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Who pays for the cost of change? On the different antibiotic use patterns in three Nordic pig-meat settings

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ABSTRACT

Animal-based food production accounts for two thirds of global antibiotic consumption (Van Boeckel et al., 2017) yet reducing antibiotic use is key to sustainable agriculture (Kirchhelle, 2018; Helliwell et al., 2020). The purpose of this empirical paper is to investigate the driving forces and hindrances behind the successful disembedding of the routine use of antibiotics in animal welfare practices in the Swedish, Norwegian and Danish pig meat settings. The Swedish and Norwegian settings represent Europe's lowest use of antibiotics for food animals and Antimicrobial Resistance (AMR) occurrence is rare. In Denmark, the use is below the EU average, but there is a high prevalence of AMR. Using the Industrial Network Approach (INA), our study shows how the current restricted use of antibiotics in the Nordic pig meat setting was the outcome of a mixture of voluntary and regulated change, and above all, the ability to distribute the costs of change. As such, multi-actor change towards more sustainable agriculture requires the ongoing collaboration between policy and business, along with significant possibilities for farmers to share the costs of change.

1. Introduction

When antibiotics for food animals were launched in the early 1950s, routine group treatment quickly became used to combat bacterial infections and accelerate growth (Smart and Marstrand, 1972). Over time, livestock husbandry practices and resources were adapted towards antibiotic-based production. This enabled "*an intensification of farming and animal husbandry that had been unthinkable before*" (Thoms, 2012: 2), including high animal density and extensive transportation of live animals (Schewe and Brock, 2018; Brock and Schewe, 2023).

Of course, the serious - and for decades neglected - drawback of extensive antibiotic use in animal production (and human health) was increasing antibiotic resistance (AMR). 1.27 million human deaths per year are estimated to be directly attributable to AMR, while 4.95 million deaths are associated with resistant bacteria (Antimicrobial Resistance Collaborators, 2022). The interplay of animal and human health (Morris et al., 2016) highlights the need to focus on both the global health and economic consequences of antibiotic use patterns in agriculture (Schewe and Brock, 2018).

After decades of ambiguity around the AMR issue, it became recognised as a global health threat (Kirchhelle, 2018). For example, the World Health Organisation (WHO), Food and Agriculture Organisation (FAO) and World Organisation for Animal Health (OIE), together launched the 'One Health' approach in the early 2000s.[1] At the EU level, after decades of accepting routine group treatment for food animals, the long-term consequences began to be seriously considered (Nordéus, 2023). Despite the opposition of the Scientific Committee, the first EU ban of an antibiotic used for growth promotion and nutrition (avoparcin) came into force in1998[2] (Dibner and Richards, 2005).

As such, the reduction of antibiotic use and antimicrobial resistance is central to the ongoing transition towards more sustainable agriculture (Kirchhelle, 2018; Bellet, 2018; Helliwell et al., 2020). It requires multi-actor changes in animal welfare practices (Thoms, 2012; Schewe and Brock, 2018; Brock and Schewe, 2023), not least because it is

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[1] https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

[2] In 1999, four other types of antibiotics used for the same purpose were banned.

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difficult for individual actors such as farmers to achieve change without outside support (Waluszewski et al., 2021; Rödiger and Home, 2023). The Nordic countries are recognised as exemplifying that in fact it *is* possible to reach a 'minimised use' (Nunan, 2022) of antibiotics. Furthermore, Sweden and Norway have also minimised resistance occurrence (Kahn, 2016). These radical reductions in antibiotic use for food animals is essentially a Nordic phenomenon (WEF, 2013). The processes of how this has been achieved are therefore important to understand, especially when viewed against increasing global usage (Van Boeckel et al., 2017).

In this paper we focus on the pig-meat setting, traditionally one of the most extensive user areas, in three Nordic countries. Sweden has the lowest use of antibiotics within the EU. Norway is a non-EU country with exceptionally low use. The use in Denmark, with a large export industry, is still below the European average, but more than three times higher than Sweden and Norway(see Table 1). Furthermore, while resistance occurrence is rare in Swedish and Norwegian pig herds (Swedres-Swarm, 2018), these are widely prevalent in European herds, including Denmark (Kobusch et al., 2020). The variations in both antibiotic use patterns and resistance occurrence across the three countries highlights that there are significant differences in how radical reductions have been achieved.

The aim of this empirical study is to identify the driving forces, hindrances and costs underpinning the efforts to both stop the routine use of antibiotics and minimise the need for antibiotic treatment in the Nordic pig meat setting. To address this aim, we adopt the Industrial Network Approach (Håkansson et al., 2009; Håkansson and Snehota, 2017), hereafter INA. In the INA, the core assumption is that economic exchange takes place in interaction as resources are combined across organisational borders to co-create value (Ibid.). As it does not take a simplified market view based on atomistic exchange, the INA has been used to investigate technological, social and economic interdependencies in multiple industries, including agriculture generally (e.g., Hoholm, 2011; Keränen et al., 2021), and the use of antibiotics specifically (e.g., Waluszewski, 2023).

In this study, we use the INA because it enables us to identify the driving forces and hindrances in efforts to reduce antibiotics use in three Nordic pig meat settings in terms of the inter-organisational interdependencies involved. This encompasses how the benefits and costs are distributed across directly and indirectly related actors. The study thereby responds to recent calls for more research about the inter-organisational interdependencies involved in reducing antibiotic usage (Hughes et al., 2021; Tompson et al., 2021).

Our theoretical position and research design are outlined below. The research question addressed is: *What are the driving forces and hindrances of the antibiotic disembedding processes in the Swedish, Norwegian and Danish pig meat settings, and how are these related to the benefits and costs of change?* We answer the research question by highlighting the main actors and resources that were involved in efforts to substantially reduce antibiotics use – hereafter referred to as disembedding - in the Nordic pig meat setting. Furthermore, we consider the distribution of benefits and costs of the reduced use.

Our main finding is that reduced antibiotic use requires the co-existence of collaborative voluntary efforts, regulated change, *and* the possibility for the costs of change to be distributed beyond the individual farm. The paper contributes to existing debates around the role of agriculture in the global need for reduced antibiotic use and the combatting of AMR (Kirchhelle, 2018; Bellet, 2018) by outlining the social, technological and economic interdependencies involved. The use of the INA enables detailed insight into the inter-organisational efforts underpinning the reductions in antibiotic use in the three Nordic pig meat settings. This empirical unravelling addresses the debate about efforts towards more sustainable agriculture (Helliwell et al., 2020). Our findings can also be pertinent for other attempts at solving sustainability challenges involving resources that have a use that is harmful to society at large.

Table 1
Population adjusted sales of antibiotics for animal-based food production (ESVAC/EMA, 2022,[31]).

2023	Mg/PCU
Norway	**2.1**
Sweden	**10.6**
Denmark	**34.1**
Germany	69.9
European average	73.9
Italy	157.5
Poland	196

2. Analysing reduced antibiotic use in agricultural networks

Research about the consequences of extensive antibiotic use has spread from natural sciences and a small number of social science papers (Achilladelis, 1993; Smart and Marstrand, 1972), to becoming a joint research field, covering use in both human health and agriculture (Bellet, 2018; Helliwell et al., 2020; Hughes et al., 2021; Lu et al., 2020). Social scientists' attention to the social and economic aspects have encompassed multiple levels, from 'antibiotic infrastructures' in agriculture (Kirchhelle, 2018) to the role of antibiotics in individuals' daily lives at different income levels (Tompson et al., 2021). Overall, the social science studies can be grouped into three, whereby the common denominator is the investigation of antibiotic use from a situated, interactive perspective (Ibid.).

The first group considers antibiotic use as a practice, and a second centres on how political and economic structures foster a reliance on antibiotics. A third, more recent, group investigates antibiotic use from network approaches. Specifically, "*considering the networks in which antibiotics are entangled offers a novel approach through which to understand antibiotic use, and their careful analysis can identify alternatives and/or render visible previously overlooked targets for stewardship*" (Ibid., p6).

In this paper, we adopt the INA (e.g., Håkansson and Snehota, 2017) to analyse how routine antibiotic use in a specific agricultural setting can be, to play on Tompson et al.'s words, '*disentangled*'. The INA is underpinned by the assumption that resources exchanged by organisations are heterogeneous, and their value depends on how they are combined across organisational boundaries (Håkansson et al., 2009). Over time, the creation of resource combinations results in technological, social and economic interdependencies in business networks.

The INA has kinship with the 'heterodox economic' research field (e.g., Lawson, 2006; Marglin, 2008; Fourcade et al., 2015) and with studies on the infrastructure of antibiotic use in agriculture (Chandler, 2019; Kirchhelle, 2018). The INA has been widely used in studies of business innovation in general (Håkansson and Snehota, 1995; Håkansson et al., 2009), and in the agricultural setting specifically (Coyral and Batt, 2022; Olsen, 2012; Hingley, 2005). For example, studies have analysed the dynamics involved in antibiotic use in both human health (e.g., Ciabuschi et al., 2021) and agriculture (e.g., Waluszewski, 2023). This is part of ongoing work about how business networks underpin the sustainability transition (Harrison et al., 2023)

2.1. Capturing the disembedding of routine antibiotic use

In the INA, any significant change in how resources are combined across organisational boundaries implies that other related resource interdependencies, both direct (in a specific relationship) and indirect (in the wider network) will be impacted. Furthermore, changes in resource combinations "… *can only be done at certain cost*" (Håkansson, 1987, p. 92). The costs of changing resources includes both the direct and indirect costs related to the adaptions impacting both sides of the exchange interface (Carlson, 1970). This is because resources become embedded across organisations over time due to technological, social and economic interdependencies (Håkansson and Waluszewski, 2002).

Reducing antibiotic usage requires changes to the established use patterns because antibiotics must be 'disentangled' (Tompson et al., 2021) or in INA terminology, disembedded, from the multiple resource combinations in which they are embedded. Studies of disembedding resources have centred on the consequences for actors which are disembedded from their established contexts. For example, the challenges faced by refugee entrepreneurs when outside of their familiar environment (Harima, 2022).

In particular, INA research has drawn attention to the economic, social and technological costs and consequences of disembedding 'unwanted' resources that are harmful to the environment and society at large (Harrison et al., 2023; Håkansson and Snehota, 2024). For example, the multi-actor efforts across organisational borders required to respond to the banning of CFCs to protect the ozone layer (Harrison, 1999), of chlorine bleaching in the paper industry (Håkansson and Waluszewski, 2002), and disembedding air from e-commerce parcels (Grönberg and Hulthén, 2022).

To disembed a resource – to stop using that resource or to radically reduce its use – is a process that entails both benefits and costs. One challenge with disembedding the routine use of antibiotics in animal production is that the benefits largely appear in terms of human healthcare, while the main cost of change is incurred by the direct users (farmers) (Waluszewski, 2023). Efforts to disembed the routine use of antibiotics will result in reactions from those actors that are both directly and indirectly affected, depending on how costs and benefits are distributed (Baraldi and Wagrell, 2022; Waluszewski et al., 2021). This implies, as underlined by Robinson (2017) and Puupponen et al. (2022), that to rely on the ability of farmers to achieve change, or even to blame individual farmers for a lack of change, is shortsighted.

3. Research design

We adopted a multiple case study methodology to identify the driving forces and hindrances involved in disembedding routine antibiotic use and minimising overall use in the three Nordic pig meat settings. Case studies facilitate in-depth, processual and contextual understanding of complex phenomena (Halinen and Törnroos, 2005; Yin, 2009). They are suitable for studying inter-organisational processes (Aaboen et al., 2012; Piekkari and Welch, 2018) and for addressing societal 'grand challenges' (Eisenhardt et al., 2016) such as the global need for reduced antibiotic use.

We selected the three cases because Sweden, Norway, and Denmark are all ascribed 'significant progress' in terms of reducing antibiotic use in agriculture, yet at the same time they have different usage levels (see Table One). This suggested differences in the disembedding patterns behind the 'Nordic phenomenon', which was a source of variation required for a multiple case design (Eisenhardt and Graebner, 2007). The cases are complementary but not fully comparable since the efforts to disembed antibiotics occurred in different times and contexts.

The cases are underpinned by multiple types of data. Primary data was collected in two ways. First, thirty-eight interviews were conducted: eighteen in Sweden, ten in Norway and ten in Denmark. Interviewees included farmers, representatives from farmers' associations, public health agencies, retailers, and researchers in related disciplines. These individuals were identified due to their involvement in the efforts to reduce antibiotic usage in each case.

We wanted to ensure comparability of data collected across the three countries. We had existing research connections in the industry that enabled data access. We started the interview process with one individual and then selected further interviewees through existing connections or by asking for assistance from interviewees to provide introductions. Over time, we learned about the organisations involved and the related interdependencies in reducing antibiotic use.

The interview guide contained the following themes. First, we addressed the current organisation of pig meat production. This included the multiple organisations involved, the current husbandry practices, key resources and activities, challenges and disagreements, and where antibiotics are used and why. Thereafter we addressed the theme of changed antibiotic usage patterns over time, with a particular focus on driving forces and the obstacles related to attempts to reduce use.

The second source of primary data was through participatory workshops (Evers et al., 2017). We arranged three one-day workshops to discuss multiple perspectives about the disembedding of antibiotics in the pig meat setting in each country. The invited participants at the three workshops represented a range of governmental and private organisations and academic researchers. The first workshop was arranged at a Swedish University in May 2019. It focused on reducing antibiotic use from the farmers, farmers organisations and consumer perspectives.

The second workshop was organised at Norwegian University in March 2020, which centred on the role of governmental support and regulations to combat overuse and resistance outbreaks. The third, arranged at Danish University in May 2021, focused on the impact of being export dependent and on current development paths related to pig meat production. The total number of participants across the three workshops was eighty-three. Of these, forty-five represented academic research, seventeen commercial companies, and twenty-one were from industry organisations.

The primary data was complemented with various secondary data sources collected between 2017 and 2023. These included policy documents, reports from National Veterinary Institutes, Public Health Agencies, and Farmers Associations, annual studies of the three national meat markets, and relevant articles in social and natural science journals.

To analyse the data, we identified inter-organisational technological, social and economic interdependencies within and across the three cases and analysed these retrospectively which is common for network research (Bizzi and Langley, 2012). We produced a descriptive narrative for each case, which revealed both how the disembedding of routine antibiotic use was achieved over time, key driving forces and hindrances, along with different abilities to distribute the costs of change.

4. Empirical cases

In 2006, the EU banned all agricultural uses of antibiotics other than for strictly medical purposes (EU, 2005: IP/05/1687[3]). However, as Nunan (2022: 5) states: *"… huge differences in the levels of farm antibiotic use currently exist between different European countries"*. The latest EU regulation, in January 2022, banned antibiotic use that compensates for a lack of investment in precautionary animal health, hygiene and welfare.[4] The efforts of the Nordic countries in reducing antibiotic use, especially Norway and Sweden, are often highlighted (Kirchhelle, 2018). Yet, beneath the surface are different patterns of use – and resistance occurrence. Below we take a closer look at three Nordic use patterns.

4.1. Sweden: Pioneering and protected

Two main characteristics underpin the Swedish engagement in minimising antibiotic use for food animals. First, efforts started decades before AMR became a global policy issue, at a time when Swedish food production was economically protected due to a self-sufficiency policy (Flygare and Isacson, 2011). Second, it was driven by environmentally concerned farmers and the Swedish Farmers Association (SFA) (Kahn, 2016): *"The pig farmers acted for change, individually, through their organisations and politicians."*[5]

[3] https://ec.europa.eu/…/document/print/es/ip_05_1687/IP_05_16 … · PDF file.

[4] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_663.

[5] Interview, former manager SFA, 2018-11-20.

4.1.1. The changes

In the early 1980s, efforts to stop routine antibiotic use by some farmers and managers at SFA began. The debate, not least in the media, had been intense for at least a decade, and animal-based food production was associated with the extensive use of chemicals, drugs, and poor welfare practices (Begemann et al., 2018). In 1981, one large newspaper ran a series scrutinising chemical usage in farming, including routine antibiotic use for animals.[6] This exacerbated both the public and farmers' concerns, especially regarding the long-term environmental consequences. Although Sweden had adopted the suggestions made by the Swann committee[7] to not use drugs reserved for human therapy as growth promoters, antibiotics continued to be an established ingredient in feedstuff for pigs and poultry.

In response, the SFA presented its first antibiotics policy. This called for the voluntary elimination of a daily low dose in feedstuff. However, the most engaged farmers were dissatisfied with the policy, because it would place those which invested in measures to compensate for routine group treatment at an economic disadvantage. They advocated for a legal ban to achieve a level playing field. At the 1984 SFA annual meeting, after an intense debate, it was decided to work towards a ban of routine antibiotic use in feedstuff.

The Government supported the bill, and in January 1986, the world's first law banning antibiotic use for nutrition and growth promotion entered into force (SFS, Swedish Code of Statutes, 1985: 295).[8] A year later, a new animal welfare law was passed, which magnified the impact of the ban by stipulating that '*animals shall in the future be protected not only from suffering but also from disease*'.[9] Animals now had regulated rights to space and materials.

4.1.2. Changes invoiced to farmers

The elimination of routine antibiotic use, which at most farms occurred without preparations, resulted in infectious diseases and mortality among piglets increasing and the prescription of antibiotics spiralling (Bengtsson and Wierup, 2006). This was taken as a clear proof of what routine use had hidden and required all the involved actors to engage in searching for compensating measures. From being an issue driven by engaged farmers, the SFA acted as a mobilising force, and involved the companies it owned. These included suppliers of feed, equipment, slaughter, and transportation, in efforts to adapt to pig-meat production without routine antibiotics use, and with as restricted overall use as possible.

In what later became labelled 'biosecurity' and 'precautionary health', various changes to material and social resources occurred, in efforts to compensate for routine antibiotics use and combatting resistance occurrence (Backhans et al., 2015; Magnusson et al., 2019). One of the most important changes was batch-wise breeding processes, with sanitary periods between each batch of piglets. This implied changes by multiple actors, in stable design, equipment, improved hygiene routines at farms, during transportation, and slaughter. The quarantine of new animals, development of feed, and introduction of vaccination programmes for sows and piglets were other important measures, which also involved inter-organisational efforts. Furthermore, farm personnel, visitors, and even the transporters, had to adapt to hygiene routines (Waluszewski, 2023). Afterwards, compared to the European average, each pig had about 50 % more space, were loose and had access to straw.

The innovative change efforts were underpinned by a general industry trust in state compensation to farmers. Compensation was a widespread practice during the decades in which the negotiated prices for Swedish-produced food were lower than those on the world market. Moreover, Sweden was not yet part of the EU and agriculture was state protected (Marglin, 2008) However, the extensive engagement in the change coincided with dropping world market prices, and the state compensation scheme failed[10].

Now a new debate emerged, this time focused on the high prices of Swedish food. The SFA was blamed for a monopoly-like situation (Flygare and Isacson, 2011; Morell, 2011). The innovative efforts of farmers, their suppliers and the veterinary community to achieve reduced antibiotic use became overshadowed by the price discussion. One result was that the costs of changes compensating for routine antibiotic use were incurred by farmers alone, rather than being shared with retailers and consumers.

The economic situation for farmers worsened after Sweden joined the EU in 1995. There was an influx of low-price meat from countries that still used antibiotics for nutrition and growth promotion. The retail industry imported low price pig meat products to attract consumers but did not make any efforts to inform consumers about the differences in how pig meat was produced domestically. Swedish farmers were badly hit, and over a few years, production fell from 4 to 2.6 million pigs annually, and most small-to medium-sized farms closed.[11]

Instead of the expected applause, the EU commission contested the Swedish ban on routine antibiotic use in feedstuff, suggesting it was not based on science. Sweden managed to get a four-year exemption but would then be forced to accept antibiotics used as feed ingredients. The EU reaction did however trigger national politicians, veterinarians, researchers, and farmers to join forces (Nordéus, 2023). Sweden argued that the EU should not only accept the Swedish antibiotic strategy but also adopt it. The argument coincided with the BSE outbreak in UK, increasing the European awareness regarding animal health. The EU conceded, and a 1998 partial ban paved the way for more extensive bans in 2006 and 2022.

Hence, there was some alignment between national and EU regulation. However, it was still price, and not the need for restricted antibiotic use, that retailers communicated to consumers. It was not until the EU election campaign in 2014 that the Swedish retail industry was challenged. The national media reviewed antibiotic use in European food production, with a special focus on the Danish pig industry. That 90 % of pigs in Denmark carried livestock-associated methicillin-resistant staphylococcus aureus (LA-MRSA) bacteria[12] was contrasted with the minimised domestic antibiotic use and exceedingly rare occurrences of LA-MRSA.

The resulting fierce media debate encouraged a concerned ICA supermarket manager to react by deciding to stop setting Danish pig meat. Essentially, the three main Swedish retail chains became forced to react rapidly considering the reporting about Danish antibiotic use patterns. The branding of 'Swedish meat' was developed and promoted, which included information for consumers regarding the domestic restricted use of antibiotics. Moreover, the specifications for the retailers' 'own brand' products changed to require production that only used antibiotics for medicinal purposes.

These efforts caused a significant shift in consumer behaviour. Even though Swedish pig meat was 10–15 % more expensive per kilo

[6] The series published in *Dagens Nyheter* was later published as 'Mass food: Swedish farming in the chemical era'.

[7] The UK government initiated 'Swann Committee,' delivered in 1969, suggesting that some antibiotics should be reserved for human medicine (Wise, 2007).

[8] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-1985295-om-foder_sfs-1985-295 2019-05-17.

[9] https://www.riksdagen.se/sv/dokument-lagar/dokument/proposition/om-djurskyddslag-mm-_GB0393/html.

[10] https://www.lrf.se/om-lrf/mer-om-lrf/lrfs-historia/organisationen/lrf-1971-1987/.

[11] https://jordbruksverket.se/download/18.28f4d91b172cdd65219b3acb/1592760271492/201801.pdf.

[12] https://www.svt.se/nyheter/utrikes/manga-grisbonder-drabbade-av-mrsa.

compared to the EU average, the market share of domestic production increased from about 65 % to 85 %.[13] About three decades after the Swedish pig farmers and related organisations started their innovative efforts, the societal debate about the importance of restricting antibiotics finally resulted in farmers getting support and the associated economic rewards.

4.2. Norway: protected change

There are two specific characteristics of the Norwegian engagement in reducing antibiotic use. First, efforts occurred within a heavily regulated market, which has the highest levels of state support among the OECD countries (Saether, 2003). Approximately 60 % of farmers' revenues stems from state support (OECD, 2021). Second, change was triggered by research on the relation between growth promotion and resistance.

4.2.1. Changing use patterns

Since the 1930s, Norwegian agriculture has been underpinned by import regulations and policies.[14] The meat market is based on stable prices and weekly volume balancing undertaken by Nortura, a cooperative owned by approximately 17,000 farmers.[15] Despite scepticism towards guidelines from the pharmaceutical industry, routine use in feed was introduced in the 1950s for pigs and poultry (Kveim Lie, 2014).

When efforts towards reducing antibiotic use began, there was a long-standing focus on animal welfare. Policies were in place for limiting the size of individual farms and there was a national program for collective breeding (Olsen and Gripsrud, 2002). Engagement was triggered by research findings presented in 1995 regarding the link between the use of avoparcin and VRE[16] (Aarestrup, 2012). This prompted reactions in veterinary circles, governmental organisations, and at Nortura. The government acted quickly and banned avoparcin as a feed additive in May 1995.

The VRE debate highlighted the link between routine use for growth promotion and the risk of resistance outbreaks. A campaign was started in 1995 to reduce antibiotic use for food animals through preventative measures (Grave et al., 2006). It was administered by the Norwegian Husbandry Organisation (NHO) and coordinated by the R&D organisation Animalia and aimed at veterinarians and farmers.[17] The key measures centred on improving animal health to compensate for routine antibiotic use. These measures included increasing the space available per pig and banning tail docking. Changes were impacted by the existing ways in which the low-scale pig production was organised (limited animal movement).

Furthermore, while the campaign was running, the slaughterhouses presented a joint action plan for the voluntary phase out of antibiotic growth promotors. This was to apply with immediate effect. The slaughterhouses also collaborated to set price penalties. The price differential was sufficient to force change amongst farmers. Within a few years antibiotics for growth promotion were eliminated.

In 1996, the slaughterhouses presented a new action plan, with the aim to reduce antibiotic use by 25 % within five years. Once more, price penalties were imposed, which acted as a core incentive for farmers to change husbandry practices. The planned 25 % reduction was achieved within two years. The focus on animal welfare has subsequently been encoded in both laws and as principles underpinning later joint action plans.

There were also efforts to control outbreaks of resistant bacteria. In 1997, the Norwegian Food Control Authority (NFCA) initiated a survey to assess the occurrence of LA-MRSA in food products sold in Norway. In 2000, the Norwegian Ministry of Health and Social Affairs (NMHSA) launched a National Action Plan (NAP) against antimicrobial resistance, against a backdrop of efforts by the EU and WHO.

The NORM-VET program was commissioned in 2000 by the Food Safety Authority (FSA) and coordinated by the Norwegian Veterinary Institute (NVI). The aim was to provide data on antibiotic usage and to record efforts to limit resistance. For example, all pharmacies (the only distribution channel) were required to register sales. These surveillance activities were integrated into both legislation and principles about who could treat production animals and under what circumstances. This involved the Department of Agriculture, the FSA, Nortura, and Animalia.

Moreover, national efforts at pig farms were ongoing to change animal welfare practices. These were coordinated by Nortura. Each individual pig farmer incurred the economic costs. As the general welfare standard increased, and the use of antibiotics decreased, regulations was put in place. In other words, "*changes to regulations come after industry efforts have been made*".[18] One implication was that pig farmers found not to be adhering to new practices could be closed after industry-led improvements were formalised into new regulations.

From summer 2008 to the end of 2012, an Integrated National Strategy for the prevention of resistance infections was established. In 2008 the first survey to assess MRSA in pig herds was conducted collaboratively, by actors including Animalia, Nortura, and farmers. "*LA-MRSA eradication in pig herds is possible with a satisfactory degree of certainty … it is a question of if you want to prioritize it*".[19] Furthermore, 2011 saw the establishment of the 'VetReg' register. All veterinarians were required to report their prescribing of antibiotics. There was controversy about data accuracy, because the sales data from pharmacies and the VetReg did not match. This had to be solved before the introduction of new national regulations to comply with the 2022 EU standards.

The first LA-MRSA outbreak was registered at a pig farm in 2011. As such, "*the issue became an issue, as it were*"[20]. Humans were suggested to be "*the probable source of the infection*". Weaknesses in hygiene routines in transportation were also identified as risk factors. A set of control measures for farms to combat LA-MRSA was put in place. Essentially, there is an immediate suspension of activity, followed by mandatory intensive disinfection. In severe cases, the whole herd is culled. The cleaning costs are the responsibility of the farmer, while insurance provides compensation should culling be necessary. As such, "*the farmers pay, and society gets the benefit*".[21] In 2016, the Department of Health coordinated the modelling of the implications should LA-MRSA became established in Norwegian pig production. The report suggested a cost to the Health Service of 22 million euros per year.

The National Strategy Against Antibiotic Resistance 2015–2020 set a target to reduce antibiotic use by 10 % by 2020. This was also a response to WHO efforts. To meet the target, Animalia *"… initiated and coordinated a joint action plan …*.[22] This led to the pig sector becoming part of the Norwegian KSL system (a quality control system) in 2018. This meant that delivering to slaughterhouses would be difficult unless farmers met strict quality standards, which forced changes at the individual farm level. In parallel, Nortura led a 'healthy pig' initiative. It was partly in response to bad press that followed from the enforced culling of pig herds due to LA-MRSA outbreaks. The result was four 'standards levels' for fattening pigs, with level 4 commanding a price premium in

[13] https://www.sverigesgrisforetagare.se/svensk-grisnaring-i-siffror/. https://www.gardochdjurhalsan.se/wp-content/uploads/2021/12/Internationella-rapporten-2021-v2.pdf.
[14] www.nortura.no.
[15] Ibid..
[16] Vancomycin-resistant enterococci.
[17] https://www.animalia.no/en/animalia-in-a-brief/about-animalia/.
[18] Interview with a veterinarian.
[19] Ibid..
[20] Interview with a veterinarian.
[21] Ibid
[22] Interview at Animalia.

the supermarket.

Overall, the actions to radically reduce antibiotic use have resulted in some of the lowest PCU data in Europe – and that MRSA outbreaks is a rare exception (see Table One). The data reflects that "*there has been systematic work over many years to reduce and eliminate diseases …*".[23]

4.3. Denmark: export focus

The Danish efforts to reduce antibiotic use were heavily influenced by the fact that they occurred in an export-based pig meat setting (FAO, 2019). '*We will never do the same as Sweden*,' is a typical comment, referring to the costs of change that were for long time incurred by Swedish farmers.

4.3.1. Changing use patterns

When the antibiotic debate started in 1994, Denmark had been an EU member for 20 years. At the time, approximately 90 % of the annual 28 million pigs produced was exported (5 % of national exports). Routine antibiotic use became established as soon as antibiotics for animals were available. Production was transformed from integrated farms in which pigs were raised from birth to slaughter, to specialised units focused on intensive breeding.[24] Between 1985 and 1995, antibiotic use increased by approximately 90 %. By the early 2000s, mega producer Danish Crown was a dominant actor in the industry (Strandskov, 2019).

The issue of overuse was raised at the Danish Veterinarians Annual Meeting in 1994. The veterinarian role was under scrutiny because "*many vets were making a huge profit from selling antibiotics to farmers*" (Aarestrup, 2012: 2). The discussion was made public by a journalist and a debate in the media ensued, with a focus on veterinary ethics (Kahn, 2016).

Soon afterwards, a connection between resistant bacterial infections and growth promotion antibiotics was proven.[25] The Danish government reacted by introducing legislation in 1995 that prevented veterinarians profiting from antibiotic sales. The legislation also banned the use of avoparcin for growth promotion (although in practice farmers had already voluntarily stopped). A research collaboration between veterinarians and human-disease epidemiologists led to the establishment of the Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP[26]). The aim was to reduce use through monitoring usage and resistance in humans and animals.

In 1998, a second growth promoting antibiotic, virginiamycin, was banned. The dominant exporter Danish Crown reacted by arguing that any change in antibiotic use had to occur without harming farmers' income, and without impacting the ongoing production specialisation. Price increases were deemed to be unrealistic. However, both the media debate around antibiotic use and governmental measures continued.

In 2000, a system for collating real-time data on sales of prescribed medicines for production animals, 'VetStat', was established by the Ministry of Environment and Food (Magnusson et al., 2019). This made the highest users of antibiotics per pig very visible. In the same year, the pig meat producers declared a voluntarily ban of antibiotics for growth promotion. Although this voluntary ban resulted in reduced routine use for growth promotion, another antibiotic application area started to increase.

The intensive production cycle made diarrhoea amongst post-weaning piglets common. 'Disease prevention', especially of post-weaning piglets, became a way for continued antibiotic use in routine group treatment (Aarestrup, 2012). The prevalence of resistant infections increased, and in 2004 the first transmission of LA-MRSA from pigs to humans was proven. New LA-MRSA guidelines were established as a result, but this did not stop people without any direct contact with pigs being infected (Larsen et al., 2015).

In attempt to control the spread of LA-MRSA, the Danish Veterinary and Food Administration (DVFA) presented a new action plan in 2012. The continued reduced antibiotic use for pigs required significant improvements in hygiene standards throughout the supply chain. Moreover, the movement of pigs from MRSA-positive herds to MRSA-negative herds had to be prevented (Schultz et al., 2019). However, studies conducted a few years later reported that 88 % of herds were still carrying LA-MRSA (Ibid.), even if the use of antibiotics measured in mg/PCU declined. The mg/PCU data was used in marketing Danish pork meat by making comparisons to higher European data.[27]

Overall, the changes made to reduce antibiotic use were underpinned by the export focus that fostered intense production methods. However, in response to the increasing awareness of the need to reduce antibiotic use, Danish Crown engaged in a multi-university collaboration with the goal to achieve 'antibiotic-free pig production'. The first products labelled '*raised without antibiotics*' were launched in the domestic market in 2018, in partnership with a retailer.

However, the project was put on hold in 2020. The label 'antibiotic-free' proved to be problematic because it drew attention to the established use of antibiotics in 'regular' production. Furthermore, for the farmers, engagement in 'antibiotic-free' production was considered as too risky. A transition to breeding methods that reduced the need for antibiotic treatment, especially of post-weaning pigs, would render higher production costs. At the same time, there was little scope for farmers to obtain better prices to cover such increased costs.

Farmers also had to address environmental regulations. For example, regulations on ammonia emissions paved the way for piglets to be exported. Piglets were then fattened and slaughtered at farms in countries such as Germany[28]. By 2018, live pig export had become significant, and the largest share (6 million) was exported to Poland, a country with one of Europe's highest antibiotics uses for food animals. This way of organizing the export business was criticized by the Danish authorities.[29] For example, long-distance transport of piglets is likely to cause infections, increasing the need for antibiotics, even if this use was not visible in the Danish statistics.

The debate regarding LA-MRSA intensified, broadly divided into concerned scientists and less worried industry representatives. Already in 2014, the Chairman of the Danish Agriculture and Food Council declared that "*the reality is that MRSA has reached a level where there is no way back. We will have to live with it both in agriculture and in the surrounding community*"[30].

5. Discussion

This study has responded to recent calls about the need for in depth research about the network interdepedencies involved in the use of antibiotics (Hughes et al., 2021, Thoms, 2012). Reducing antibiotic use is viewed as core in the transition to more sustainable agriculture (Kirchhelle, 2018; Bellet, 2018; Helliwell et al., 2020). We have answered our research question by using the INA to investigate the antibiotic disembedding processes in the pig meat setting in three Nordic

[23] Interview at Nortura.

[24] Interview with industry expert.

[25] Danish microbiologists reported the isolation of vancomycin resistant enterococci (VRE) from healthy pigs and poultry, probably due to the extensive use of avoparcin (Aarestrup, 2012).

[26] Home - DANMAP.

[27] https://lf.dk/aktuelt/nyheder/2019/januar/copy-of-vi-har-givet-antibiotikaforbruget-en-paa-trynen.

[28] Ibid..

[29] https://www.ft.dk/da/statsrevisorerne/nyheder/2020/01/dyretransporter.

[30] https://lf.dk/aktuelt/e-nyhedsbreveudsende/nyt-fra-formandskabet/2014/36-14/presidency/mrsa-er-kommet-for-at-blive.

[31] Sales of veterinary antimicrobial agents in 31 European countries in 2022 - Trends from 2010 to 2022 - Thirteenth ESVAC report.

countries in terms of (i) the role of farmers, farmers organisations, retailers and policy makers, (ii) the changes made, and (iii) and the benefits and costs of change.

Our main finding is that minimised antibiotic use requires the co-existence of collaborative voluntary efforts, regulated change, *and* the possibility for the costs of change to be distributed beyond the individual farm. The benefits of low antibiotic use are both direct (in terms of animal welfare) and indirect (in terms of human health). Table Two provides an analytical summary of the three cases. It highlights the key features of the usage patterns over time, in terms of contextual features, main driving forces, the ability to distribute the costs of change, legislation, and change outcomes.

By using the INA as the theoretical approach, the cases underpin our main finding by showing in depth and over time how social and material resources have been adapted to take economic advantage of routine antibiotic use, and differences in the efforts to disembed routine use and combatting resistance. The dynamics across the organisations in the Swedish and Norwegian cases, countries which have the most limited use of antibiotics for animals in Europe and have also succeeded in making resistance occurrence rare, highlight the importance of sharing the economic burden for change efforts.

In the Swedish case, the disembedding process had been ongoing for more than a decade when Sweden became a member of the EU in 1995. The efforts by farmers, the SFA, and its cooperatively owned suppliers took off in an era characterised by an intense general debate on animal welfare and overuse of drugs for animals and was furthermore based on trust in continued economic state support for the costs of disembedding routine use. When conditions changed after Sweden entered the EU, the transition to a minimised use was already embedded into Swedish farming and was defended by the SFA and the scientific community.

In the Norwegian case, pressure from the scientific community based on considerations of human and animal health spurred voluntary changes, coordinated by the slaughterhouses. These were accompanied by national regulations which 'levelled the playing field'. Furthermore, price differentials enacted by the slaughterhouses acted as a strong incentive for disembedding routine use. Subsequent national strategies to reduce antibiotic use and eliminate resistance outbreaks followed. The heavily regulated domestic market, along with the close relation between governmental organisations, cooperatively owned organisations, and representatives for researchers and veterinarians, underpinned the rapid and extensive disembedding process.

By contrast, the changes made by Danish pig farmers were influenced by the understanding that these would not be compensated by the state. Here, the attempts to disembed antibiotics had to be adapted to different contextual features and driving forces (see Table 2). By contrast to Sweden and Norway, in Denmark, MRSA prevalence is both high and accepted.

The use of the INA as the theoretical point of departure to investigate the 'disentangling' (Tompson et al., 2021) – or in this paper disembedding – of antibiotics in agricultural networks is a novel answer to recent calls for more studies about network interdependencies and antibiotic use. The INA is established as an approach to analyse interdependencies in agriculture generally (e.g., Hoholm, 2011; Keränen et al., 2021), and in antibiotic use specifically (e.g., Waluszewski, 2023). We argue that the INA enables what Tompson et al. (2021, p6) refers to as a "*careful analysis*" of the inter-organisational technological, social and economic interdependencies involved in trying to change networks from the routine use of antibiotics, and the related distribution of benefits and costs.

Overall, the use of the INA adds a novel dimension to existing network studies in AMR by facilitating the identification of the direct and indirect related resources that over time have been adapted to take economic advantage of routine use, and the costs involved in changing these. It provides a lens to understanding the dynamics involved in the networks involved in working towards minimised antibiotic use in animal production.

Table 2
Main usage patterns in the three Nordic countries.

	Sweden	Denmark	Norway
Contextual features (both national setting and production setting)	State protection (until EU entry in 1995). Domestic focus.	Open, export-oriented (EU member). Export focus.	State protection (non- EU member). Domestic focus.
Expected/ realised ability to distribute cost of change	**State compensation expected**, not realised.	**No expectations** of ability distribute cost of change to retailers/ consumers	**State compensation expected**, partly realised.
Overall characteristics of the disembedding settings	**State protection** (until EU membership 1995). Domestic focus. Farmer cooperation dominating owner of suppling, processing and marketing companies.	**Open, export-oriented** (EU member). Export focus. About 90 % of pig meat production exported, representing 5 % of the total export. Focus on rationalisation and large-scale production.	**State protection** (non- EU member). Domestic focus. About 60 % of farmers revenues stems from state support. State regulation of maximum production volumes and consumer prices. Close ties among public private actors.
Main driving forces	Farmers and farmers cooperation, based on environmental concerns.	Researchers and veterinaries, based on scientific findings.	Researchers and veterinaries, based on scientific findings. Public and private actors join.
Legislation	Legal ban of antibiotics for growth and nutrition **1986**. Strengthened animal welfare regulation 1987.	Legal ban of ban of avoparcin as feed additive in **1995.** Users voluntarily agree on stop for all antibiotics for growth promotion in **2000**.	Legal ban of avoparcin as feed additive in **1995.** Slaughterhouses collective mobilises towards voluntary change to phasing-out growth promotors.
Outcomes of changes	Elimination of routine use for feed and growth promotion. Minimised use for animal welfare. Increased production costs. MRSA outbreaks rare	Elimination of routine use for feed and growth promotion. Change not allowed to increase production costs. MRSA outbreaks common and accepted.	Elimination of routine use for feed and growth promotion. Minimised use for animal welfare. Increased production costs. MRSA outbreaks rare
Change in relation to expected/ realised ability to distribute the cost of change	Routine use totally disembedded. Compensatory measures radically change production system. Increased production costs. Use of antibiotics stabilised around **11 mg/PCU.** MRSA outbreaks rare exceptions.	Decreased but still practised routine use for disease prevention Change not allowed to increase production costs. MRSA outbreaks common and accepted.	Routine use totally disembedded. Compensatory measures changes production system. Increased production costs. Use of antibiotics stabilised around **6 mg/PCU.** MRSA outbreaks rare exceptions.

Our study of disembedding antibiotic use in pig meat production is also complementary to existing studies about disembedding resources in the INA. While Grönberg and Hulthén's (2022) research centred on the actors directly involved in the supply chain in their study about making

e-commerce parcels more sustainable, the empirical study here takes a multi-actor, international perspective. This broader scope is also reflected in differences regarding the role of legislation as a trigger for disembedding resources. For example, the study reported here contrasts with that of Harrison's (1999) study about industry responses to the Montreal Protocol that banned the use of CFCs in two main ways. The disembedding of antibiotics in the three Nordic pig meat cases exemplifies a mixture of voluntary actions and legislative bans (at different levels). In the CFC case, the 33 producers of CFCs impacted by the Montreal Protocol were allocated the responsibility – and costs – of the technological changes of resource disembedding through an enforced need to innovate alternative technologies.

6. Conclusion

In sum, this empirical study provides an important message to antibiotic and sustainability policy. That is, for systemic change towards sustainable agriculture to be achieved, it cannot be centred around individual farmers (Waluszewski et al., 2021; Rödiger and Home, 2023). Instead, it requires the co-existence of collaborative voluntary efforts and regulated change across businesses and industries – which requires significant involvement of governmental bodies. Our empirical findings show that it is possible to reach a successful disembedding of routine use of antibiotics – at least if others' than the farmers and the pig meat producing setting are prepared to share the economic burden of change. This contributes to the debate about the transition to more sustainable agriculture (e.g., Helliwell et al., 2020).

That context matters, and more precisely, that the 'antibiotic infrastructure' matters are recognised in existing studies of antibiotic use for food animals (e.g., Kirchhelle, 2018). The disembedding processes in the three cases point to several key aspects of how reducing antibiotic use towards sustainable agriculture can be managed. First, promoting good practices and 'prudent use' in animal-based food production is not sufficient for a significant disembedding process to occur. If low-priced food product imports are accepted by retailers, and prioritized by consumers, there is a negative impact on the ability to distribute costs of disembedding routine use. For example, the Danish case shows how disembedding routine use had to proceed without interfering with the price requirements necessitated by an export focus.

Second, although policy regulations are important, these are not enough for a significant disembedding process and combatting resistance prevalence to occur. If the economic burden of disembedding cannot be shared by others; for example, through governmental compensation, and/or by retailers and consumers engagement, the ability to succeed will be limited. Retailers and end consumers must share the economic burden of antibiotic disembedding processes. Increasing knowledge about the animal husbandry system, which results in higher prices for end products, is necessary in the face of a general demand for low priced food (as in the Swedish case). Policy measures must reach out beyond farms, to involve retailers and consumers.

Furthermore, there is a need for considering how pig-meat and other producers of animal-based food can be economically compensated for their engagement in minimising antibiotics use. As such, we underline existing research that recognizes the challenges faced by farmers and retailers to achieve systemic change without contextual support (Waluszewski et al., 2021; Rödiger and Home, 2023). As both Robinson (2017) and Puupponen et al. (2022) stress, relying on farmers alone to achieve change, or even to blame individual farmers for a lack of change, is shortsighted.

6.1. Suggestions for further research

In terms of antibiotic use, we would like to call for further research that unpicks the mutual shaping of successful, collaborative innovation processes and the distribution of costs. The routine use of antibiotics and high usage levels is still the norm in many European settings, which is a challenge in terms of meeting the requirements of the 2022 EU ban. If and how disembedding processes are to be realised, with the involvement of government agencies, retailers and end-consumers, is important to study. There is also a need for future research to unravel the processes undertaken outside of the EU setting, to increase the understanding of technological, social and economic inter-organisational interdependencies that facilitate and hinder change.

Lastly, other sustainability challenges revolve around resources that cause harm to society, such as pollution, waste, etc. There is a need for both sector based and comparative research that uncovers the processes involved in disembedding such resources, or in reformatting these resources to become products, as in various forms of the circular economy.

CRediT authorship contribution statement

Alexandra Waluszewski: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Debbie Harrison:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kristin B. Munksgaard:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Aino Halinen:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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Data availability

The data that has been used is confidential.

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