Extended Abstract
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Paper/Poster Title	Can differentiated restriction of antibiotic classes influence farm economic outcomes? Evidence from Denmark

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Abstract	***200 words max***

As animal agriculture represents the primary sector for antibiotic consumption, there is a growing call for regulating their use to mitigate the increasing threat of antimicrobial resistance. In this context, current arguments for regulating the therapeutic application of antibiotics are shifting away from blanket restrictions towards more precise, class-specific restrictions. This paper presents the first empirical estimates regarding the effects of a differentiated restriction of antibiotic classes on farm antibiotic use and economic outcomes. We exploit the variations in the intensity/stringency of the restrictions under the latest Danish differentiated-yellow card scheme, which assigns varying weights for different classes in the existing yellow card antibiotic quota, as a quasi-policy experiment and use state-of-the-art econometric methods. Our findings indicate that the targeted restriction significantly reduces overall antibiotic use, particularly a threefold reduction in tetracycline, with smaller reductions in other classes. Furthermore, the differentiated restriction has led to increased farmers' operational costs and decreased profit. Higher rate of substitution to vaccination, higher veterinary and medical expenses and higher labor hours and costs are identified as the main pathways through which the restriction influenced farmers' production behavior. Results also show heterogenous responses across different age groups, with weaners and finishers displaying significant reductions in tetracycline.

Keywords	*Antibiotics, Antimicrobial Resistance, Yellow Card Initiative, Denmark, Difference-in-Differences*
JEL Code	Agricultural Economics: Empirical Analysis (D12) Economics of Regulation (L51) Agricultural Policy (Q18)

Introduction ***100 – 250 words***

Antimicrobial resistance in farm animals is rapidly increasing, leading to concerns about antibiotic use in the livestock sector. This is due to the rapidly increasing use of antimicrobials in animal-based food production, as there is growing demand for livestock and animal protein worldwide (Michael et al., 2014; Teillant, 2015). In Denmark, two-thirds of total antibiotic consumption goes to the livestock sector, with

the pig industry accounting for 75% of this consumption (Van Boeckel et al., 2015). In response, several interventions have been implemented, particularly in pig production, though rigorous empirical studies on the impact of such interventions are scant (Belay & Jensen, 2022a). The Yellow Card initiative was established in 2010 to monitor the highest antibiotic users and impose quantitative restrictions on antibiotic use on Danish pig farms (DVFA, 2017). The 2016 revised Yellow Card introduced varying weights for different classes in the existing antibiotic quota, referred to as the "differentiated-yellow card scheme (DYC). In this study, we exploit the variations in the intensity/stringency of restrictions under the 2016 DYC as a quasi-policy experiment. The study uses datasets of veterinary drugs and economic accounts for the entire population of Danish pig farms and uses state-of-the-art econometric methods to estimate the effects of differentiated restriction of antibiotic classes for therapeutic use on farmers' antibiotic use and economic outcomes.

Methodology	***100 – 250 words***

Antibiotic use data comes a national database monitoring antibiotic application in livestock, where the herd-level veterinary antimicrobial use (AMU) prescription data has been recorded since 2000 (Kruse et al., 2019; Stege et al., 2003a). Data farm outcomes is obtained from SEGES, an independent consultancy firm, provides annual financial information for the agriculture sector, including pig farms (Aigner & Asmild, 2021).

The study aims to determine the causal impact of differentiated antibiotic class (DYC) restrictions on farm antibiotic use and economic outcomes. After we identify the counterfactuals which is a non-random assignment, we employee Difference-in-differences (DiD) to evaluate causal effects by accounting for unobservables. The estimates from a DiD method relies on an identifying assumption that the farms affected by the DYC restrictions and (always) low-user farms not affected by the restriction would have followed a similar trend in the absence of the DYC.

For our main analyses, we specify a two-way difference-in-differences model using fixed effects as follows:

$$O_{it} = \alpha_0 + \beta \text{ post }_{it} * \text{ CDyellowcard }_{it} + \phi X_{it} + \omega_i + \tau_t + \varepsilon_{it} \qquad (6)$$

where O_{it} stands for main outcome variables in the study given in logarithms such as antibiotic use, total operating cost, vaccinations, feed cost, veterinary medical cost, labor cost, hired labor hour, profit and revenue of farm i at year t. β is the parameter estimate of the policy variable (DYC), ϕ the vector of estimates for other covariates (Xs). ω_i stands for farm fixed effects, τ_t stands for year-fixed effects and ε_{it} is an idiosyncratic random error term to capture unobserved random variables affecting farm outcomes.

Results	***100 – 250 words***

The results indicate that, on average, the class-differentiated yellow card intervention has reduced overall antibiotic use on pig farms in the treatment group by around 10% compared to those in the comparison group. Examining the sub-samples reveals that the policy has led to a significant decline in tetracycline use of approximately 28%. Moreover, there has been a reduction of approximately 5% observed in classes other than tetracycline due to the regulation, when controlling for covariates.

The results reveal that the intervention has increased total farm operating costs and decreased profits, though the effect on revenue is insignificant. The class-differentiated yellow card intervention has not had a significant effect on revenue. It is also indicated that the class-differentiated yellow card intervention has exerted a significant 7% negative effect on farm profit.

The DYC intervention has led to a 6-10% increase in vaccine use on farms, potentially due to farms substituting antibiotics for vaccines. Feed costs have increased by around 7% due to the intervention, aligning with previous findings. Moreover, a significant increase in labor hours and labor costs are observed as consequences of the intervention.

The effects of DYC on antibiotic use, veterinary and medical costs, and vaccination are heterogeneous across different age groups of pig farms. The reduction in antibiotic use is significantly higher on weaner farms compared to finisher and sow farms. The policy's effect on veterinary medical costs is significant for both weaners and sows, with the effect being more pronounced on weaner farms than on sow farms.

Discussion and Conclusion	***100 – 250 words***

The study examines the effects of differentiated restrictions on antibiotic use and economic performance in Danish pig farms. The results show a substantial reduction in antibiotic use and tetracycline, with a class of antibiotics facing greater weight. However, there is also a modest decrease in other classes of antibiotics, possibly due to regulatory spillover effects.

The economic performance of farms declines due to an increase in operating costs, which are primarily due to increased purchases of inputs such as feed, labor, and veterinary and medical services. The effects of the class-differentiated yellow card scheme on antibiotic use, veterinary and medical costs, and vaccination utilization are heterogeneous across different age groups of pig farms. Weaner farms experience a higher reduction in antibiotic use than finisher and sow farms.

Antibiotic restriction regulations are critical for public health, as they help diminish the development and spread of antibiotic-resistant bacteria. However, the study focuses solely on assessing the regulation's impact on farm outcomes, excluding consideration of its potential public health benefits. The effect of the regulation is anticipated to be positive if approached from a One Health perspective, taking into consideration the broad societal benefits and costs.

Future research might explore the effects of the class-differentiated yellow card intervention using a more rigorous synthetic control analysis, perhaps using data from neighbouring countries. It could also be worth investigating efficient and sustainable farming methods that can maintain farm profitability by curbing operating costs amid reduced antibiotic use, analysing the underlying reasons for the heterogeneous treatment effects, and conducting an in-depth cost-benefit analysis that encompasses both economic outcomes and public health benefits arising from the regulation.