temps et d'argent étant deux freins principaux de l'accès à l'information des éleveurs (Friedman et al., 2007).

1.2. Rôle de la coordination verticale au sein des filières

Les travaux sur le rôle de la coordination verticale au sein des filières sur la réduction d'utilisation des antibiotiques ont principalement porté sur la filière de viande de JBB. En effet, nous avons considéré que la problématique était plus pertinente qu'en filière lait de vache, où les circuits d'approvisionnement en lait sont directs et la traçabilité de l'origine et des conditions de production bien établie. Les laiteries connaissent la provenance du lait. De plus, l'existence de labels valorisant certaines pratiques (label d'Agriculture Biologique) et certains terroirs (appellations d'origine protégée) renforcent la coordination verticale et la traçabilité des produits est renforcée. Les circuits d'approvisionnement en JBB sont par contre complexes du fait d'une production en plusieurs étapes, les systèmes de traçabilité imparfaits, et les labels de qualité inexistants en France pour la viande de JBB.

1.2.1. Evaluer les risques de maladies respiratoires pour adapter l'utilisation des antibiotiques : importance de la transmission de l'information et limites inhérentes aux pratiques de terrain

Les résultats de la thèse ont montré l'importance de l'organisation de la chaîne de valeur des JBB sur les niveaux de risque de maladies respiratoires (Chapitres 1 et 6). La gouvernance des transactions a une influence sur la transmission de l'information permettant ou non d'évaluer le risque de maladies respiratoires des broutards à l'entrée à l'engraissement (provenance, mélanges d'animaux au sein d'un lot, vaccination, etc.). Pourtant, l'influence des modes de gouvernance des transactions sur les pratiques d'antibioprévention des éleveurs engraisseurs n'a pu être établie. Lorsque le risque de maladies respiratoires est plus faible, et l'information disponible, les pratiques d'utilisation systématique préventive d'antibiotiques ne sont pas différentes des autres situations plus risquées. Ces observations ont été relevées aussi bien en France et qu'au Canada (Chapitre 7). La différence majeure entre les deux pays tient à des différences d'échelle (lots plus gros, distances plus grandes, etc. au Canada qu'en France).

Deux résultats ont montré que les éleveurs ne semblent actuellement pas utiliser les informations dont ils disposent pour évaluer les risques de maladies respiratoires, et ainsi, adapter leurs mesures de prévention (Chapitres 1 et 3). Premièrement, l'organisation de certains modes de gouvernance des

transactions entre les naisseurs et les engraisseurs a montré une influence sur la transmission de l'information permettant d'évaluer les niveaux de risque des lots de broutards. Ainsi, lorsque les broutards sont transférés sans intermédiaires d'un élevage naisseur à un élevage engraisseur, les engraisseurs disposent des informations permettant d'établir le niveau de risque du lot pour les maladies respiratoires. Dans ce cas, le niveau de risque de maladies respiratoires est réduit par rapport aux autres modes de gouvernance impliquant au moins un transfert via un commercial. Mais les pratiques de maîtrise du risque de maladies respiratoires des éleveurs pratiquant des transferts directs ne se différencient pourtant pas de celles autres éleveurs (Chapitre 4). Ce mode de gouvernance des transactions concerne en outre une minorité d'éleveurs. Deuxièmement, dans la majorité des cas, un commercial intervient selon différents modes de gouvernance (contrat écrit formel, contrat oral informel, ou marché au comptant) pour assurer le transfert des broutards depuis les élevages naisseurs vers les élevages engraisseurs. La seule information alors transmise aux éleveurs engraisseurs concerne des critères de qualité visibles à l'achat (taille, poids, âge) (Chapitre 5). Commerciaux et engraisseurs ne semblent pas requérir d'informations supplémentaires auprès des naisseurs pour évaluer le niveau de risque de maladies respiratoires. En outre, aucun éleveur n'a évoqué le fait qu'il est toujours possible, grâce au numéro d'identification des bovins, de connaître le département de provenance des broutards (Chapitres 1 et 2). Le département d'origine permet pourtant d'évaluer une partie du risque de maladies respiratoires, via l'évaluation de la distance parcourue par les broutards, et dans une moindre mesure, les mélanges de provenance des broutards au sein d'un même lot.

Trois hypothèses pourraient expliquer le manque de considération des éleveurs et acteurs de la filière pour le risque de maladies respiratoires (vétérinaires salariés et libéraux exclus).
Tout d'abord, les éleveurs et les commerciaux pourraient ne pas avoir d'incitation forte à repenser leurs pratiques (incluant les modes de gouvernance des transactions). La réduction d'utilisation des antibiotiques et les problèmes d'antibiorésistance sont en effet une question assez récente. Les éleveurs et les commerciaux pourraient ne pas avoir pris la mesure de l'importance des enjeux liés à l'utilisation des antibiotiques (Friedman et al., 2007; Moreno, 2014; Visschers et al., 2015).
Ensuite, les maladies respiratoires sont des maladies multifactorielles dont la prévention demande la prise en compte de nombreux paramètres (e.g. De Vliegher *et al.*, 2012; Hay *et al.*, 2014). Les informations dont les éleveurs disposent dans la majorité des modes de gouvernance des transactions (notamment dès qu'un commercial intervient dans la transaction) permettent seulement d'approximer un niveau de risque. Mais même lorsque les éleveurs disposent de l'ensemble des informations concernant le passé des broutards (transferts directs), l'évaluation du risque de maladies respiratoires reste une approximation. En effet, la période de l'année et les propres caractéristiques de l'élevage d'engraissement (bâtiment, ambiance) peuvent aussi influencer les niveaux de risque (e.g. Gay and Barnouin, 2009; Cernicchiaro *et al.*, 2012). L'initiative d'une coopérative de l'Ouest de la France cherche à sensibiliser ses éleveurs aux risques de maladies respiratoires et aux pratiques de prévention à adapter en conséquence. Une grille établie en collaboration avec des vétérinaires et des acteurs de la filière vise à évaluer les niveaux de risque des lots à l'entrée en engraissement, prenant en compte les facteurs de risques liés à l'historique amont des broutards ainsi qu'à la situation de l'exploitation d'engraissement[62]. Cette initiative permet d'apporter une information à l'éleveur engraisseur, même imparfaite. Mais elle reste à ce jour isolée.

[62] Source : Projet PSDR Sant'Innov, disponible le 08/05/0218 sur https://www6.inra.fr/santinnov/Productions/Resumes-de-stage/stage-2016-2017

Enfin, les antibiotiques constituent un moyen de gestion du risque peu coûteux et efficace. Ce point de vue a été particulièrement appuyé par les éleveurs et parties prenantes de la chaîne de valeur des JBB canadienne, qui défendent une rationalité économique à l'utilisation des antibiotiques de manière systématique et préventive par une réduction de la mortalité et de la morbidité des broutards (Chapitre 7).

1.2.2. Transmission de l'information et transfert de risque pour une valorisation des pratiques de vaccination des naisseurs

La vaccination chez le naisseur quelques semaines avant le transport des broutards est un point de maîtrise important du risque des maladies respiratoires (Assié et al., 2009; John G Kirkpatrick et al., 2008; J E Macartney et al., 2003). Le risque économique lié aux maladies respiratoires se situe chez l'engraisseur, mais le naisseur peut participer à le prévenir. Le naisseur, par la transmission de l'information sur ses pratiques de prévention, pourrait améliorer la gestion du transfert de risques avec l'engraisseur. Or les entretiens réalisés auprès d'éleveurs naisseurs ont montré que la vaccination de broutards leur demande un investissement en temps de travail et en argent conséquent (Chapitre 7). L'information concernant les pratiques vaccinales du naisseur étant rarement transmise (ou même demandée) par les maillons suivants de la chaîne de valeur (commerciaux et engraisseurs), il est rarement possible d'attribuer dans les transactions de valeur ajoutée à des broutards vaccinés chez le naisseur (Chapitre 2). Les naisseurs ont donc peu d'incitations pour améliorer leurs pratiques de prévention des risques de maladies respiratoires des broutards survenant en début d'engraissement. La valorisation de pratiques vertueuses des éleveurs interviewés a semblé rencontrer une limite auprès des engraisseurs canadiens, qui refusent de payer un supplément pour des broutards vaccinés. En France la limite semble plutôt venir des éleveurs naisseurs, pour lesquels la vaccination des broutards constitue une contrainte importante, et a priori supérieure aux bénéfices d'une prime sur le prix des broutards (Chapitre 7).

En effet, l'analyse de la chaîne de valeur a montré que chaque maillon de la chaîne dégage peu de valeur ajoutée (Chapitre 2). La valorisation de la qualité (incluant le fait que les broutards soient vaccinés chez les naisseurs) reste très minoritaire, constituant un marché de niche. Ces initiatives pourraient néanmoins constituer un premier pas vers une diffusion plus large de ces nouvelles pratiques (Bidaud, 2013). Par ailleurs, la filière française des JBB est principalement tournée vers l'export (de broutards vivants et de viande de JBB) (Chapitre 2). La valorisation de critères de qualité sur des marchés internationaux est donc complexe. Cependant au cours des entretiens, des commerciaux ont expliqué que les engraisseurs Italiens, vers lesquels presque la moitié des broutards français sont exportés[63], pourraient augmenter leur demande pour des broutards vaccinés chez les naisseurs, faisant de ce critère un prérequis à la conclusion de transactions (Chapitre 2). Cette modification de la demande sur le marché français du broutard pourrait avoir des effets de levier sur les pratiques de par l'importance des volumes concernés, ou au contraire différencier les marchés selon la destination des broutards et leurs caractéristiques : pour la France les broutards non vaccinés ; pour l'Italie les broutards vaccinés. Une telle différenciation aurait un effet incitatif sur la réduction d'usage d'antibiotiques au niveau européen, mais non au niveau français.

[63] Source : Institut de l'élevage, 2015. Economie de l'élevage. Institut de l'élevage. Dossier annuel. 464

1.2.3. Absence de dynamique de filières bovines pour une réduction d'utilisation des antibiotiques

L'analyse de la chaîne de valeur des JBB a permis par ailleurs de montrer une structure morcelée, où différents acteurs tiennent une place importante dans l'organisation de la filière, mais ne travaillent pas de manière concertée à la réduction de l'utilisation des antibiotiques : coopératives, associations de producteurs à vocation non commerciale, interprofessions, vétérinaires etc. Différentes initiatives pour améliorer la transmission et l'addition de valeur ajoutée à des broutards ayant des protocoles vaccinaux efficaces ont été décrits (une coopérative, une organisation de producteurs à vocation non commerciale), mais les volumes concernés restent limités et concernent un marché de niche (Chapitre 2).

Pourtant, les dynamiques de filière, lorsque l'ensemble des parties prenantes s'investit ont montré leur efficacité, notamment en filières porcines et cunicoles. La filière porcine a par exemple développé un moratoire sur l'utilisation des céphalosporines de dernière génération, permettant rapidement une réduction de 98,1% des consommations (Méheust et al., 2017). La filière cunicole a mis en place en 2011 une charte interprofessionnelle visant une amélioration des pratiques d'antibiothérapie. Plus récemment, la filière des veaux de boucherie a mis en place une charte interprofessionnelle visant une réduction d'utilisation des antibiotiques. Les éleveurs et acteurs de la filière (section viande de la Coordination rurale, section veaux de la Fédération Nationale Bovine, Syndicat de la Vitellerie Française, Société Nationale des Groupements Techniques Vétérinaires, etc.) ont signé cet engagement[64].

Certains acteurs de la filière viande de JBB développent des outils pour valoriser les broutards protégés par une vaccination effectuée chez le naisseur (Chapitre 7). Une coopérative et une organisation de producteurs à vocation non commerciale ont débuté il y a quelques mois leurs programmes respectifs. Ces initiatives restent cependant limitées. La concertation de l'ensemble des acteurs pour aboutir à une position commune permettant une meilleure gestion des risques de maladies respiratoires semble peu envisageable dans un avenir proche, spécialement dans un secteur concurrentiel où les principaux acteurs n'ont pas l'habitude de collaborer (Chapitre 2). Les vétérinaires libéraux et salariés, par l'apport de connaissances sur les enjeux biologiques et techniques pourraient renforcer un mouvement pour la construction d'une charte interprofessionnelle visant à l'amélioration des bonnes pratiques de gestion des maladies respiratoires.

Par ailleurs, l'accès à l'information est un point clé du progrès dans ces initiatives de filière. Il pourrait également être important de donner les moyens aux éleveurs d'évaluer leurs pratiques au regard du reste de la filière. Leur donner les moyens de connaître leur consommation d'antibiotiques par rapport aux autres éleveurs pourrait permettre de donner des objectifs pour progresser. Une initiative gouvernementale danoise permet par exemple aux éleveurs porcins de positionner leurs consommations d'antibiotiques par rapport à des seuils autorisés[65].

A l'extrémité aval des chaînes de valeur des filières lait de vache et viande de JB, les consommateurs jouent un rôle important dans l'orientation de la demande et de la qualité des produits. La valorisation

[64] Source : Charte interprofessionnelle de bonne maîtrise sanitaire et de bon usage des traitements médiamenteux en production de veaux de boucherie, 2015. Disponible le 04/05/2018 sur http://www.interbev.fr/wp-content/uploads/2015/09/2015-09-16-charte-interprofessionnelle-bonne-maitrise-sanitaire-bon-usage-traitements.pdf

[65] Special provision for the reduction of the consumption of antibiotics in pig holding (the yellow card initiative). Ministry of Food, Agriculture and Fisheries, Danish Veterinary and Food Administration. 3 page.

d'attributs du produit fini tels que la non-utilisation d'antibiotiques auprès des consommateurs est une démarche existant sur les marchés intérieurs de différents pays, notamment en France. Cependant ces produits demeurent encore positionnés sur des marchés de niche et concernent uniquement les achats directs par le consommateur. La question de la valorisation de ces pratiques dans les principaux pays destinataires de viande de JBB se pose, d'autant plus qu'une part très importante de la production est commercialisée à l'export. Par ailleurs, l'image véhiculée par des labels « produit sans antibiotiques » questionnent l'image des filières auprès des consommateurs. Sur une question complexe et technique comme l'utilisation des antibiotiques, les messages de valorisation de pratiques vertueuses devraient être utilisés avec précaution. Par ailleurs, la reconnaissance par l'industrie de pratiques vertueuses pourrait être un levier auprès des éleveurs pour une amélioration de leurs pratiques (Valeeva et al., 2007). Faire évoluer les pratiques dans les filières bovines correspondrait à une anticipation d'une pression sociétale grandissante.

2. Aspects méthodologiques : apports et limitations

Pour aborder les questions de freins et leviers à une réduction de l'utilisation d'antibiotiques en élevage bovin, nous nous sommes appuyés sur différentes approches méthodologiques. Compte tenu du niveau des connaissances sur les filières étudiées (lait de vache et viande de JBB), la mobilisation de méthodologies existantes visait un apport de connaissances empiriques. Nous discutons plus particulièrement dans ce paragraphe du choix des méthodes de collecte des données (méthodes quantitatives et qualitatives), puis du choix des cadres conceptuels d'analyse (chaîne de valeur, économie des coûts de transaction).

2.1. Analyses quantitatives et qualitatives : apports respectifs et limites au regard des résultats obtenus

Les méthodes quantitatives et qualitatives visent des stratégies de recherche différentes.

Dans le travail de thèse, l'exploration qualitative de la filière des JBB a permis de prendre une connaissance large d'un terrain complexe et peu décrit. L'approche qualitative a permis de formuler des hypothèses de recherche basées sur des observations de terrain pour poursuivre un travail plus précis sur une étape particulière de la filière des JBB : la transaction de broutards depuis l'élevage naisseur jusque l'élevage engraisseur (Chapitre 3). Les travaux qualitatifs ont également permis de s'intéresser à des initiatives minoritaires, d'innovations, permettant une réduction de l'utilisation des antibiotiques (Chapitre 7). Ces initiatives, concernant une proportion moindre d'éleveurs et un volume faible de broutards n'étaient pas visibles dans l'analyse quantitative de la filière. L'approche qualitative permet donc d'être original, parce que s'intéressant au particulier plus qu'au général. Les apports principaux de cette méthode sont empiriques, sur un sujet d'étude encore peu exploré. Décrire et comprendre ces initiatives de filière a permis d'envisager des leviers d'action pour une amélioration des pratiques en se basant sur l'existant, ses atouts et limites. Par ailleurs, l'approche qualitative, en s'inspirant d'initiatives innovantes de terrain permet d'envisager des leviers d'actions adaptées aux conditions de travail des éleveurs.

Les travaux quantitatifs visaient une caractérisation et une compréhension des transactions impliquant les éleveurs de JBB dans leur globalité (Chapitre 4). Ils ont par exemple permis d'orienter des leviers d'action majoritaires (notamment action publique), visant des populations pour lesquels la marge de progrès est la plus importante. Ceci permet de cibler les actions à mettre en place tout en comprenant mieux les logiques d'action de la majorité des éleveurs. Dans la filière des JBB par exemple, il semble

important de pouvoir sensibiliser les éleveurs engraisseurs à l'importance de choisir des broutards ayant un faible niveau de risque. Pour les éleveurs naisseurs, la valorisation des pratiques de mise en place de prévention des maladies respiratoires paraissait être important pour une incitation à la mise en place de bonnes pratiques en engraissement (Chapitre 7).

Analyses quantitatives et qualitatives donnent parfois des résultats qui pourraient sembler contradictoires : en filière JBB, les travaux qualitatifs ont montré qu'une amélioration de la coordination entre les acteurs permettait une amélioration de la transmission de l'information et de la valorisation d'attributs non visibles de la qualité liés au risque de maladies respiratoires, ces deux éléments permettant une moindre utilisation d'antibiotiques (Chapitre 3). Les travaux quantitatifs montrent une amélioration de la transmission de l'information dans un seul mode de coordination verticale, et pas d'influence des modes de coordination verticales sur les pratiques (Chapitre 4). Ces différences de résultat observées peuvent s'expliquer par le fait que les pratiques vertueuses (vaccination précoce, peu de trajets, peu de mélanges d'animaux, pas d'utilisation préventive d'antibiotiques) concernent une part réduite des éleveurs et ne sont donc potentiellement pas visibles dans l'analyse quantitative. Par ailleurs, afin de construire un modèle statistique, les perceptions et pratiques des éleveurs sont codées et simplifiées. Ceci limite une description détaillée des perceptions et pratiques, permettant de dégager des facteurs principaux influençant la mise en place des pratiques de prévention de maladies respiratoires.

Les méthodes quantitatives et qualitatives sont parfois complémentaires. Dans le cadre de la mise en place et de l'évaluation de l'étude d'intervention en élevage laitier (Chapitre 8), les apports des méthodes quantitatives et qualitatives ont permis :

- De prendre en compte les profils comportementaux des éleveurs impliqués dans l'étude vis-à-vis du conseil. Or ces profils (évaluation plutôt qualitative) ont montré une influence sur leur observance du dispositif.
- De pouvoir évaluer un programme de formation complexe faisant appel à différents formats de formation (présentiel et virtuel) et de suivi des éleveurs. L'articulation des données quantitatives et qualitatives a permis de discuter de l'influence du programme sur les connaissances, perceptions et pratiques des éleveurs, ainsi que sur l'appréciation de la formation, sa faisabilité et sa reproductibilité.

La complémentarité des approches qualitatives et quantitatives pour l'évaluation d'études d'interventions complexes effectuées sur une population limitée en taille ont montré leur intérêt et sont reconnues (Duval et al., 2017; Moore et al., 2015).

Les efforts à déployer (temps et moyens financiers) pour les deux types d'approches scientifiques sont assez différentes. Un accès aux acteurs du terrain est un prérequis pour les deux analyses. Pour la filière viande de JBB, peu documentée, la constitution d'un jeu de données statistiques suffisamment grand et sans biais de représentativité a été complexe (Chapitres 3 et 4). Les efforts déployés ont dû être considérables pour constituer une base de données suffisamment large d'éleveurs à enquêter ainsi que pour administrer le questionnaire auprès d'eux. Certaines populations d'éleveurs (les engraisseurs spécialisés par exemple) étant moins nombreux, il était parfois difficile d'accéder à leur contact pour leur proposer une participation à l'étude. L'accès au terrain facilité dans la région Grand-Ouest a rendu les enquêtes qualitatives moins chronophages et coûteuses que l'enquête quantitative (Chapitres 1, 2 et 5).

2.2. Cadres théoriques de la chaîne de valeur et des coûts de transaction : apports et limites au regard des résultats obtenus

L'analyse de l'influence des filières sur une possible réduction d'utilisation des antibiotiques en élevage de JBB a fait appel à deux cadres d'analyse théoriques : la chaîne de valeur et l'économie des coûts de transaction. Ces deux méthodes d'analyse permettent de proposer un cadre théorique adapté aux questions de recherche, et faisant appel à des concepts compréhensibles largement. Ces cadres théoriques d'analyse ont en outre permis d'aborder les questions de recherche dans la filière de JBB où très peu de données et d'analyses de la filière sont disponibles (Brocklebank et al., 2008; Marty et al., 2015). Ils ont permis de construire une première vision d'ensemble de la filière des JBB et de l'influence de l'organisation économique de cette filière sur les pratiques d'utilisation d'antibiotiques actuelles, ainsi que d'envisager des leviers pour les faire évoluer (Chapitres 1, 2, 3, 4 et 7).

L'utilisation de la notion de chaîne de valeur a permis de comprendre les flux matériels (JBB) et non matériels (information, valeur ajoutée) au sein de la filière, nous permettant d'identifier le transfert du broutard (jeune bovin âgé entre 6 et 9 mois) entre le naisseur et l'engraisseur comme un des points clé de la compréhension de l'influence de l'organisation verticale de la filière JBB sur les pratiques d'antibiothérapie observées (Chapitre 2). En particulier, l'analyse des flux au sein de cette filière a permis de révéler les transferts de risques économiques (flux descendant, du naisseur vers l'engraisseur) et l'absence de transfert de valeur ajoutée pour la gestion préventive de ces risques (flux montant, de l'engraisseur vers le naisseur). La théorie des coûts de transaction a par la suite permis d'explorer plus finement l'influence des transactions de broutards entre les naisseurs et les engraisseurs sur ces pratiques (Chapitre 3). Enfin, la mobilisation conjointe de ces deux cadres théoriques a permis l'analyse des leviers identifiés sur le terrain pour faire évoluer les pratiques des éleveurs vers des modes plus prudents de l'utilisation des antibiotiques (Chapitre 7). Les leviers ainsi identifiés mobilisaient les deux cadres théoriques, visant une modification des pratiques à l'échelle des éleveurs, de leurs conseillers et des filières.

L'utilisation du cadre théorique de la chaîne de valeur reste cependant partielle puisque pour la production de viande de JB, seuls les maillons de la chaîne de valeur concernant la production d'animaux avant engraissement ont été étudiés (Chapitre 2). L'analyse des maillons aval de la chaîne de valeur (depuis l'abattage jusqu'à la distribution) ont plutôt servi à la compréhension d'un contexte plus large dans lequel s'insère la filière (débouchés principaux, valorisation possible de la qualité, etc.). L'analyse plus particulière d'un maillon de la chaîne de valeur est possible (Lambert and Cooper, 2000), mais elle est peu classique. Elle s'explique par la longueur des processus de production en filière viande de JB avec l'enchaînement de deux étapes de production longues (environ 9 mois chacune). Usuellement, les analyses de chaîne de valeur considèrent l'ensemble des étapes de valorisation de produits ou services finis, et englobent donc toutes les étapes de production, de transformation et de distribution pour être mises en relation avec la demande des consommateurs (e.g. Croom, Romano and Giannakis, 2000).

L'utilisation du cadre théorique des coûts de transaction n'a permis de confirmer qu'une partie limitée des hypothèses de recherche initiales (Chapitre 5). L'influence de l'organisation économique des transactions sur les pratiques d'utilisation préventive des antibiotiques par les éleveurs n'a par exemple pas pu être montrée. Ces résultats s'expliquent notamment par le peu de connaissances disponibles sur la filière de viande de JBB, et aussi par les caractéristiques de la théorie utilisée. En effet, la théorie des coûts de transaction analyse l'influence des coûts de transaction et d'autres

facteurs de l'environnement économique sur les modes de coordination verticale observés (Williamson, 1994). Au total, environ huit paramètres peuvent influencer les modes de coordination verticale (parmi lesquels : spécificités d'actifs ; risque incertitude et complexité ; fréquence des transactions ; disponibilité de l'information ; spécificité temporelle). Par ailleurs, chacun de ces paramètres, compréhensible analytiquement, se décrit dans des analyses quantitatives à l'aune d'approximations. Plusieurs variables peuvent être utilisées pour décrire un unique coût de transaction. Ainsi, dans le contexte de la filière des JBB, pour laquelle peu de données et d'études sont disponibles, peu d'éléments pouvaient être a priori écartés pour expliquer les modes gouvernance des transactions. Cela explique notamment les choix effectués pour la collecte de données quantitatives, où nous avons cherché à obtenir un maximum d'information des enquêtes afin de ne négliger aucun aspect des transactions, en l'absence de littérature économique sur ce sujet qui aurait pu nous guider dans des choix plus spécifiques d'analyse. En outre, compte tenu de la diversité structurelle et organisationnelle des exploitations de JBB aujourd'hui en France, beaucoup de variables ont été utilisées pour décrire les coûts de transaction. Mais certaines approximations n'étaient parfois pas suffisamment précises. La multiplication des variables utilisées a complexifié les modèles statistiques réalisés, et n'a pas toujours permis d'aboutir à des résultats probants. Les modes de coordination verticale majoritaires ont pu être décrits qualitativement. Néanmoins une analyse plus précise des transactions n'a pas été possible en raison du manque de données comptables accessibles à l'échelle individuelle. L'analyse de l'organisation des transactions de broutards a néanmoins permis de construire une première analyse pour la compréhension des dynamiques à l'œuvre dans la filière des JBB. Ce travail constitue ainsi un premier jalon pour la recherche appliquée aux échanges économiques en élevage bovin viande.

3. Perspectives de recherche et d'application pour une réduction de l'utilisation des antibiotiques en élevage bovin

Nous abordons ici les questions de recherche qu'il semble souhaitable d'explorer dans la continuité des travaux effectués dans cette thèse. Nous présentons également des applications possibles de ces travaux de thèse pour poursuivre une amélioration et une diminution d'utilisation des antibiotiques dans les filières bovines.

3.1. Perspectives scientifiques

3.1.1. Comprendre l'influence de l'organisation logistique de la filière sur les possibilités d'améliorer les pratiques de prévention de maladies respiratoires

L'identification de leviers pour améliorer les pratiques d'utilisation d'antibiotiques dans la filière viande de JBB s'appuie sur des initiatives de niche, qui concernent seulement une faible part des volumes de broutards échangés entre les naisseurs et les engraisseurs (Chapitre 7). Nous avons pu constater que dans un contexte stable, le développement de ces leviers (transfert d'information, valorisation) semble peu prometteur. L'analyse par la chaîne de valeur de la filière a par ailleurs montré l'importance des questions logistiques (allotement, transport des broutards entre les naisseurs et les engraisseurs) pour comprendre les risques de maladies respiratoires existant aujourd'hui en début d'engraissement (Chapitre 2). Son importance est exacerbée par la temporalité dans laquelle s'inscrivent les transactions : une fois achetés par un intermédiaire, les broutards mis en marché doivent être achetés par des engraisseurs le plus rapidement possible, et dans la limite d'une semaine. Une analyse fine des flux de broutards (incluant des questions de temporalité) entre les élevages naisseurs et engraisseurs devrait permettre de mieux quantifier les marges de progrès possibles sur

ces questions, et de mieux comprendre pourquoi l'adoption de certaines pratiques demeure limitée (par exemple une valorisation économique supplémentaires des broutards vaccinés chez le naisseur). Les explorations suivantes pourraient être conduites : les broutards vaccinés dans le cadre d'un programme de certification d'une coopérative sont-ils mélangés avec d'autres broutards pour lesquels l'information sur la vaccination n'est pas disponible ou pour lesquels aucune vaccination n'a été mise en place ? Les durées de transfert depuis les élevages naisseurs vers les élevages engraisseurs sont-elles minimisées ? Cela permettrait d'évaluer les possibilités de passer d'innovations de niches concernant les formes de coordination verticale à une diffusion plus large de pratiques vertueuses (Bidaud, 2013). La France présente l'avantage par rapport au Canada d'engraisser les broutards en lots de taille réduite (environ 10 broutards par lots, comparé au Canada, environ 250). Ceci permet d'envisager des stratégies d'optimisation de remplissage des cases d'engraissement tout en limitant les mélanges de provenance des broutards au sein d'un même lot, ce qui réduit considérablement les risques de maladies respiratoires. La base de données nationale d'identification (BDNI) permet aujourd'hui de suivre les mouvements de bovins au cours de leur vie. Une analyse des réseaux sur plusieurs années devrait donc permettre de mieux comprendre les mouvements de broutards ainsi que les progrès possibles pour améliorer la gestion logistique de leur transport au regard des enjeux de la maîtrise prudente des maladies respiratoires.

Par ailleurs, une analyse des marchés de bovins vifs reste essentielle à l'analyse des arbitrages économiques des agents en matière de gestion sanitaire des troupeaux. Du point de vue analytique, la recherche économique a montré que, de manière générale, les asymétries d'informations dans les échanges étaient à même de dégrader lourdement l'état des marchés (Akerlof, 1970). Dans le cadre des incitations à des changements de pratiques sanitaires en élevage, des travaux récents ont montré qu'un plus grand partage de l'information sanitaire assorti d'une meilleure rétribution des efforts préventifs étaient en mesure de corriger les défaillances de marché et d'enrayer les pratiques les moins vertueuses (Wang and Hennessy, 2014). Sur le plan empirique, le manque de disponibilité de données comptables sur les transactions de bovins est un frein à l'évaluation des déterminants d'achat et de vente d'animaux. Nos travaux ont permis de montrer que, concernant les BPI dans la filière JBB, les naisseurs opéraient à un transfert de risque vers les engraisseurs en l'absence de rétribution d'un éventuel effort de vaccination. En retour, les pratiques d'antibiothérapie des engraisseurs relèvent usuellement d'une sécurisation –voire sur-sécurisation– de leur production. Afin d'analyser ces phénomènes plus finement et pour pouvoir proposer des mesures correctives, des approches économiques expérimentales seraient à privilégier, où des expériences de terrain permettront d'évaluer les niveaux d'aversion au risque (ou à l'incertain) des agents (en particulier les engraisseurs), le consentement à payer des animaux vaccinés des engraisseurs, ainsi que le consentement à accepter des naisseurs pour l'effort de vaccination. De telles recherches sont à même d'aboutir à des recommandations en termes d'incitations (financières ou non) pour une modification des pratiques au sein de la filière.

3.1.2. La recherche participative pour envisager de nouveaux leviers

Les travaux de la thèse ont mis en évidence que l'utilisation systématique des antibiotiques permettait de masquer un risque sanitaire réel et d'en faciliter la prévention. Des freins et des leviers à un changement des pratiques ont été décrits, avec toutefois la limite de compréhension et de capacité d'innovation du chercheur. La recherche participative pourrait aujourd'hui permettre de proposer de nouveaux leviers d'action.

La recherche participative est un courant des sciences économiques et sociales qui se développe. Elle se base sur des initiatives et des actions d'acteurs de terrain pour proposer des leviers d'action adaptés (Slocum et al., 2006). Le rôle du chercheur est alors d'organiser la réflexion en apportant les connaissances et informations nécessaires à la diversité des acteurs en présence, ces derniers proposent alors les initiatives et leviers qui leurs semblent les plus adaptés. En filière lait de vache et viande de JBB, il pourrait donc être intéressant de poursuivre les travaux sur des leviers d'action à mettre en place en se basant sur des propositions des parties prenantes. Deux points importants pourraient limiter l'intérêt de la mise en œuvre de telles démarches.

Tout d'abord en filière viande de JBB, convoquer l'avis des seuls éleveurs semble être insuffisant. En effet, les dynamiques de filières jouent un rôle important sur les niveaux de risque de maladies respiratoires et leur gestion. Il faudrait donc envisager une consultation large d'acteurs de la filière exerçant des rôles à des échelles différentes de la production et du territoire (éleveurs, commerciaux, coopératives, etc.). Cependant, selon les acteurs envisagés, certaines institutions en concurrence directe sur les marchés, pourraient refuser de collaborer et de partager des informations considérées comme étant stratégiques. La richesse et la diversité des leviers d'action proposés pourrait alors en être réduite.

Par ailleurs, l'apport de connaissances aujourd'hui disponibles pour permettre aux éleveurs d'envisager des leviers d'action pour un changement de pratiques s'appuie sur des facteurs de risques biologiques et techniques connus. Cependant, les coûts et bénéfices associés aux différentes pratiques ne sont pour l'instant pas évalués. Ainsi, le raisonnement complet sur l'intérêt des pratiques de prévention des maladies en regard des avantages biomédicaux (notamment résistance aux antibiotiques) et sur les conséquences économiques n'est aujourd'hui pas envisageable. Ceci pourrait limiter l'intérêt d'une exploration de leviers par des méthodes participatives. Les éléments financiers sont en effet un point important pour justifier de la mise en place d'une pratique (Ge et al., 2014; Russell and Bewley, 2013).

3.2. Perspectives d'application

3.2.1. Des outils pour faciliter la prise de décision des éleveurs sur les moyens de prévention à privilégier

Pour la mise en place de traitement, les éleveurs agissent schématiquement selon : (i) une action automatisée sans évaluation préalable, pour des traitements routiniers, inscrits dans une pratique systématique ; ou (ii) une action basée sur une évaluation d'éléments concrets leur permettant d'évaluer les différentes possibilités (Murray-Prior, 1998).

Les éléments financiers sont en effet un point important pour justifier de la mise en place d'une pratique (Ge et al., 2014; Russell and Bewley, 2013). En élevage bovin allaitant, les éleveurs naisseurs n'ont pas d'outils permettant d'évaluer les risques ou le retour sur investissement d'une vaccination des broutards. En revanche au Canada, un dispositif disponible en ligne permet de prendre en compte des caractéristiques de l'élevage (province, coût de la main d'œuvre, etc.) pour évaluer les gains ou pertes d'une vaccination contre les risques de maladies respiratoires en fonction des prix du marché et de potentiels bonus liés à la qualité des animaux[66]. Selon le même raisonnement, les engraisseurs ne disposent d'aucun outil pour évaluer les coûts et bénéfices liés à l'achat de broutards vaccinés chez le naisseur, sans utilisation préventive d'antibiotiques. Aucun travail ne permet d'évaluer les coûts et

[66] Source : Preconditioning calculator, Beef Cattle Research Council. Disponible le 04/05/2018 sur www.beefresearch.ca/research/preconditioning.cfm

bénéfices économiques d'une adaptation des pratiques d'approvisionnement des broutards et de leurs choix selon des caractéristiques de santé, par rapport à un approvisionnement ne prenant pas en compte les critères sanitaires, mais avec utilisation préventive systématique d'antibiotiques. L'absence de ces outils ne permet donc pas aux éleveurs naisseurs et engraisseurs d'adapter leurs pratiques rationnellement, en fonction des risques, coûts et bénéfices auxquels ils font face. Les éleveurs pourraient ainsi choisir de mettre en place des pratiques pour lesquelles ils évaluent plus facilement les coûts et les bénéfices par eux-mêmes (Lhermie et al., 2015).

3.2.2. Importance d'actions de formation et de sensibilisation développées sur le long terme

Les résultats du chapitre 8 montrent une amélioration des connaissances, perceptions et pratiques des éleveurs, mais limitée par rapport aux résultats attendus. La durée du dispositif d'intervention n'a pas permis de capitaliser les apprentissages et changements de perception en changements de pratiques. En outre, les conseillers et vétérinaires impliqués dans le dispositif devaient changer leurs pratiques d'accompagnement, multipliant les visites de conseil en élevage sur une période restreinte. Il est possible que ce changement de pratique leur demande également un temps d'adaptation dans leur manière d'accompagner les éleveurs.

Les changements de pratiques s'accompagnent sur le long terme car ils correspondent à des processus individuels longs à se mettre en place : intention de changer, réflexion, apprentissages, mise en œuvre, consolidation (Sutherland et al., 2012). Pour un accompagnement sur la durée de changement de pratiques, il est important que les actions de sensibilisation et de conseil soient menées en concertation et en cohérence les unes avec les autres. En effet, les éleveurs utilisent des informations en provenance de différentes sources : pairs (Friedman et al., 2007), vétérinaires (S. Mcdougall et al., 2017; Russell and Bewley, 2013) et autres conseillers (Pardon et al., 2012).

Pour sensibiliser les acteurs à une réduction de l'utilisation des antibiotiques et à l'importance de mettre en place des mesures de prévention, il semble donc important d'utiliser différents outils de communication ainsi que de s'appuyer sur différentes catégories de professionnels. Les conseillers et vétérinaires pourraient eux-mêmes avoir à modifier leurs pratiques d'accompagnement pour s'adapter aux formes de suivi permettant de réduire l'utilisation d'antibiotiques.

3.2.3. Réduire l'utilisation des antibiotiques, rôle des politiques publiques

Compte tenu de la large diffusion de pratiques systématiques d'utilisation d'antibiotiques en prévention, et des difficultés à faire changer les habitudes établies (Pol and Ruegg, 2007b), la réglementation pourrait être un levier pour faire changer rapidement les pratiques. La contrainte semble être un levier efficace pour limiter les usages systématiques en élevage bovin laitier (via la réglementation du label d'Agriculture Biologique) (Chapitre 6).

Par ailleurs, un durcissement de la loi au cours de l'année 2016 a interdit l'usage en première intention d'antibiotiques dits critiques[67], ayant eu pour effet une diminution de leur utilisation (Méheust et al., 2017).

Plus généralement, le durcissement des réglementations européenne et française depuis les années 2006 (avec une interdiction d'utilisation des antibiotiques comme promoteurs de croissance) et les progrès observés en termes de consommation d'antibiotiques en France montrent les effets positifs du renforcement de ces contraintes. Tant que les usages d'antibiotiques systématiques restent autorisés à des rapports coûts/bénéfices avantageux, les évolutions de pratique sur ce point pourraient

[67] Décret n°2016-317 du 16 mars 2016

être lentes et limitées. Les Pays-Bas ont par exemple interdit l'utilisation préventive d'antibiotiques pour les animaux d'élevage en 2013 (Scherpenzeel et al., 2016). Dans le cas d'un durcissement de la réglementation française de cette nature, il faudrait pouvoir évaluer l'impact d'une telle mesure sur l'économie de la filière, sous réserve de faisabilité pour la filière viande de JBB. Des adaptations logistiques importantes pourraient en effet être nécessaires, et les conséquences financières pour les éleveurs au regard des risques de maladies respiratoires conséquentes. Cette étude d'impact prendrait en compte une analyse sur les prix des produits finis, sur leur accès au marché en tenant compte de l'importance de l'export pour la filière des JBB, des revenus des exploitations et des cabinets vétérinaires. Une autre mesure, pourrait être d'utiliser la politique agricole commune comme un levier soutenant les pratiques vertueuses de prévention des maladies ou de non utilisation préventive des antibiotiques. Certaines aides pourraient alors être soumises à des conditionnalités, comme c'est le cas en production végétale pour certaines mesures agro-environnementales.

Par ailleurs, l'Etat, par les plans nationaux développés en France depuis 2007, permet également une concertation et une mise en lien des différents acteurs des filières pour un progrès et une harmonisation des pratiques. Dans le plan EcoAntibio 2 mis en place depuis 2017, la communication est un des principaux axes de fonctionnement. Accompagner ces campagnes de communication d'outils pour permettre aux éleveurs d'évaluer les coûts et bénéfices de leurs pratiques de prévention pourrait permettre d'en augmenter l'impact auprès des éleveur et conseillers de la filière.

Conclusion générale

L'antibiorésistance est une menace mondiale pour la santé des êtres vivants. Réduire l'utilisation des antibiotiques en médecine humaine et animale est un des leviers majeurs pour limiter l'expansion de bactéries résistantes aux antibiotiques.

Les filières lait de vache et viande de jeune bovin de boucherie (JBB) que nous avons étudiées dans cette thèse sont très peu intégrées. Les éleveurs sont indépendants, et produisent sous contrat (pour les éleveurs laitiers) ou sans contrat (majorité des éleveurs de JBB). En outre, de nombreux conseillers techniques et vétérinaires salariés d'entreprise ou libéraux accompagnent ces éleveurs pour la gestion de la santé de leur troupeau. Les vétérinaires libéraux impliqués dans le suivi des élevages sont principalement investis dans la gestion des urgences médicales, n'ayant majoritairement pas le temps de développer avec les éleveurs des changements de pratiques sur le long terme. Par ailleurs, aucune de ces deux filières ne valorise aujourd'hui des modes de production n'utilisant pas d'antibiotiques.
Dans ces conditions, des usages systématiques préventifs pour maîtriser des risques de maladies de production à des moments clés sont la norme. Les observations concernant l'organisation verticale et les pratiques en place dans la filière de viande de JBB française sont transposables à la situation existant au Canada. S'inspirant d'initiatives françaises et canadiennes, des leviers pour des changements de pratiques ont été identifiés : valorisation de pratiques vertueuses de prévention, meilleure prise en compte des risques de maladie par une transmission transparente des niveaux de risques auxquels les broutards sont exposés, etc. Ces initiatives concernent cependant une part très limitée et minoritaire des modes de production. En outre, ces changements de pratiques pourraient ne pas être valorisés sur les marchés, notamment dans le cadre de la filière de viande de JBB où une majorité des produits est destinée à l'export.
Les enquêtes et entretiens réalisés en élevage de jeunes bovins de boucherie et en élevage laitier ont également montré un manque de prise en compte par les éleveurs et les acteurs de la filière des enjeux liés à l'antibiorésistance et à la maîtrise des maladies de production par des pratiques de prévention plus vertueuses. En outre, les vétérinaires ont exprimé les mêmes réserves que les éleveurs quant à l'abandon de pratiques systématiques et préventives d'usages d'antibiotiques. Il semble donc essentiel de sensibiliser largement les acteurs aux enjeux de l'antibiorésistance, afin de leur donner les outils et compétences pour améliorer leurs pratiques. La formation et le conseil pour donner aux éleveurs les outils de la mise en place d'une réduction d'utilisation d'antibiotiques et pour les accompagner sur le long terme dans des démarches complexes ont par exemple montré des effets positifs lors de l'évaluation d'une étude d'intervention réalisée en élevage bovin laitier.

L'abandon de pratiques d'utilisation systématique des antibiotiques semble donc être difficile, d'autant plus qu'elles sont admises comme étant une norme permettant de gérer un risque sanitaire réel. Les initiatives et potentiels leviers identifiés dans les filières lait de vache et viande de JBB ne concernent encore qu'un volume marginal de la production. A la lumière de ces observations et analyses, le levier réglementaire, par un durcissement du cadre d'utilisation des antibiotiques pourrait permettre une évolution rapide des pratiques, pour une moindre utilisation des antibiotiques, et un meilleur respect des enjeux de santé publique liés à l'antibiorésistance. En filière viande de JBB, cela pourrait nécessiter une réorganisation profonde de l'organisation logistique de la filière qu'il faudrait accompagner.

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Productions

Publications à comité de lecture

Internationales

Poizat, A., Bonnet-Beaugrand, F., Rault, A., Fourichon, C., Bareille, N., 2017. Antibiotic use by farmers to control mastitis as influenced by health advice and dairy farming systems. Prev. Vet. Med. 146. https://doi.org/10.1016/j.prevetmed.2017.07.016

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Poizat, A., Bareille, N., Frappat, B., Roussel, P., Lecaime, M., Neau, M., Le Guénic, M., 2017. Pratiques des éleveurs de bovins laitiers vis-à-vis des mammites et des usages d'antibiotiques. Bulletin des GTV. 85.

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Présentations orales

Congrès internationaux

Joly, N., Adam, C., Bonnet-Beaugrand, F., Defois, J., Ducrot, C., Fortané, N., Frappat, B., Gros, A., Hellec, F., Manoli, C., Paul, M, Poizat, A., Samedi, C., 2016. 12th European IFSA Sympsium. July 12-15 2016, Newport, UK.

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Titre : Freins et leviers a une réduction d'utilisation des antibiotiques en élevage bovin lies a l'organisation économique des filières, aux systèmes d'exploitation et au conseil.

Mots clés : Chaîne de valeur, coûts de transaction, information, antibiotiques, élevage bovin, formation.

Résumé : Réduire les usages d'antibiotiques est un des leviers principaux pour contrer l'avancée de l'antibiorésistance qui menace l'efficacité du traitement des maladies bactériennes humaines et animales. En filières bovin laitier et jeunes bovins de boucherie, deux maladies de production sont responsables des principaux usages d'antibiotiques, respectivement les mammites et les maladies respiratoires. L'objectif de la thèse a été d'identifier auprès des acteurs des filières des verrous limitant l'amélioration les pratiques de l'utilisation d'antibiotiques, puis d'identifier des leviers d'action. En élevage de jeunes bovins de boucherie, des entretiens auprès d'acteurs de la filière (éleveurs et responsables) et des enquêtes auprès d'éleveurs ont permis d'identifier que l'organisation de la filière est un des principaux verrous. Cependant, les caractéristiques des systèmes d'exploitations et les compétences des éleveurs constituaient également de potentielles limites. En élevage bovin laitier, des entretiens ont permis de montrer que les perceptions et connaissances des éleveurs semblaient être un des freins majeurs à l'amélioration des pratiques, le système d'exploitation semblant intervenir à la marge. En élevage bovin allaitant, des leviers permettant d'améliorer la coordination entre les acteurs de la chaîne de valeur ont été identifiés. En élevage laitier, un programme innovant de formation et de conseil a été évalué dans le cadre d'une étude d'intervention, montrant une amélioration des connaissances et perceptions des éleveurs sur la prévention et l'utilisation des antibiotiques.

Title: Limitation and levers to a reduction of antibiotic use in cattle sector related to the economic organisation of sectors, of farming systems, and of advice.

Keywords: Value chain, transaction costs, information, antibiotics, cattle farming, training.

Abstract: Reducing antibiotic use is one of the main levers to limit the increase of antimicrobial resistance, which threatens the effectiveness of the treatments of human and animal bacterial diseases. In dairy and young beef bull sectors, antibiotics are mainly used to control two production diseases, respectively mastitis and bovine respiratory diseases (BRD). The objective of the thesis was to identify with sectors' stakeholders' limitations for the improvement of antibiotic use practices, then to identify levers of action. In the young beef bulls' sector, interviews with stakeholders and farmers showed that the organization of the value chain, because of its potential influence on BRD risk factors, was one of the main limitation identified. However, the characteristics of farming systems and farmers' skills were also a potential limitation. In the dairy sector, interviews have shown that farmers' perceptions and knowledge seemed to be one of the major limitation to the improvement of the practices. The farming system seemed to have only limited influence. In young beef bulls sector, levers to improve coordination between stakeholders in the value chain have been identified. In dairy farming, an innovative training and advising program was evaluated as part of an intervention study, showing an improvement in the knowledge and perceptions of farmers regarding prevention measures and antibiotic use