Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2025:14
Faculty of Natural Resources and Agricultural Sciences

Agriculture, trade, and environmental policy

Julia Wahtra

Agriculture, trade, and environmental policy

Julia Wahtra
Faculty of Natural Resources and Agricultural Sciences
Department of Economics
Uppsala

SWEDISH UNIVERSITY
OF AGRICULTURAL
SCIENCES

DOCTORAL THESIS
Uppsala 2025

Acta Universitatis Agriculturae Sueciae
2025:14

ISSN 1652-6880
ISBN (print version) 978-91-8046-449-9
ISBN (electronic version) 978-91-8046-499-4
https://doi.org/10.54612/a.390od59imo

Swedish University of Agricultural Sciences, Department of Economics, Uppsala, Sweden

Print: SLU Grafisk service, Uppsala 2025

Agriculture, trade, and environmental policy

Abstract

Agriculture plays a pivotal role in shaping global land use, with nearly half of the world's habitable land dedicated to agricultural activities. While essential for meeting humanity's food needs, agriculture also exerts considerable pressure on local and global environments. Addressing these environmental externalities presents an urgent challenge for policymakers. This thesis comprises three papers that aim to inform policy by examining the sources behind agricultural pollution trends and exploring how shifting food preferences and different emissions policy strategies impact agricultural land use, emissions, trade flows, consumption patterns, and social welfare.

Paper I uses index decomposition methods to decompose nitrogen and phosphorus leakage trends from Swedish arable land. Importantly, we find only modest leakage-decreasing technique effects, mainly driven by increased yields per hectare rather than reductions in per-hectare nutrient leakage. We argue that lax regulation of agricultural pollutants is a key factor behind these results.

Paper II studies the use of strategic trade policy by high-income countries to reduce global emissions, providing theoretical definitions and quantitative evidence on the relevance of 'Environmental Comparative Advantage' (ECA). Our results show that if a region has a global ECA in a pollution-intensive good whose production emits a transboundary pollutant, there may be a role for subsidising that good to displace even dirtier production elsewhere. We test policy alternatives quantitatively using a novel Ricardian EU–South America trade model, focusing on beef and GHGs.

Paper III uses a structural trade model calibrated to food and feed crop production in the Global South and the Global North to analyse the quantitative implications of a hypothetical decline in wealthier consumers' relative preference for meat. The results suggest that a five percent decline increases the share of global cropland allocated to food crops, and net meat consumption falls by one percent, with some shifting from the North to the South. These changes benefit all consumers but reduce landowners' rents due to lower crop prices. The limited impacts suggest that making the food system more resource-efficient will require additional targeted policy.

Keywords: agriculture, local and global pollution, land use, strategic trade policy, environmental comparative advantage, emissions regulations, meat consumption

Jordbruk, handel, och miljöpolitik

Sammanfattning

Jordbruk spelar en avgörande roll för den globala markanvändningen; nästan hälften av världens beboeliga landyta används för jordbruksverksamhet. Samtidigt som det är helt nödvändigt för att möta världens livsmedelsbehov, medför jordbruk också betydande miljöbelastningar. Att hantera dessa utgör en brådskande utmaning för beslutsfattare. Den här avhandlingen består av tre artiklar som syftar till att stödja styrmedelsutformning genom att undersöka källorna bakom föroreningstrender från jordbruket samt hur förändrade matpreferenser och strategisk miljöpolitik påverkar jordbrukets markanvändning, utsläpp, handel, konsumtion och välfärd.

Artikel I använder index-dekompositionsmetoder för att studera källorna bakom trender i kväve- och fosforläckage från svensk åkermark. Avgörande är att vi endast finner små utsläppsminskande teknikeffekter, som främst drivs av ökade skördar per hektar, snarare än minskningar i näringsläckage per hektar. Vi menar att bristande reglering av jordbrukets utsläpp är en avgörande faktor bakom dessa resultat.

Artikel II studerar höginkomstländers användning av strategisk handelspolitik för att minska de globala utsläppen, och ger teoretiska definitioner och kvantitativa bevis för relevansen av ’miljömässig komparativ fördel’ (ECA). Våra resultat visar att om en region har en global ECA i en utsläppsintensiv vara vars produktion släpper ut en gränsöverskridande förorening, kan det vara motiverat att subventionera den varan för att ersätta ännu smutsigare produktion i andra regioner. Vi testar alternativa miljöpolitiska styrmedel kvantitativt genom en ny Ricardiansk EU–Sydamerika-handelsmodell, med fokus på nötkött och växthusgasutsläpp.

Artikel III använder en strukturell handelsmodell kalibrerad till produktion av mat- och fodergrödor i det Globala Syd och det Globala Nord. Vi studerar kvantitativa effekter av en hypotetisk minskning i rikare konsumenters relativa preferens för kött. En femprocentig minskning ökar andelen global åkermark med matgrödor, och den globala köttkonsumtionen minskar med en procent, med viss omfördelning från Nord till Syd. Detta gynnar alla konsumenter, men lägre avräkningspriser minskar markägares arrenden. De begränsade effekterna tyder på att övergången till ett mer resurseffektivt livsmedelssystem kommer att kräva mer riktad politik.

Nyckelord: jordbruk, lokala och globala föroreningar, markanvändning, strategisk handelspolitik, miljömässig komparativ fördel, utsläppsregleringar, köttkonsumtion

Dedication

To my dad, Sven, who has always been one of my biggest supporters—from the sidelines of the football pitch to the sidelines of my academic pursuits.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Wahtra, J. and Johnsson, H. (2024). The Sources of Slow Declines in Agricultural Nutrient Leakage: Evidence from Sweden (revise and resubmit, AJARE).

II. Wahtra, J. and Hart, R. (2024). Environmental Comparative Advantage and Strategic Trade (manuscript).

III. Wahtra, J. (2024). If Meat Preferences Wane: Land Use and Welfare Effects (manuscript).

The contribution of Julia Wahtra to the papers included in this thesis was as follows:

I. Julia Wahtra was the main author of the paper. She was responsible for developing the paper idea, conceptualisations, data management, economic analysis, and writing. Holger Johnsson was responsible for data provision and proofreading.

II. The paper is jointly authored. Julia Wahtra was solely responsible for data collection and data management. She was also primarily responsible for the numerical programming part. The paper idea and the economic model were developed jointly, and the writing was also joint.

III. Julia Wahtra was the sole author of the paper.

Abbreviations

WTP	Willingness to pay
GHG	Greenhouse gas
GE	General equilibrium
EU	European Union
SEK	Swedish krona
SCC	Social cost of carbon
BCA	Border carbon adjustment

1. Introduction

Agriculture is connected to several critical global challenges, ranging from environmental externalities to food security. With nearly half of the world's habitable land dedicated to agricultural activities—and its close relationship with the environment—the sector plays a pivotal role in shaping global land use patterns, biodiversity provision, and the climate. The urgency of addressing the sustainability challenges related to these areas is underscored by international agreements, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). The former calling for a concerted effort to limit global temperature rise to well below two degrees Celsius (United Nations, 2015), and the latter emphasising the need for sustainable agriculture (SDG 2), climate action (SDG 13), responsible consumption and production (SDG 12), and zero hunger (SDG 2). Achieving these ambitious goals requires, among other things, rethinking traditional agricultural policies, which historically have prioritised production over environmental and social concerns. The shift towards sustainable agricultural systems must also contend with the complexities of global agricultural commodity markets, where disparities in environmental regulations and economic development across regions complicate policy interventions, and lead to trade-offs. This thesis aims to assist policymakers in reforming the agricultural policy landscape by addressing central issues related to polluting emissions, agricultural land use, food provision, and environmental policy.

Paper I addresses the relatively slow declines in polluting emissions from agriculture. By utilising index decomposition methods tailored to the crop sector, and spatial leakage data, we decompose historical nitrogen and phosphorus leakage trends from Swedish arable land. This allows for explicitly analysing the sources behind these trends. Papers II and III shift focus to the meat sector, applying structural general equilibrium modelling techniques. Specifically, the papers employ Ricardian general equilibrium models within a Global South–Global North framework. Paper II examines whether a region with a high willingness to pay (WTP) for emissions reductions, and intrinsically cleaner production of a pollution-intensive good, could use subsidies and trade policy strategically to displace even dirtier production elsewhere. Paper III focuses on the demand side, exploring the implications of a decline in wealthier consumers' relative preference for

meat on regional and global cropland use, meat consumption, food provision, and welfare.

Figure 1 presents a graphical summary of the three papers, highlighting their interrelationships and specific focuses in terms of scope, environmental emphasis, and methodological approach. The remainder of this thesis introduction consists of two additional sections. Section 2 provides summaries of the three appended papers, including further details on background, methods, results, and policy implications, while Section 3 offers concluding remarks.

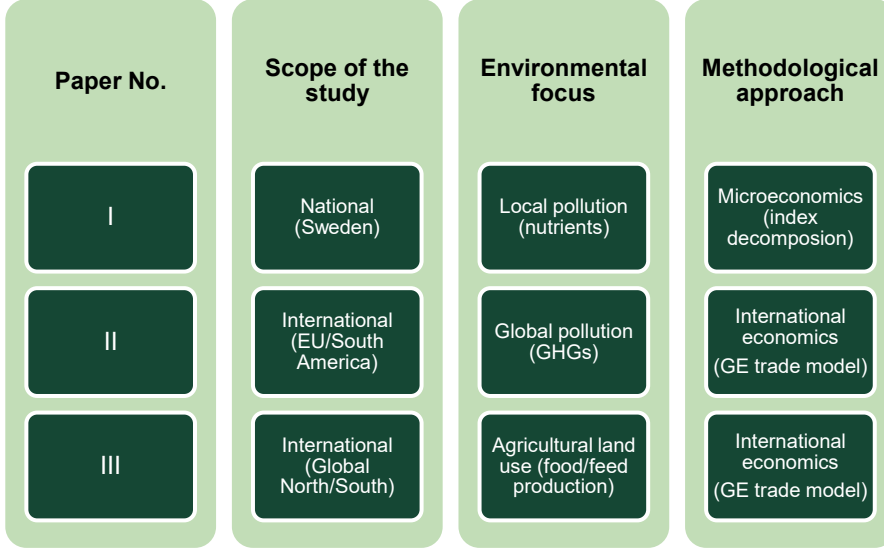

Figure 1. Graphical summary of the three thesis papers.

2. Summaries of appended papers

2.1 Paper I

The first paper of the thesis starts from the observation that, despite the increasing adoption of agri-environmental policies over time, nitrogen and phosphorus leakage from agricultural land continues to exceed critical levels in most EU regions (European Environment Agency, 2019). Equivalent observations are also made in many other parts of the world. To better understand why we generally observe much slower reductions in polluting emissions within agriculture than in other sectors of the economy, we apply state-of-the-art decomposition methods (Grossman and Krueger, 1991; Levinson, 2009, 2015) but adapted to the arable farming sector. The analysis targets agricultural nutrient leakage from Swedish arable land to aquatic environments—a severe but unresolved global environmental problem (Kanter et al., 2020a,b; Richardson et al., 2023). Specifically, we show to what extent leakage trends are explained by changes in: total hectares cultivated (extensive scale effects); yields (intensive scale effects); crop rotations (composition effects); and nutrient leakage coefficients (technique effects). By using simulated leakage data we are able to derive year, region, crop and soil-specific leakage coefficients (i.e. annual leakage of nitrogen or phosphorus per Swedish krona (SEK) of crop value produced), allowing us to calculate technique effects directly.

Although well-established within the environmental economics literature and very useful for gaining a basic understanding of the sources behind emission flows, decomposition methods are seldom used in agricultural economics. One explanation is the difficulty in identifying and measuring diffuse pollutants, which is why previous decomposition literature studying agricultural nutrient leakage typically relies on indirect nutrient leakage measurements (Wier and Hasler, 1999; Cai et al., 2018; Fujii et al., 2016). The data on nitrogen and phosphorus leakage used in this paper, referred to as leakage rates, was simulated through a soil science calculation system (Johnsson et al., 2022) and has never been used in an economic context. The calculation system consists of two model packages—one for nitrogen and one for phosphorus. It has been parameterised and tested by cross-checking with nutrient measurement data from various field trials, under different conditions, and using different production techniques.

The results, provided for Sweden as a whole and for Sweden divided into five geographical groups, show considerable heterogeneity; technique and composition effects caused leakage to increase in some areas and decrease in others. Crucially, we find no indication of industry-wide technological improvements leading to cuts in nutrient leakage coefficients. For the crops and regions where we do see reduced annual leakage per SEK of crop value produced, this is largely attributed to increased productivity per hectare rather than reduced leakage per hectare. We contend that inadequate regulation of agricultural emissions, including a lack of clear incentives, is an important reason behind this outcome. These findings align with those in the existing literature, showing that the direction of technological advancements is strongly driven by economic incentives. For example, empirical evidence indicates that directed price signals have been instrumental in shifting manufacturing away from emission-intensive production processes to cleaner technologies (Popp, 2002; Aghion et al., 2016; Shapiro and Walker, 2018). Meanwhile, scholars argue that the design and implementation of current agricultural nutrient leakage programs, such as those addressing eutrophication in the Baltic Sea, are neither sufficient nor cost-effective (Elofsson, 2012; Ollikainen et al., 2019; Brady et al., 2022).

2.2 Paper II

The second paper shifts focus from analysing the sources of agricultural emissions to exploring policy options for mitigation. In brief, we study whether a single region with a high willingness to pay (WTP) for emissions reductions could use subsidies and trade policy strategically to affect production decisions in another region, thereby lowering net global emission levels. The use of strategic trade policy by high-income countries to enhance global environmental objectives is a large area of research. Influential scholars within this field argue that country-specific distributions of comparative advantages are central to the impact of trade on the local and global environment, which in turn depends on factors such as local pollution policies (Copeland and Taylor, 2004; Baylis et al., 2021). Our contribution to this discourse includes providing general definitions and quantitative results concerning the importance of 'Environmental Comparative Advantage' (ECA). We define ECA in a pollution-intensive good as either local or global, triggered by locally or globally optimal policies.

The paper concerns the case when regions tax global emissions according to their local social cost of carbon (SCC) or WTP for emissions reductions. Then, under plausible conditions, the Global South has a local ECA in pollution-intensive goods, whereas the Global North has a global ECA. It follows that locally optimal emissions taxes may drive international trade flows in the wrong direction, resulting in suboptimal emission levels. A border carbon adjustment (BCA) could help correct this, but we show that there may also be a role for strategic policies, such as subsidising pollution-intensive production in the Global North, to displace even dirtier production in the South. We test policy alternatives quantitatively using a novel Ricardian EU–South America general equilibrium trade model, focusing on beef production and greenhouse gas (GHG) emissions. The model entails production and trade in a manufacturing (numeraire) good, crops, and beef, where beef is the most GHG-intensive good. Emissions arise directly from manufacturing and beef production, with South America having significantly higher beef emission intensities than the EU, while crop production only generates indirect emissions.

The paper primarily contributes to two strands of the trade modelling literature. The first body of literature is limited but growing, mainly using computable general equilibrium models to study how pollution flows and global food supply are affected by pricing agricultural GHG emissions (Avetisyan et al., 2011; Golub et al., 2013; Frank et al., 2017; Henderson et al., 2018; Frank et al., 2019; Jansson et al., 2023). We extend this growing source of literature by developing a theoretically grounded trade model in which we also analyse the effect of including the beef sector in BCA and export rebate schemes. The second strand of literature closely related to our work is the rich literature on carbon leakage (see for instance Fowlie et al. (2022) and Ambec et al. (2024)). A few of these studies focus on agricultural emissions leakage in the EU as a response to emissions taxes or BCAs. However, these are limited to using computable partial equilibrium-type models. Such models risk overstating the advantages of strategic trade policy, which we avoid by using a general equilibrium approach that accounts for countervailing effects of production changes in other sectors.

The calibrated model studies four counterfactual policy scenarios and a baseline 'business as usual' scenario, serving as the point of comparison. Our first policy scenario is (i) First best, where an emissions tax equal to the global SCC is applied to all polluting emissions in both regions. The other

three scenarios involve different combinations of second-best policies only implemented in the EU to mitigate global GHG emissions in the absence of (i). These scenarios are: (ii) Conventional trade policy (an emissions tax, a BCA, and export rebates); (iii) Strategic trade policy (an emissions tax, a BCA, and export rebates—strategically chosen for EU beef exports); and (iv) Strategic production subsidy (strategically chosen output-based production subsidy to all EU beef producers). Scenarios (iii) and (iv) involve allowing a benevolent regulator to strategically set export rebates or subsidy levels in the EU beef sector, with respect to a welfare maximisation condition. We thus explore whether, in the absence of first best (i.e., international carbon taxes), it would benefit society to excessively subsidise a region's dirty-good production if the region has a global ECA in that good.

Our quantitative results show that while the reach of strategically chosen export rebates is greater than that of conventional, strategic production subsidies are ineffective in reducing GHG emissions from international beef production. Hence, scenario (iii) Strategic trade policy performs the best among the second-best policy alternatives. Under this scenario, the regulator sets an export rebate to EU beef producers higher than the global SCC (USD 150 instead of USD 66), resulting in a ten percent reduction in global emissions from beef production and nearly a two percent decline in total GHG emissions. Nevertheless, only a quarter of the welfare increase attained under first best is accomplished in scenario (iii). Our findings, highlighting the importance of local and global ECA in determining the impacts of strategic trade policy, could support policymakers in designing climate policies when international cooperation on climate change mitigation is lacking.

2.3 Paper III

The third and final paper of the thesis then turns to the demand side. Unlike the two previous papers, which study agricultural emissions, the third paper focuses on global cropland use and food provision. Since the 1950s, there has been a surge in wealthier regions' meat demand, largely shaping global land use patterns; feed crops are currently cultivated on 40 percent of worldwide croplands, implying considerable competition with crop production for direct human consumption. While wealth has been the main driver of high-income countries' rising meat consumption, existing data

suggests that a decoupling between GDP growth and meat intake is taking place; meat consumed per person is stagnating—or even decreasing—in many rich countries (Bodirsky et al., 2015; Godfray et al., 2018; Parlasca and Qaim, 2022). An important explanation behind the observed slowdown in wealthier countries' demand for meat is increased awareness of the adverse effects of meat consumption. As a calorie source, meat production has a high resource-input demand, and its pressure on the climate and natural environments is much larger than what most plant-based foods bring about (Godfray et al., 2018; Poore and Nemecek, 2018). Excessive consumption of red meat could also cause negative health effects (Godfray et al., 2018).

This paper analyses the quantitative impacts for cropland usage, food prices, consumption, land rents, and social welfare from a potential reduction in wealthier regions' relative preference for meat. If meat is increasingly opted out of plates in high-income countries, this could induce significant shifts in the allocation of global cropland devoted to food versus feed crops. To study the potential implications, a general equilibrium quantitative trade model calibrated to the production and trade of crops between countries in the Global South and the Global North is employed. The model is based on a structural trade model developed by Mérel et al. (2023), which builds on works such as Costinot et al. (2016) and Gouel and Laborde (2021), while adopting a more parsimonious approach. Previous work within this field has studied the role of market-mediated adjustments in mitigating the impacts of climate change, or the effect on food production and prices from increasing richer countries' share of land devoted to organic crops, but not the market implications from changes in food preferences.

The model is calibrated on four crops (wheat, maize, rice, and soybean) and 51 countries representing the majority of total production, consumption, and trade in agricultural commodities. Crop harvests could either be used as feed for meat production or for producing final consumption plant-based food. The paper studies two counterfactual scenarios: (i) a five, and (ii) a one, percent reduction in the Global North consumers' relative preference for meat. The results suggest that a five percent reduction (scenario (i)) would cause the Northern consumers' meat consumption to decrease by two percent, leading to a cut in regional prices of feed and meat. Hence, food crop revenues rise relative to feed crop revenues, inducing an increase in the share of cropland allocated to food crops. The increase in provision of food crops in the North, in turn, leads to reduced prices for food crops and plant-based

foods. Since prices are intertwined through trade, and preferences remain unchanged in the South, the consumers in the South use the extra surplus from price cuts to boost overall food consumption. The decline in food prices causes consumer welfare to rise, but in the South, this increase does not outweigh the negative impact on landowners from falling land rents. The overall change in social welfare is still positive (albeit small). For a one percent change in the North's relative meat preferences, the directions of the results are the same but more limited.

The results agree with previous literature, showing that decreasing meat demand may have favourable effects on food security and agricultural land use (see for instance Parzianello and Carvalho (2024), Westhoek et al. (2014), and Doelman et al. (2019)). I find that a reduction in wealthier consumers' meat preferences results in a modest reduction in overall meat consumption and global cropland allocated to feed crops. Accomplishing impacts that are more significant would likely require larger changes in consumer preferences. For example, increasing efforts to communicate the adverse environmental effects of different foods to consumers could encourage more sustainable dietary choices (Poore and Nemecek, 2018). However, since dietary changes are typically a slow process, policymakers should not rely solely on behavioural changes on the demand side to reduce resource-intensive food production.

3. Concluding remarks

The present agricultural policy landscape is largely a result of historical trajectories (De Schutter, 2017; McNeill, 2019; Conti et al., 2021). In the wealthier parts of the world, the development of the modern industrialised food system began during the 1930s, resulting in an increased dependency on external inputs, such as fertilisers and pesticides, and a prioritisation of producing large volumes. The surge in population rates, along with weak productivity growth during the second half of the 20th century, further came to shape a 'productionist' agricultural policy approach (De Schutter, 2017; Conti et al., 2021). This evolution was not confined to high-income countries but it gradually extended to other areas like South Asia and South America, leading to overproduction of many food products.

The first paper of this thesis demonstrates that while agri-environmental policies have become more prevalent in agricultural policy, large-scale adoption of production techniques that drastically mitigate polluting emissions within agriculture remains limited. As a result, levels of many polluting emissions from agriculture are either stagnating—or decreasing much more slowly—than in other sectors of the economy, where targeted emissions regulations have been implemented.

In the second paper, we find that international agreements to tax global emissions from agriculture could lead to substantial emission cuts and welfare improvements. But, given that globally optimal emissions taxes are unlikely to be materialised, policymakers must turn to second-best alternatives. We show that it may be motivated for a region with a high WTP for emissions reductions, like the EU, to include the agricultural sector in existing carbon-tax schemes while simultaneously favouring exports of domestic agricultural produce through excessive export rebates. Considering the agricultural market and policy landscape, such a policy scenario also appears unlikely in the near future. Rather, the most straightforward policy measure, both from the perspective of international trade rules and policy acceptance, may be to subsidise agricultural output in regions like the EU to displace relatively more pollution-intensive production in other parts of the world. However, unsurprisingly, the results in Paper II suggest that such a policy has very limited prospects, primarily due to the countervailing effect on emissions caused by increased domestic production.

The conclusions from Papers I and II leave us with the task of influencing the demand side: could a shift towards more resource-efficient diets positively affect outcomes related to the allocation of agricultural land use, emission flows, and global food provision? Paper III finds that reducing meat preferences in the Global North could have such implications, but these remain limited. To achieve the large-scale impacts necessary to make the global food system sustainable, policymakers should target both the supply and demand sides. In other words, implementing targeted environmental policy regulations is crucial for advancing cleaner production technologies within agriculture, which are necessary for achieving society's sustainability goals.

References

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., Reenen, J.V. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political Economy*, 124, 1–51.

Ambec, S., Esposito, F., Pacelli, A. (2024). The economics of carbon leakage mitigation policies. *Journal of Environmental Economics and Management*, 125, 102973. https://doi.org/10.1016/j.jeem.2024.102973.

Avetisyan, M., Golub, A., Hertel, T., Rose, S., Henderson, B. (2011). Why a global carbon policy could have a dramatic impact on the pattern of the worldwide livestock production. *Applied Economic Perspectives and Policy*, 33, 584–605. https://doi.org/10.1093/aepp/ppr026.

Baylis, K., Heckelei, T., Hertel, T.W. (2021). Agricultural trade and environmental sustainability. *Annual Review of Resource Economics*, 13, 379–401. https://doi.org/10.1146/annurev-resource-101420-090453.

Bodirsky, B.L., Rolinski, S., Biewald, A., Weindl, I., Popp, A., Lotze-Campen, H. (2015). Global food demand scenarios for the 21st century. *PLOS ONE*, 10(11), e0139201. https://doi.org/10.1371/journal.pone.0139201.

Brady, M.V., Andersen, M.S., Andersson, A., Kilis, E., Saarela, S.R., Thorsøe, M.H. (2022). Strengthening the policy framework to resolve lax implementation of the Baltic Sea Action Plan for agriculture. *Ambio*, 51(1), 69–83. https://pubmed.ncbi.nlm.nih.gov/34145560/.

Cai, J., Xia, X., Chen, H., Wang, T., Zhang, H. (2018). Decomposition of fertilizer use intensity and its environmental risk in China's grain production process. *Sustainability (Switzerland)*, 10(2). https://doi.org/10.3390/su10020498.

Conti, C., Zanello, G., Hall, A. (2021). Why are agri-food systems resistant to new directions of change? A systematic review. *Global Food Security*, 31, 100576. https://doi.org/10.1016/j.gfs.2021.100576.

Copeland, B.R., Taylor, M.S. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, 42(1), 7–71. https://www.aeaweb.org/articles?id=10.1257/002205104773558047.

Costinot, A., Donaldson, D., Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 Million Fields around the World. *Journal of Political Economy*, 124(1), 205–248. https://doi.org/10.1086/684719.

De Schutter, O. (2017). The political economy of food systems reform. *European Review of Agricultural Economics*, 44(4), 705–731. https://doi.org/10.1093/erae/jbx009.

Doelman, J.C., Stehfest, E., Tabeau, A., van Meijl, H. (2019). Making the Paris agreement climate targets consistent with food security objectives. *Global Food Security*, 23, 93–103. https://doi.org/10.1016/j.gfs.2019.04.003.

Elofsson, K. (2012). Swedish nutrient reduction policies: An evaluation of cost-effectiveness. *Regional Environmental Change*, 12, 225–235. https://doi.org/10.1007/s10113-011-0251-8.

European Environment Agency (2019). The European environment — state and outlook 2020: knowledge for transition to a sustainable Europe. Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2800/96749.

Fowlie, M.L., Werner, K.D., Gordon, H., Preonas, L., Wang, J., Woerman, M., Wright, K. (2022). Mitigating emissions leakage in incomplete carbon markets. *Journal of the Association of Environmental and Resource Economists*, 9(2). https://doi.org/10.1086/716765.

Frank, S., et al. (2017). Reducing greenhouse gas emissions in agriculture without compromising food security? *Environmental Research Letters*, 12, 105004. https://doi.org/10.1088/1748-9326/aa8c83.

Frank, S., Havlík, P., Stehfest, E., van Meijl, H., Witzke, P., Pérez-Domínguez, I., van Dijk, M., Doelman, J.C., Fellmann, T., Koopman, J.F.L., Tabeau, A., Valin, H. (2019). Agricultural non-CO_2 emission reduction potential in the context of the 1.5°C target. *Nature Climate Change*, 9, 66–72. https://doi.org/10.1038/s41558-018-0358-8.

Fujii, H., Nakagawa, K., Kagabu, M. (2016). Decomposition approach of the nitrogen generation process: Empirical study on the Shimabara Peninsula in Japan. *Environmental Science and Pollution Research*, 23, 23249–23261. https://doi.org/10.1007/s11356-016-7522-3.

Godfray, H.C.J., Aveyard, P., Garnett, T., Hall, J.W., Key, T.J., Lorimer, J., Pierrehumbert, R.T., Scarborough, P., Springmann, M., Jebb, S.A. (2018). Meat consumption, health, and the environment. *Science*, 361(6399), eaam5324. 361. https://doi.org/10.1126/science.aam5324.

Golub, A.A., Henderson, B.B., Hertel, T.W., Gerber, P.J., Rose, S.K., Sohngen, B. (2013). Global climate policy impacts on livestock, land use, livelihoods, and food security. *Proceedings of the National Academy of Sciences*, 110(52), 20894–20899. https://doi.org/10.1073/pnas.1108772109.

Gouel, C., Laborde, D. (2021). The crucial role of domestic and international market-mediated adaptation to climate change. *Journal of Environmental Economics and Management*, 106, 102408. https://doi.org/10.1016/j.jeem.2020.102408.

Grossman, G.M., Krueger, A.B. (1991). Environmental impacts of a North American Free Trade Agreement. *NBER Working Paper* (No. 3914). http://www.nber.org/papers/w3914.

Henderson, B., Golub, A., Pambudi, D., Hertel, T., Godde, C., Herrero, M., Cacho, O., Gerber, P. (2018). The power and pain of market-based carbon policies: A global application to greenhouse gases from ruminant livestock production. *Mitigation and Adaptation Strategies for Global Change*, 23, 349–369. https://doi.org/10.1007/s11027-017-9737-0.

Jansson, T., Malmström, N., Johansson, H., Choi, H. (2023). Carbon taxes and agriculture: the benefit of a multilateral agreement. *Climate Policy*, 24(1), 1–13. https://doi.org/10.1080/14693062.2023.2171355.

Johnsson, H., Mårtensson, K., Lindsjö, A., Persson, K., Blombäck, K. (2022). NLeCCS – a system for calculating nutrient leakage from arable land. Ekohydrologi 177, SLU, Uppsala 2022. https://pub.epsilon.slu.se/28767/1/johnsson-h-et-al-20220905.pdf.

Kanter, D.R., Bartolini, F., Kugelberg, S., Leip, A., Oenema, O., Uwizeye, A., (2020a). Nitrogen pollution policy beyond the farm. *Nature Food*, 1, 27–32. https://doi.org/10.1038/s43016-019-0001-5.

Kanter, D.R., Chodos, O., Nordland, O., Rutigliano, M., Winiwarter, W. (2020b). Gaps and opportunities in nitrogen pollution policies around the world. *Nature Sustainability*, 3, 956–963. https://doi.org/10.1038/s41893-020-0577-7.

Levinson, A. (2009). Technology, international trade, and pollution from US manufacturing. *American Economic Review*, 99(5), 2177–2192. https://www.jstor.org/stable/25592554.

Levinson, A. (2015). A direct estimate of the technique effect: changes in the pollution intensity of US manufacturing, 1990–2008. *Journal of the Association of Environmental and Resource Economists*, 2(1), 43–56. https://doi.org/10.1086/680039.

McNeill, D. (2019). The contested discourse of sustainable agriculture. *Global Policy*, 10(S1), 16–27. https://doi.org/10.1111/1758-5899.12603.

Mérel, P., Qin, Z., Sexton, R.J. (2023). Policy-induced expansion of organic farmland: Implications for food prices and welfare. *European Review of Agricultural Economics*, 50(4), 1583–1631. https://doi.org/10.1093/erae/jbad024.

Ollikainen, M., Hasler, B., Elofsson, K., Iho, A., Andersen, H.E., Czajkowski, M., Peterson, K. (2019). Toward the Baltic Sea Socioeconomic Action Plan. *Ambio*, 48, 1377–1388. https://doi.org/10.1007/s13280-019-01264-0.

Parlasca, M.C., Qaim, M. (2022). Meat consumption and sustainability. *Annual Review of Resource Economics*, 14, 17–41. https://doi.org/10.1146/annurev-resource-111820-032340.

Parzianello, L., Carvalho, T.S. (2024). What if Brazilians reduce their beef consumption? *Ecological Economics*, 219, 108132. https://doi.org/10.1016/j.ecolecon.2024.108132.

Poore, J., Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392), 987–992. https://doi.org/10.1126/science.aaq0216.

Popp, D. (2002). Induced innovation and energy prices. *The American Economic Review*, 92(1), 160–180. https://www.aeaweb.org/articles?id=10.1257/000282802760015658.

Richardson, K., et al. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37). https://doi.org/10.1126/sciadv.adh2458.

Shapiro, J.S., Walker, R. (2018). Why is pollution from US manufacturing declining? The roles of environmental regulation, productivity, and trade. *American Economic Review*, 108(12), 3814–3854. https://doi.org/10.1126/sciadv.adh2458.

United Nations (2015). Paris Agreement. United Nations Framework Convention on Climate Change. Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Westhoek, H., Lesschen, J.P., Rood, T., Wagner, S., Marco, A.D., Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M.A., Oenema, O. (2014). Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change*, 26, 196–205. https://doi.org/10.1016/j.gloenvcha.2014.02.004.

Wier, M., Hasler, B. (1999). Accounting for nitrogen in Denmark—a structural decomposition analysis. *Ecological Economics*, 30(2), 317–331. https://doi.org/10.1016/S0921-8009(99)00004-X.

Popular science summary

Agriculture is vital for feeding the world, but it also puts significant pressure on the environment. It is one of the biggest drivers of land use change, biodiversity loss, and climate change. Balancing the need to produce enough food while minimising environmental harm is a pressing challenge for society. This thesis aims to support the transition towards a more sustainable agricultural system by addressing policy-relevant issues related to agricultural pollution, trade, land use, and food preferences.

The first study analyses historical nutrient leakage from Swedish cropland and explores the sources behind the relatively slow pollution reductions. The results suggest that farmers' adoption of leakage-reducing production techniques, such as precision farming methods, has been relatively modest. Weak regulation of agricultural pollutants likely plays a key role in why reductions in per-hectare nutrient leakage have not been more significant.

The second paper examines different policy options available to a single environmentally conscious country seeking to cut global GHG emissions in the absence of international climate policy agreements. It finds that the country could strategically subsidise its exports to crowd out more polluting production abroad, thereby reducing total emissions. This is illustrated through a case study of trade in beef, crops, and manufactured goods between the EU and South America, where beef is the most GHG-intensive good.

The third and final paper looks at the effects of reduced meat consumption preferences in wealthier countries. The results show that if wealthier consumers demand less meat on their plates, the share of global cropland used for food crops increases, total meat demand shrinks, and overall calorie provision rises. However, the effects are rather modest, leading to the conclusion that policymakers should not only rely on consumers switching to less resource-intensive foods but should also incentivise changes on the production side.

Together, the three papers highlight the complexity of transitioning to a sustainable agricultural system, with trade-offs between firms, consumers, and regions arising along the way. The main message is that policymakers need to combine efforts to change consumer behaviour with policies targeting agricultural production and trade to address the environmental challenges facing the agricultural sector and, by extension, our society.

Acknowledgements

First, I would like to thank my excellent supervisors—Rob, Pedro, Shon, and Efi—for their invaluable advice and unwavering support, both academically and personally, throughout my doctoral studies. To Rob, I am grateful for having learnt (to some extent) how to be a good economist, and for being challenged by your encouragement to explore my own research ideas. I am also grateful to Tore and Gerda, whose inspiration and support motivated me to pursue a PhD.

I also want to express appreciation to all colleagues at SLU, especially my fellow PhD colleagues including those at Uppsala University. Without Kristina (and, of course, the Pomodoro technique), I would probably not have managed my first year of remote coursework. Altogether, I am truly happy to have been surrounded by such friendly and clever people during my time as a PhD student.

I would also like to extend special thanks to the members of the research group for Environmental Economics over the years: Johanna, Alberto, Max, Louie, Polina, Bahre, Jonathan, Martin, Aemiro, Levi, Roweno, Vivian, and Tabaré. I will always remember the inspiring group awaydays at 'Helt OK Linné'. I also want to send warm thanks to my wonderful office mate, Anne. May we always either agree or disagree, and never find ourselves agreeing on anything in between.

Beyond the office, there are the people without whom I could not imagine life (or finishing a PhD) without: my dear friends and family. Muchísimos abrazos grandes to all my loving friends, near and far, for distracting me from work and offering your unconditional support. Then, to my big, caring, and funny family, I just want to say that you all mean the world to me. My mom, Marie, my dad, Sven, my extra parents, Widar and UC, my sisters and my brother, Lisa, Elin, Lotta, and Jim, along with your partners and kids (more or less furry)—Alice, Ylva, Natalia, Wille, Ines, Sami, Pippa, and Sixten.

Finally, but by no means least, I want to thank Gabriel. I will be forever grateful for your sincere interest in what an Environmental Economist do, and for choosing to ask me.

Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2025:14

This thesis aims to inform policymakers on issues related to agriculture and the environment. Paper I uses index decomposition methods to analyse the sources behind agricultural nutrient pollution trends. Papers II and III apply general equilibrium trade models to examine how different emissions policy strategies and shifting food preferences impact agricultural land use, global emissions, consumption patterns, trade, and social welfare.

Julia Wahtra earned her PhD in Economics from the Department of Economics at the Swedish University of Agricultural Sciences in Uppsala. She holds an MSc in Economics and an MSc in Agriculture from the Swedish University of Agricultural Sciences.

Acta Universitatis Agriculturae Sueciae presents doctoral theses from the Swedish University of Agricultural Sciences (SLU).

SLU generates knowledge for the sustainable use of biological natural resources. Research, education, extension, as well as environmental monitoring and assessment are used to achieve this goal.

ISSN 1652-6880
ISBN (print version) 978-91-8046-449-9
ISBN (electronic version) 978-91-8046-499-4