Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

WORKING PAPER 2024:03

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Shon Ferguson[a], Anna Wallenbeck[b], Sigrid Agenäs[c], and Helena Hansson[d]

ECONOMICS

[a] Department of Economics, Swedish University of Agricultural Sciences (SLU), Box 7013, 750 07 Uppsala, Sweden. Corresponding author. Email: shon.ferguson@slu.se
[b] Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences (SLU), Box 7024, 750 07 Uppsala, Sweden.
[c] Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences (SLU), Box 7024, 750 07 Uppsala, Sweden.
[d] Department of Economics, Swedish University of Agricultural Sciences (SLU), Box 7013, 750 07 Uppsala, Sweden.

Sveriges lantbruksuniversitet, Institutionen för ekonomi
Swedish University of Agricultural Sciences,
Department of Economics, Uppsala
ISSN 1401-4068
ISRN SLU-EKON-WPS-2403-SE

Working Paper Series 2024:03

Corresponding author:
shon.ferguson@slu.se

The Impact of Animal Welfare Regulations on Pork Trade: Evidence from European Countries*

Shon Ferguson[a], Anna Wallenbeck[b], Sigrid Agenäs[c], and Helena Hansson[d]

November 2024

Abstract

We analyse the impact of stricter national animal welfare (AW) regulations on imports and exports of pork between 13 European countries during the period 1991–2020, a period in which EU directives and national actions related to AW regulations significantly affected pig farming practices. We exploit the fact that some countries have stronger AW regulations for pigs compared with EU's regulations and other countries' regulations. Our analyses utilize a new detailed dataset capturing the dynamics of pig AW regulations over time for several EU member states, taking into account multiple aspects of pig AW that can have significant cost impacts for pork producers. We focus on countries with relatively stringent AW legislation for pigs or those that are major pork producers. Using both a panel regression and event study analysis, we find that an increase in the relative stringency of pig AW regulations in a country is associated with a reduction in pork exports. We find mixed evidence suggesting that stricter AW regulations for pigs reduced pork imports. Our results have important implications for other jurisdictions that plan to mandate AW regulations for pigs in the near future.

JEL Classification Codes: Q18, Q17, F14

Keywords: International trade, competitiveness, comparative advantage, animal welfare

* Financial support from Formas (Grant 2019-02067) is gratefully acknowledged. We thank seminar participants at the 2023 EAAE congress and the Brown University Economics of Animal Welfare Conference for comments and suggestions.

[a] Department of Economics, Swedish University of Agricultural Sciences (SLU), Box 7013, 750 07 Uppsala, Sweden. Corresponding author. Email: shon.ferguson@slu.se

[b] Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences (SLU), Box 7024, 750 07 Uppsala, Sweden. Email: anna.wallenbeck@slu.se

[c] Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences (SLU), Box 7024, 750 07 Uppsala, Sweden. Email: sigrid.agenas@slu.se

[d] Department of Economics, Swedish University of Agricultural Sciences (SLU), Box 7013, 750 07 Uppsala, Sweden. Email: helena.hansson@slu.se

1. Introduction

Modern industrialised agriculture with intensive animal production has led to ethical concerns regarding how livestock are managed and kept. In response to this, livestock producers in many countries are facing demands from both consumers of animal sourced products and from citizens in general for better welfare standards for farm animals (Eurobarometer, 2016; 2023). Consumers express increasing concern about how production animals are housed and managed (Thorslund, Aaslyng and Lassen, 2017; Ingenbleek and Immink, 2011). Consequently, governments have enacted legislation aimed at enhancing the conditions for these animals. Pork production in EU countries, which is the focus of this paper, has been particularly scrutinized, leading to the introduction of EU directives and national regulations to improve animal welfare (AW) standards for pigs.

However, while raising AW standards, there are also concerns about stricter regulations leading to increasing production costs (Harvey and Hubbard, 2013 Lee et al, 2023). Such production costs can lead to an erosion of countries' competitiveness in pork production, leading to a potential reduction in exports and/or increase in dependence on imports. More importantly, a decline in pork production in one country due to stricter AW regulations may simply encourage production to shift to other countries with more relaxed rules. Divergences in AW regulations could thus lead to "low AW havens" (Grethe, 2007) that reduce the overall effectiveness of the policy in improving AW. The extent to which more stringent AW rules for pigs erodes countries' comparative advantage in pork production is thus an important empirical question. National stakeholders in countries such as Sweden have long voiced a concern that stricter AW regulation negatively affects competitiveness (SOU 2015:15), and the question is again subject to discussion in an ongoing governmental investigation (Swedish Government, 2023) yet the question has never been analysed using rigorous empirical methods.

In this study, we evaluate the impact of stricter national AW regulations on the European pork sector, using international trade flows as an indicator of competitiveness. Using both a panel regression and event study analysis, we focus on bilateral trade flows of pork between 13 European countries between 1991 and 2020, a period in which EU directives and national actions significantly affected pig farming practices. These 13 countries include those with relatively stringent animal welfare (AW) legislation for pigs or significant pork production. We exploit the fact that some countries have stronger AW-regulations for pigs compared to others, with some countries only meeting EU minimum standards and others having national regulations that extend beyond EU minimum standards. Our analysis utilizes a new dataset capturing the dynamics of pig AW-regulation stringency for the 13 countries in our study for the entire 1991–2020 period, which takes into account multiple aspects of pig AW that can have significant cost implications for pork producers. Our analysis also includes bilateral trade flows of chicken and beef, which serve as useful "comparison group" products, as production costs for broilers and beef cattle have arguably been much less affected by EU and national AW regulations during the same 1991–2020 period.

This study contributes to a new and growing literature assessing the economic impacts of stricter AW-regulations on the production and trade of animal-based food products. Ex-ante analysis suggest that pork production costs and competitiveness are particularly sensitive to AW regulations (Harvey et al., 2013; Grethe et al., 2017). Our work is the first ex-post analysis of the impact of pig AW regulations on trade. More generally, there are very few ex-post studies of the impact of AW regulations on trade, and the few studies that exist concern battery cage bans for laying hens. Mullally and Lusk (2018) found that imports from other states in the US compensated for this decrease in production due to the California battery cage ban. Carter et al. (2021) examined the inter-state trade effects in more detail and found that imports to California became more concentrated in a small number of firms. Ferguson (2023) did not detect any significant impact of cage bans in EU countries on egg imports. Battery cage bans have been relatively straightforward for economists to analyse, as laying hen AW is dominated by the single key issue of battery cages. In contrast, AW regulations governing pork production are more complex, as there are multiple key issues involved.

EU countries during the period 1991–2020 serve as an ideal setting to study the impact of AW regulations on countries' comparative advantage in pork production for several reasons. First, there is a great deal of variation in AW regulations for pigs in the EU during this period, both across countries and over time. Second, meat trade between countries within the EU single market is commonplace and economically important. Third, trade within the EU single market is not subject to tariffs or other trade restrictions that may otherwise confound an analysis of AW stringency on trade flows. Finally, the long time span of the analysis allows us to observe the long-term effects of AW regulations. Analysis of the EU thus can provide important lessons for other jurisdictions that plan to mandate new AW regulations for pigs.

The rest of the analysis proceeds as follows. In Section 2 we provide a brief history of AW legislation for the EU and the 13 countries included in the analysis, describing the main changes over time at the EU-level and summarizing the substantial differences between countries. We then explain in Section 3 how changes in AW stringency relate to theories of international trade, allowing us to make theoretical predictions regarding the expected impact of AW stringency on exports and imports. A description of our empirical methodology follows in Section 4, including a description of our AW measures, and the panel and event study regression approaches. In Section 5 the data used in the analysis is described in detail, and the results are presented in Section 6. We then discuss the policy implications of our results in Section 7, followed by conclusions in Section 8.

2. A brief history of EU and national AW legislation

We now describe the changes in pig AW legislation at the EU-level and national-level used in the analysis. Since the analysis compares trade in pork with chicken meat and beef, we also describe the AW legislation for cattle and broilers.

2.1 AW legislation for pigs

Regulations on several aspects of pork production have been introduced in EU countries since 1991, as a result of both EU directives and national initiatives. We focus here on the following six AW key issues where more stringent rules can affect pork production costs:

1. Sow housing during gestation
2. Sow housing during lactation
3. Housing of growing/finishing pigs
4. Weaning age
5. Tail docking
6. Manipulable enrichment material

Regulations pertaining to these six AW key issues were not only important from an AW perspective (e.g. Veissier et al., 2008; Lundmark Hedman, 2020), but are likely to have affected production costs by e.g. reducing stocking densities, and by affecting construction costs in order to comply with the regulations. Provisions for larger unobstructed floor areas could be met by reducing stocking densities, but restrictions for slatted floors, group sow housing and loose farrowing systems sometimes required barns to be reconstructed or replaced. Providing manipulable enrichment material, such as straw, is in itself associated with a production cost, but also require suitable systems for handling manure and potentially increased costs for labour. Higher weaning ages increases the demand on farrowing housing and management. Moreover, the production flow (number of piglets delivered per sow per time unit) is decreased when the production time is increased, which may increase production costs per pig. Reducing tail biting (the reason for tail docking) could be handled in various ways, including the provision of manipulable enrichment material, reducing stocking densities, or other more labour intensive management. At the same time, compliance with new regulations related to these six AW key issues may be associated with reduced costs associated with improved animal health, due to decrease in veterinary treatments, drugs and labour costs associated with caring for sick animals and with increased incomes related to improved production performance (e.g. growth and reproduction performance).

EU legislation specific to pig animal welfare have existed for over 30 years. Council Directive 91/630/EC was the first directive to specify minimum standards for the protection of pigs. This directive, passed in 1991, required all farms to provide minimum unobstructed floor area for weaner and rearing pigs by 1998, and it also prohibited the construction of tethered sow stalls after 1995. Restrictions to tail-docking and a minimum weaning age of 28 days was required by 1994. Council Directive 2001/93/EC states that "piglets may be weaned up to seven days earlier (21 days) if they are moved into specialised housings which are emptied and thoroughly cleaned and disinfected before the introduction of a new group and which are separated from housings where sows are kept, in order to minimise the transmission of diseases to the piglets."

The 1991 EU directive was vague regarding specific requirements for sow housing and manipulable enrichment materials, and contained no restrictions on slatted floors. These issues were dealt with in 2001 via Council Directive 2001/93/EC, with further details given in 2008 via Council Directive 2008/120/EC. The more strict minimum requirements stipulated in the 2001 directive regarding sow housing, manipulable enrichment material, and slatted floors (often entailing construction costs for producers) came into force in 2013. See Wallenbeck et al. (2024) for more detail surrounding changes in EU AW legislation between 1991 and 2020.

Several EU member states have had national AW regulations that go beyond the EU minimum level, and in many cases national regulations were put in place many years before the EU rules came into force. Austria, the Netherlands, Sweden, and the UK (still a member state during the studied time period) require group sow housing during a longer part of the gestation period, compared with the 2013 EU minimum. Whereas the EU still allows farrowing crates, Sweden, for example, has required loose housed farrowing since 1988. The

Netherlands and Sweden have substantially more far-reaching space and flooring requirements for weaner and rearing pigs than the EU minimum level. According to compliance audits (European Commission, various years), Sweden and Finland are the only countries to have fully complied with EU rules banning tail docking. Many countries were ahead of the EU in requiring manipulable enrichment material. See Wallenbeck et al. (2024) for more detail on differences between EU and national pig AW legislation.

2.2 AW legislation for beef cattle and broilers

In stark contrast to pork production, there are arguably no new EU or national laws that have substantially affected the competitiveness of beef cattle production in the EU since 1991. Austria, Finland, and Sweden have minimum requirements for cattle to graze in pasture during part of the year. However, the grazing requirements have more of an impact on dairy cattle and very little impact on beef cattle, which typically graze on pasture much of the growing season in any case.

Similarly, the competitiveness of broiler production in EU has arguably not been substantially affected by the Broilers Directive (2007/43/EC) of 2007. The main potential impact of this directive was to specify maximum stocking densities for broiler production. A final report by the Directorate-General for Health and Food Safety (2017) found that average stocking densities were not substantially affected in EU countries as a result of the Directive. Higher stocking densities were still permitted as long as producers met certain requirements, which meant that stocking densities were roughly similar before versus after the Broilers Directive came into force.

3. The economics of AW stringency and international trade

A national regulator charged with the task of maximizing welfare would consider the market and non-market benefits accrued to citizens and consumers due to altruism (McInerney, 2004; Lusk and Norwood, 2011), as well as the additional fixed and variable production costs associated with more stringent AW. Variable and fixed production costs are critical determinants of trade patterns in gravity models, common in the agri-food trade literature (Hertel, 2002; Gaigné and Gouel, 2022).

If AW regulations increase the marginal cost of production, all else being equal, then gravity models of international trade predict that more stringent AW rules for pigs will reduce the value of the country's pork exports and increase the value of pork imports. Gravity models also predict that greater fixed production reduce entry and hence the size of the domestic industry by raising the average cost of production (Melitz, 2003), which indirectly affects imports and exports. These models also allow for the possibility that good AW may also increase the demand for pork, which can in theory increase exports and reduce imports.

Although we expect AW regulations to affect, and possibly be affected by, international trade in meat to some extent, a preference to consume domestically-produced goods (so-called "home bias") may reduce the sensitivity of trade to AW regulations. In particular, home bias may reduce the sensitivity of imports to AW regulations in the destination country. Home bias has been shown empirically to reduce international trade for merchandise trade in general (Anderson and van Wincoop, 2003). It is thus reasonable to expect that exports will be more sensitive to AW regulations than imports.

4. Empirical methodology

4.1 Measures of pig AW stringency

As discussed earlier, rules regarding pig AW differ in many dimensions between countries and over time. It is thus difficult to find a single metric that adequately quantifies the stringency of AW regulations, even within a single key issue. We use a categorical variable for each of the six pig AW key issues in order to capture when a country's AW regulations are substantially more stringent than the EU minimum. The categorical variable is equal to 1 each year a country's AW regulations entail additions with potential impact on production costs compared to the EU minimum in that year, and zero otherwise. This measure of each country's AW stringency thus captures deviations in the level of AW relative to the EU minimum in each year of the data.

In the case of sow housing during gestation, we define an addition as requiring group housing at all times except for the last week of pregnancy. Four countries met this condition: Sweden (since 1988), the UK (since 1999), the Netherlands (since 2013) and Austria (since 2018). Such strict requirements for group housing during gestation go beyond the EU minimum standard that entered into force in 2013, requiring sows to be kept in group housing from four weeks after service until one week before expected farrowing (Council Directive 2008/120/EC).

In the case of sow housing during lactation, we define the banning of farrowing stalls as an addition. Sweden has required loose farrowing systems at all times since before 1991, and Austria began allowing farrowing stalls only for the first 10 days after farrowing since 2018. Farrowing stalls have not yet been banned at the EU level.

In the case of housing for growing/finishing pigs, an addition is defined as providing substantially more space compared to the EU minimum, which entered into force in 2013. For a finishing pig of 110 kg live weight, Sweden's space requirement since before 1991 is 1.02 m2, and the Netherlands requirement since 2013 is 1.00 m2. In contrast, the space requirement for the same size pig in the EU since 2013 is 0.65 m2.

In the case of weaning age, we define an addition as a shorter weaning age than the EU minimum of 21 days if certain conditions are met, a rule that entered into force in 2001. Sweden was the only country to exceed this condition, requiring a minimum of 28 days with no exceptions during the period from before 1991 to 2017.

In the case of tail docking, EU restrictions have been in place since 1994 and routine taildocking has been prohibited since 2003. However, only Sweden (pre-1991) and Finland (since 2004) have fully complied with this rule, which we define as an addition for this key issue.

Finally, in the case of manipulable material, we define the provision of sow nesting material as an addition, which was undertaken by Sweden (pre-1991), Austria (since 2005) and Finland (since 2012). EU minimum requirement for manipulable material, which was roughly equivalent to the earlier requirements in Sweden, Austria and Finland, entered into force in 2013.

Using a categorical variable to capture divergences in AW regulations across jurisdictions has been commonly used in empirical studies of the economic impacts of AW regulations. The empirical literature evaluating the impact of battery cage bans, for example, has used categorical variables to identify the timing of bans (Mullally and Lusk, 2018; Carter et al., 2021; Ferguson, 2023). In the context of pig AW regulations, several of the AW key issues can be easily summarized as a discrete variable, such as whether farrowing crates are allowed or not, whether group sow housing is required or not, and whether the tail docking ban is effectively enforced. In other cases, such as minimum space and flooring types for growing/finishing pigs, there are so many different combinations of regulations that creating a single continuous measure is all but impossible.

4.2 Panel regression methodology

We begin the analysis using a panel regression approach, employing a Poisson pseudo-likelihood regression model with multiple levels of fixed effects (Correia et al., 2019; 2020). Compared to Ordinary Least Squares, which uses the logarithm of trade values as the dependent variable, Poisson regression models have the advantage of allowing for zeros in the bilateral trade flow data. Poisson regression models have gained popularity in the international trade literature, starting with work by Silva and Tenreyro (2006). We analyse bilateral trade flows at the product-origin-destination-year level. In some specifications we focus on pork only, and in others we include control products (chicken or beef).

When analysing bilateral trade flows of pork only, we estimate the following equation:

$$trade_{odt,pork} = exp\begin{pmatrix}\alpha^o AW_{ot} + \alpha^d AW_{dt} + \beta^o Y_{ot} + \beta^d X_{dt} + \gamma \mathrm{T}_{odt} \\ +\delta_{od} + \delta_t + \varepsilon_{odt}\end{pmatrix}, \tag{1}$$

Where $trade_{odt,pork}$ is the value of bilateral trade in pork from origin country *o* to destination country d in year *t*. AW_{ot} and AW_{dt} are animal welfare relative stringency measures for pigs in the origin and destination countries respectively, compared to the EU minima. Y_{ot} and X_{dt} are covariates affecting pork export supply and import demand in the origin and destination countries respectively. T_{odt} is a vector of country-pair-year covariates, such as trade costs. δ_{od} and δ_t are country-pair and year fixed effects respectively.

The main coefficients of interest are α^o and α^d, which capture the impact of substantially more stringent national regulations on pork exports and imports respectively. Trade theory predicts a negative impact of cost-increasing pig AW regulations on exports of pork ($\alpha^o < 0$), and a positive impact on imports of pork ($\alpha^d > 0$) if competitiveness is strictly driven by considerations of production costs. However, consumers' willingness to pay for higher AW standards or a prevalence of home bias may reduce the overall effects of higher costs.

When analysing bilateral trade flows of pork versus a comparison meat product (chicken or beef), we estimate the following equation, which includes the product dimension *k*:

$$trade_{odkt} = exp\begin{pmatrix}\alpha^o AW_{okt} + \alpha^d AW_{dkt} + \beta^o Y_{okt} + \beta^d X_{dkt} + \gamma \mathrm{T}_{odkt} \\ +\delta_{odk} + \delta_{odt} + \delta_{kt} + \varepsilon_{odkt}\end{pmatrix}. \tag{2}$$

Compared to equation (1), the specification in equation (2) includes species-specific animal welfare stringency (AW_{okt}, AW_{dkt}) as well as product-specific covariates (Y_{okt}, X_{dkt}, T_{odkt}).

The multi-product specification in equation (2) allows for higher-dimensional fixed effects, with δ_{odk} denoting panel fixed effects and δ_{odt} and δ_{kt} denoting origin-destination-year and product-year fixed effects respectively. The panel fixed effects control for all time-constant determinants of trade. The origin-destination-year fixed effects control for changes in trade over time for each country-pair that are not specific to a single type of meat. These fixed effects include country-year price indices that are typically included in gravity models of trade, as well as GDP and GDP per capita. Any changes in trade policies for non-EU members that affect all types of meat will also be captured by the origin-destination-year fixed effects. Finally, the product-year fixed effects capture any changes in intra-EU trade over time that are specific to a particular type of meat, but not specific to any particular EU country.

An important caveat when analysing the impact of country-specific policies is that we cannot use fixed effects to control for product-destination-year and product-origin-year determinants of trade, known as "multilateral resistance terms" (Anderson and van Wincoop, 2003; Head and Mayer, 2014; Yotov et al., 2016). Our estimations thus do not yield a theoretically-consistent estimation of the gravity model. Instead, our empirical approach follows other studies that analyse country- or region-specific policies or shocks using trade data (Luo and Tian, 2018; Andersson, 2019; Fiankor et al., 2020, Raimondi et al., 2020, Dall'Erba et al., 2021; Ferguson, 2023).

4.4 Event study regression methodology

We estimate a Difference-in-Differences (DiD) model with multiple periods, as introduced by de Chaisemartin and D'Haultfœuille (2024). This method allows for panel units to move in and out of treatment status and also allows for time-varying, heterogeneous treatment effects. In the event study, all 2x2 DiD estimates are first obtained by this approach including pre- and post-treatment effects, which takes the following form when estimating the impact of AW stringency in the origin country:

$$trade_{odt,pork} = \gamma_{od} + \gamma_t + \gamma_F^{-F} AW_{it}^{<-F} + \sum_{s=-F}^{-2} \gamma_s^{lead} \cdot AW_{ot}^{s} + \sum_{s=0}^{L} \gamma_s^{lag} \cdot AW_{ot}^{s} + \gamma_s^{-L} AW_{ot}^{>L} + \epsilon_{odt}, \quad (3)$$

where the notation closely follows the panel specification in equation (1). AW_{okt}^{s} is the AW stringency measure in origin country o being s periods away from initial treatment at time t. The approach provides an estimate of the average treatment effect on the treated (ATT), which reflects the decrease in trade (in constant 2015 USD millions) associated with a one-unit change in the AW stringency indicator in a given period.

We perform separate event studies of AW stringency in the origin country and destination country. The event study regression when including control products (chicken or beef) takes the following form:

$$trade_{odkt} = \gamma_{odk} + \gamma_t + \gamma_F^{-F} AW_{it}^{<-F} + \sum_{s=-F}^{-2} \gamma_s^{lead} \cdot AW_{okt}^{s} + \sum_{s=0}^{L} \gamma_s^{lag} \cdot AW_{okt}^{s} + \gamma_s^{-L} AW_{okt}^{>L} + \epsilon_{odkt}, \tag{4}$$

The event study approach permits the graphical inspection of parallel trends pre-treatment, which is an important assumption for DiD designs. The analysis uses the year before the regulation entered into force (t-1) as the base year. However, it is possible that trade could respond in advance of the regulations, so it is plausible that anticipation effects may be present. The main drawback to the event study approach in this context is that it is not possible to include time-varying covariates, including the fixed effects.

4.3 Threats to identification

It is important to consider potential concerns regarding endogeneity when regressing bilateral trade flows on AW stringency. Endogeneity may arise if changes in international trade over time lead countries to a change in national AW regulations. For example, increased international trade could lead to a convergence in AW regulations, as consumers in export markets demand that imported pork meets higher AW standards. Although the domestic market dominates exports in most cases, reverse causation via the convergence channel is impossible to completely rule out. Another possible source of reverse causation is the case where lower export competitiveness for reasons unrelated to AW lead to a national pork industry that caters primarily to domestic consumer concerns, which could encourage more strict domestic AW regulations.

Another potential concern is that changes over time in AW and intra-EU trade may be spuriously correlated if they are both driven by another underlying factor, such as the overall level of prosperity in a country. However, explanatory factors such as GDP and GDP per capita are controlled for by country-year fixed effects.

Finally, a third potential concern is that of omitted variable bias. The fixed effects in equations (1) and (2) eliminate the problem of omitted variables in all dimensions except the country-product-year level and country-pair-product-year level. At the product-country-year level, we control for the impact of within-EU export bans due to bovine spongiform encephalopathy (BSE) and foot-and-mouth disease (FMD), African swine flu and Classical swine fever outbreaks using indicator variables. Nonetheless, omitted variable bias may still occur if there are additional country-product-year covariates that can explain trade flows over time and are also correlated with changes in pig AW over time. This could include anything that differentially affects a country's exports or imports of pork versus beef and chicken. One example is differences in trade policy for pork versus beef or chicken for countries in the analysis prior to their EU ascension. Although the vast majority of trade observations are between EU member states (thus having no tariffs or trade restrictions), we include an indicator variable controlling equal to one if the country-pair are both EU members in a given year, and zero otherwise. This approach will control for any omitted country-pair-product-year-specific variables that are driven by EU trade policy with non-EU countries.

5. Data and descriptive statistics

5.1 Bilateral trade data

The bilateral trade data is taken from the FAOstat detailed trade matrix. We restrict the analysis to trade flows of pork, beef and chicken meat between the 13 countries for which we have detailed AW regulation data 1991–2020 (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Spain, Sweden, and the United Kingdom). These countries were selected for the analysis because they represent a diversity of AW levels for pigs, and include the largest European meat exporters. 1991 is an ideal starting year because it was the year of the first EU directive pertaining specifically to pig AW (Council Directive 91/630/EC). 1991 also happens to be the earliest year that trade data for post-unification Germany is available in FAOstat.[1]

[1] We do not include domestic trade flows in the analysis because the FAOstat Value of Agricultural Production database contains too many missing country-year observations for pork production. However, in a robustness

We argue that both beef and chicken serve as suitable products to include in the analysis for comparison since AW regulations have had very little impact on their competitiveness compared to the substantial changes to AW legislation that affected the economics of pork production. Pork, chicken and beef constitute the vast majority of meat trade between the countries included in the analysis.

When preparing the data, we combine Luxembourg trade data with that of Belgium, which is customary in the trade literature, since they were not reported separately in the trade data until 1999. We use the value of trade in million US dollars in the analysis. We convert the nominal trade values to constant 2015 prices using the Euro Area consumer price index, taken from OECD.stat. FAOstat includes both importer-reported and exporter-reported bilateral trade data. We use importer-reported trade data whenever available, and fill in missing trade flows using the exporter-reported data whenever possible. This is mainly an issue for trade flows to and from Poland, which did not always report trade data during the 1990's. Using importer-reported trade data likely introduces more measurement error on exporting decisions compared to importing decisions, but importer-reported trade data is commonly regarded as more trustworthy.

After combining the various data, we obtain a fully balanced panel of 4680 unique bilateral trade flow observations for each meat type. In the trade data, we include meat, edible offal, and processed meat for pork, beef and chicken. A complete list of FAO product codes and their descriptions is provided in Table A.1 in the appendix.

Summary statistics for the trade value data are provided in Table 1. Pork trade constituted around half of total bilateral meat trade (pork+beef+chicken) between these 13 countries during the period we study. The average bilateral trade flow for pork during this period was 88 million USD (constant 2015 values).

5.2 AW regulation data

We construct the pig AW-regulation stringency data based on several sources. We first gleaned as much information as possible from existing academic literature and government reports. A few studies provide detailed information about differences between pig AW regulations in a particular year, such as 2010 (Mul et al., 2010), but there is a dearth of literature that describes the dynamics of additional rules at the national level. We compared

check reported in Table A.5 we include destination-product-year or destination-product-year fixed effects, which controls for domestic trade flows.

the texts of EU directives with national laws in order to determine the years when countries' national AW requirements greatly exceeded the prevailing EU legislation for each key issue in our study. We complemented our review of official documents with a questionnaire sent to AW experts from governmental, academic and animal protection organisations in the countries we study. The details of the methodology and sources of information are summarized in Wallenbeck et al. (2024).

Inspection of the pairwise correlation coefficients for the six different AW indicator variables in Table 2 reveals that many of the AW measures are highly correlated. In order to avoid problems of collinearity, we construct an aggregate measure of pig AW-regulation that is the sum of the six indicator variables for each country and year. We construct a variable based on this aggregate AW measure for the origin country in each trade flow observation ($sumAW_{ot}$) and a corresponding variable for each destination country ($sumAW_{dt}$). These aggregate measures of pig AW-regulation take a value between zero and six. The evolution of the aggregate measure of AW regulation for each country in the analysis is illustrated in Figure 1. Several countries increased the stringency of their AW regulations beyond EU minima during the study period. We also construct an inverse covariance weighted index of the six AW indicators, which we use in a robustness check.

5.3 Other variables

We control for whether the origin country or destination country is an EU member, using a categorical variable. This variable takes a value of 0 for Sweden, Finland, and Austria 1991–1994, Poland 1991–2003, and the UK in 2020, and takes a value of 1 otherwise.

We include an indicator variable for the EU ban on UK beef exports due to BSE, which equals 1 for bilateral trade flows of beef to or from the UK between 1996 and 2007, and 0 otherwise. The indicator variable for FMD export bans takes a value of 1 for pork and beef trade flows to and from the United Kingdom, France, the Netherlands and Ireland for the year 2001, and also the United Kingdom in 2007, and takes a value of 0 otherwise (European Commission 2003, 2024). We also include indicator variables for outbreaks of African swine fever (EFSA 2022) and Classical swine fever (EFSA 2021).

We also include country-year controls for national environmental regulations that may have affected the competitiveness of animal farming in EU countries. The Nitrate Directive (91/676/EEC) is one example of an environmental regulation that directly affects animal production by limiting the amount of manure that can be applied to agricultural lands. This restriction forced some producers to transport their manure to spread on fields further away, which reduces the value of this by-product. Since nitrogen application levels are obviously endogenous to a trade, we instead use the OECD Environmental Policy Stringency Index, a broader measure of countries' environmental policy strictness.

In some specifications we use only panel and year fixed effects, which allows for the use of controls at the origin-year and destination-year level. In these specifications we control for countries' Gross Domestic Product (GDP) and GDP per capita, which are common controls in the empirical trade literature. The data on GDP and GDP per capita is taken from FAOstat. In these specifications we also control for whether or not the origin country or destination country is an EU member, using a categorical variable. This variable takes a value of 0 for Austria, Finland and Sweden 1991–1994, Poland 1991–2003, and the UK in 2020, and takes a value of 1 otherwise.

The summary statistics reported in Table 1 indicate that there is large variation in the control variables. Reassuring, correlation coefficients between the AW index and the control variables are generally low, as reported in Table A.2 in the appendix.

Global trade in pork between the EU member states included in our study, the rest of the EU28, and the rest of the world in 1991 (Panel A) and 2020 (Panel B) is illustrated in Figure A.1 in the appendix.[2] World trade in pork increased substantially between 1991 and 2020, from 22 billion to 55 billion constant 2015 USD. International trade in pork between the 13 countries included in the analysis grew modestly during this time, while exports to other EU-28 countries and the rest of the world grew substantially. The 13 countries included in the analysis have historically been self-sufficient in pork, with very limited imports from other countries. Figure A.1 also illustrates that the other EU28 countries not included in our analysis have much smaller trade flows compared to the countries that we study. Our sample of countries thus covers the vast majority of EU pork trade.

[2] The EU28 consisted of the following countries: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

Table 1: Panel data summary statistics, *n*=4680.

Description	Variable name	Mean	SD	Min	Max
Pork bilateral trade value, constant 2015 USD, millions	$trade_{odt, pork}$	88.1	177	0	1,505
Beef bilateral trade value, constant 2015 USD, millions	$trade_{odt, beef}$	57.2	124	0	1,236
Chicken bilateral trade value, constant 2015 USD, millions	$trade_{odt, chicken}$	32.0	86.8	0	1,010
<u>Indicator variables, additional pig AW regulations, by key issue:</u>					
Housing during gestation	$gestAW_{okt}$, $gestAW_{dkt}$	0.16	0.37	0	1
Housing during lactation	$lactAW_{okt}$, $lactAW_{dkt}$	0.085	0.28	0	1
Housing for growing/finishing pigs	$finiAW_{okt}$, $finiAW_{dkt}$	0.097	0.30	0	1
Weaning age	$weanAW_{okt}$, $weanAW_{dkt}$	0.069	0.25	0	1
Tail docking	$tailAW_{okt}$, $tailAW_{dkt}$	0.12	0.33	0	1
Manipulable material	$manipAW_{okt}$, $manipAW_{dkt}$	0.038	0.19	0	1
Sum of pig AW indicators	$AWsum_{okt}$, $AWsum_{dkt}$	0.57	1.39	0	6
AW index	$AWindex_{okt}$, $AWindex_{dkt}$	0.35	1.19	-0.18	6.32
<u>Other control variables:</u>					
EU member indicator	$EUmember_{ot}$, $EUmember_{dt}$	0.93	0.25	0	1
Gross domestic product, constant 2015 USD, billions	GDP_{ot}, GDP_{dt}	1,031	968	82.1	3,599
Gross domestic product per capita, constant 2015 USD, thousands	$GDPpc_{ot}$, $GDPpc_{dt}$	36,473	11,753	4,771	79,464
Bovine spongiform encephalopathy trade ban indicator, beef only	BSE_{okt}, BSE_{dkt}	0.028	0.17	0	1
Foot-and-mouth disease outbreak indicator, beef and pork only	FMD_{okt}, FMD_{dkt}	0.013	0.11	0	1
African swine fever outbreak indicator, pork only	ASF_{okt}, ASF_{dkt}	0.028	0.17	0	1
Classical swine fever outbreak indicator, pork only	CSF_{okt}, CSF_{dkt}	0.018	0.13	0	1
Environmental policy stringency index	$EnvPol_{ot}$, $EnvPol_{dt}$	2.40	0.99	0.47	4.89

Note: The dataset contains 14,040 observations in total, 4680 per product. Descriptive statistics are based on observations for the relevant product, hence *n*=4680. For example, descriptive statistics for the pig AW variables are restricted to pork trade observations.

Table 2: Pairwise correlation coefficients, AW-regulation indicator variables

	$gestation_{ot/dt}$	$lactation_{ot/dt}$	$finishing_{ot/dt}$	$weaning_{ot/dt}$	$tail_{ot/dt}$
$lactation\_housing_{ot/dt}$	0.69				
$finishing\_housing_{ot/dt}$	0.75	0.83			
$weaning_{ot/dt}$	0.62	0.90	0.83		
$tail\_docking_{ot/dt}$	0.48	0.74	0.68	0.74	
$manip\_material_{ot/dt}$	0.13	0.23	0.20	0.26	0.21

Note: The panel is strongly balanced, implying that the correlation coefficients for the origin-year and destination-year variables are identical, hence the "ot/dt" notation after each variable name.

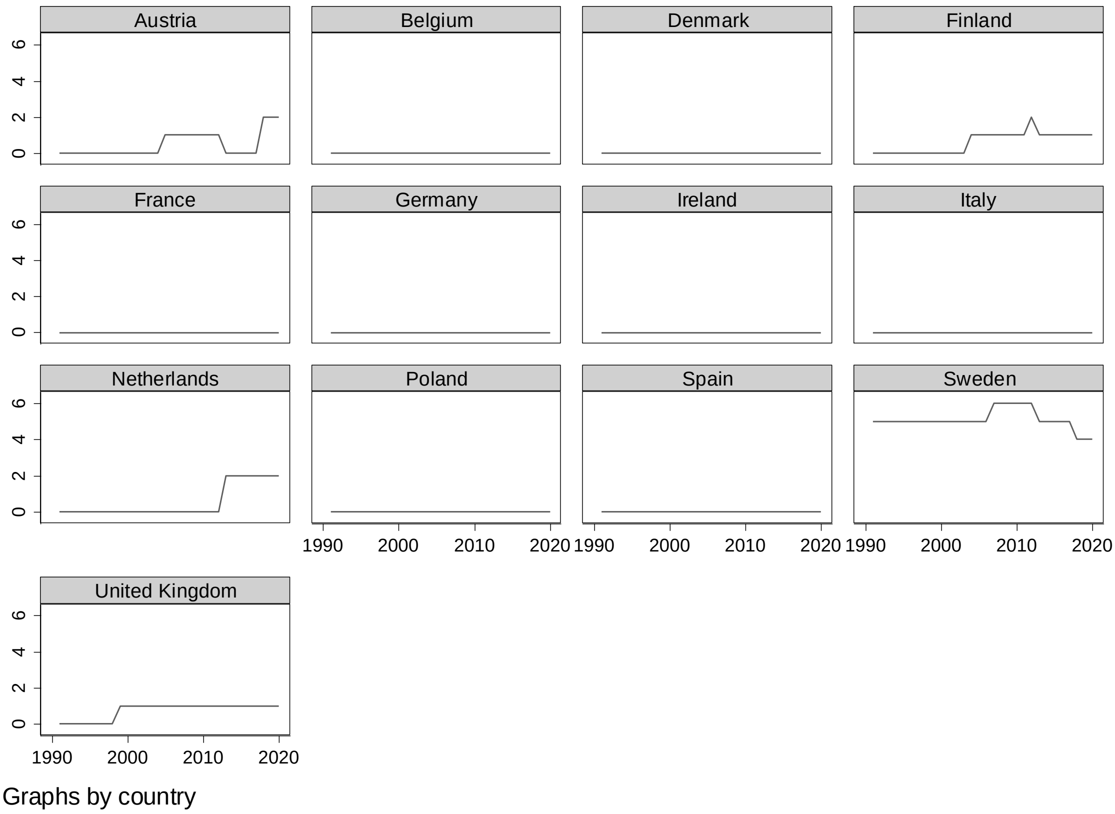

Figure 1: Aggregate national AW index (stringency in AW regulation in relation to EU directives) by country and year, 1991–2020. Source: Authors' calculations.

Total annual trade in pork between the 13 countries we study over the period 1991–2020 is illustrated in Figure A.2 in the appendix. Trade in pork among these countries declined slightly in the 1990's, then grew rapidly in the 2000's, only to fall again slightly during the 2010's. Trade in live animals between these countries has been relatively small in comparison, valued at 780 million USD per year on average for pigs under 50 kg and 1.06 billion on average for pigs 50 kg and over. As indicated by Table A.3 in the appendix, average annual imports and exports to partners within the study group vary by country, with Germany being the largest trade partner and Finland the smallest.

6. Results

6.1 Panel regression results, pork trade flows only

In Table 3 we report the regression results when estimating equation (1). Column 1 includes the AW index for the origin country and destination country, as well as controls for GDP and EU membership. Controls for disease are added in column (2), and the environmental policy control is added in column (3). All specifications include panel and year fixed effects and cluster at the panel (country-pair) level.

Across all columns of Table 3 we find that the stringency of AW regulations in the origin country has a negative and statistically significant relationship with the value of exports. The point estimate for $AWsum_{ot}$ in column (3) suggests that each key issue with substantially more stringent AW regulations is associated with a $(exp(-0.27) - 1) \times 100 \cong 24$ percent decrease in pork exports.

The results in Table 3 suggest that the impact of more stringent AW regulations in the destination country is relatively small compared to those of the origin country, with weakly positive estimates. The point estimate for $AWsum_{dt}$ in column (3) suggest that each key issue with substantially more stringent AW regulations is associated with a $(exp(0.094) - 1) \times 100 \cong 10$ percent increase in imports, although this estimate is imprecise.

Table 3: Panel regression results, pork trade flows only

	(1)	(2)	(3)
$AWsum_{ot}$	-0.24***	-0.24***	-0.27***
	(0.071)	(0.069)	(0.063)
$AWsum_{dt}$	0.084	0.082	0.094
	(0.070)	(0.070)	(0.062)
$EUmember_{ot}$	1.67***	1.65***	1.79***
	(0.36)	(0.35)	(0.33)
$EUmember_{dt}$	0.87***	0.86***	0.77***
	(0.23)	(0.23)	(0.21)
ln_GDP_{ot}	-2.78	-2.81	-2.25
	(2.48)	(2.49)	(1.95)
ln_GDPpc_{ot}	3.41	3.48	2.51
	(2.72)	(2.74)	(2.11)
ln_GDP_{dt}	1.35	1.37	1.00
	(1.94)	(1.93)	(1.42)
ln_GDPpc_{dt}	0.54	0.50	1.08
	(2.01)	(2.02)	(1.47)
FMD_{ot}		0.081	-0.047
		(0.093)	(0.087)
FMD_{dt}		0.084	0.12**
		(0.060)	(0.051)
ASF_{ot}		-0.0056	0.072
		(0.13)	(0.13)
ASF_{dt}		0.018	0.011
		(0.12)	(0.13)
CSF_{ot}		0.16*	0.24***
		(0.086)	(0.070)
CSF_{dt}		0.022	0.031
		(0.082)	(0.080)
$EnvPol_{ot}$			-0.52***
			(0.11)
$EnvPol_{dt}$			0.10
			(0.089)
Fixed effects	Panel and year	Panel and year	Panel and year
Constant	-29.5*	-29.8*	-25.6**
	(16.8)	(17.0)	(12.6)
Observations	4,680	4,680	4,680

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

Some control variables yield statistically significant point estimates with the expected sign in Table 3. EU membership has a positive and statistically significant effect on both the origin and destination country's value of pork trade. We find weak results with respect to origin and destination country GDP and GDP per capita. We do not detect any detrimental effects of disease outbreaks on pork trade. Surprisingly, outbreaks of Classical swine fever (CSF) in the origin country exhibit a positive relationship with pork trade. The estimates suggest that a country's overall environmental policy stringency is negatively associated with its exports, but we do not detect a statistically significant association between environmental policy and countries' imports.

6.2 Panel regression results, pork versus beef or chicken

The results when estimating equation (2) are presented in Table 4. Odd-numbered columns use beef trade flows as the comparison group, while the even-numbered columns display the results using chicken meat trade as the comparison group. Panel and year fixed effects are used in the estimations reported in columns (1) and (2). Estimates using panel, origin-year, destination-year and product-year fixed effects are reported in columns (3) and (4). The estimates using our preferred specification based on equation (1), using panel, origin-destination-year and product-year fixed effects, are reported in columns (5) and (6).

Across all columns of Table 4 we find that the stringency of AW regulations in the origin country has a negative and statistically significant relationship with the value of exports. The point estimate for $AWsum_{okt}$ in column (5) suggests that each key issue with substantially more stringent AW regulations is associated with a $(exp(-0.27) - 1) \times 100 \cong 24$ percent decrease in pork exports, using beef as the comparison product. When using chicken as the comparison product in column (6), each key issue with substantially more stringent AW regulations implies a decrease in exports of $(exp(-0.18) - 1) \times 100 \cong 16$ percent.

The results in Table 4 suggest that the impact of more stringent AW regulations in the destination country is relatively smaller compared to those of the origin country. The point estimate for $AWsum_{dkt}$ using chicken as the comparison product with the full battery of fixed effects in column (6) suggest that each key issue with substantially more stringent AW regulations is associated with a $(exp(0.10) - 1) \times 100 \cong 11$ percent increase in imports. The corresponding results using beef as the control product in column (5) are inconclusive.

Controls for export bans due to BSE and other disease outbreaks are included specifications using beef as the control product in Table 4. Unsurprisingly, our estimates suggest that BSE export bans in the export country ($BSEdum_{okt}$) have a negative, large and statistically significant effect on exports. The point estimate for $BSEdum_{okt}$ in column (5) suggests that exports drop by $(exp(-1.32) - 1) \times 100 \cong 73$ percent in response to a BSE export ban. We do not detect any effects of BSE export bans on a country's imports. African swine fever (ASF) outbreaks have a negative effect on exporters and a positive effect on importers, as expected. We do not detect effects of Foot-and-mouth disease (FMD) or Classical swine fever (CSF) outbreaks.

We include several control variables at the country-year level when estimating the model using panel and year fixed effects, as reported in columns (1) and (2) of Table 4. The estimates suggest that a country's overall environmental policy stringency is negatively associated with its exports, but we do not detect a statistically significant association between environmental policy and countries' imports. EU membership has a positive and statistically significant effect on both the origin and destination country's value of trade.

6.3 Results by AW key issue

We explore the relationship between AW-regulation stringency and trade flows in Tables 5 and 6, where we regress each of the six AW key issues separately on the value of trade. We used our preferred specification, including chicken or beef as a comparison product and including and the full set of fixed effects as used in columns (5) and (6) of Table 4. When using beef as the comparison group (Table 5) we find mixed results. AW-regulation stringency in the origin country with respect to sow housing during gestation and housing of growing/finishing pigs are negative and statistically significant, but several point estimates are insignificant or the unexpected sign. When we use chicken as the comparison product (Table 6), we find negative and statistically significant point estimates for three out of six key issues in the origin country, and more mixed results by key issue for the destination country.

Overall, we find in the panel regression analysis that the impact of AW-regulation stringency has a stronger impact on a country's exports than on its imports. We also find stronger results when using chicken as the comparison product, while the results using beef as the comparison product were somewhat weaker. We find that the stronger results using chicken as the comparison group are reassuring, given that the characteristics of chicken production are arguably more similar to pork than to beef.

Table 4: Panel regression results, pork versus beef or chicken

	(1) pork vs beef	(2) pork vs chicken	(3) pork vs beef	(4) pork vs chicken	(5) pork vs beef	(6) pork vs chicken
$AWsum_{okt}$	-0.24***	-0.30***	-0.27***	-0.18***	-0.27***	-0.18***
	(0.065)	(0.061)	(0.087)	(0.060)	(0.091)	(0.047)
$AWsum_{dkt}$	0.11*	0.040	-0.023	0.079	-0.045	0.11**
	(0.059)	(0.062)	(0.058)	(0.079)	(0.063)	(0.053)
$EUmember_{ot}$	1.42***	1.54***				
	(0.30)	(0.24)				
$EUmember_{dt}$	0.68***	0.72***				
	(0.19)	(0.16)				
ln_GDP_{ot}	-1.29	-3.37**				
	(1.30)	(1.51)				
ln_GDPpc_{ot}	2.12	4.40***				
	(1.54)	(1.69)				
ln_GDP_{dt}	0.32	1.20				
	(1.17)	(1.13)				
ln_GDPpc_{dt}	2.09*	0.86				
	(1.23)	(1.20)				
BSE_{okt}	-1.34***		-1.36***		-1.32***	
	(0.25)		(0.24)		(0.22)	
BSE_{dkt}	-0.13		0.052		0.053	
	(0.094)		(0.11)		(0.11)	
FMD_{okt}	-0.24**	-0.063		-0.075		-0.043
	(0.10)	(0.073)		(0.091)		(0.076)
FMD_{dkt}	0.082	0.11**		-0.051		-0.046
	(0.050)	(0.052)		(0.098)		(0.056)
ASF_{okt}	0.062	-0.057	-0.11	-0.21*	-0.12	-0.19**
	(0.12)	(0.12)	(0.12)	(0.11)	(0.11)	(0.083)
ASF_{dkt}	-0.040	-0.045	-0.31**	0.11	-0.32**	0.21*
	(0.13)	(0.13)	(0.13)	(0.12)	(0.13)	(0.11)
CSF_{okt}	0.20***	0.31***	0.26***	0.12	0.26***	0.12
	(0.064)	(0.067)	(0.079)	(0.13)	(0.067)	(0.086)
CSF_{dkt}	0.050	0.058	0.34***	0.0043	0.33***	-0.058
	(0.079)	(0.075)	(0.098)	(0.099)	(0.100)	(0.084)
$EnvPol_{ot}$	-0.34***	-0.44***				
	(0.090)	(0.089)				
$EnvPol_{dt}$	-0.023	0.094				
	(0.071)	(0.076)				
Fixed effects	Panel and year		Panel, origin-year, destination-year, product-year		Panel, origin-destination-year, product-year	
Constant	-33.6***	-37.2***	5.52***	5.46***	5.54***	5.47***
	(9.45)	(10.3)	(0.018)	(0.023)	(0.019)	(0.017)
Observations	9,360	9,360	9,360	9,360	9,166	9,156

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

Table 5: Panel regression results by AW key issue, pork versus beef

	(1)	(2)	(3)	(4)	(5)	(6)
$gestAW_{okt}$	-0.58***					
	(0.17)					
$gestAW_{dkt}$	-0.13					
	(0.13)					
$lactAW_{okt}$		0.32				
		(0.24)				
$lactAW_{dkt}$		-0.47***				
		(0.081)				
$finiAW_{okt}$			-0.69***			
			(0.20)			
$finiAW_{dkt}$			-0.19			
			(0.15)			
$weanAW_{okt}$				0.24		
				(0.18)		
$weanAW_{dkt}$				0.13		
				(0.18)		
$tailAW_{okt}$					0.71***	
					(0.15)	
$tailAW_{dkt}$					0.093	
					(0.26)	
$manipAW_{okt}$						0.27***
						(0.090)
$manipAW_{dkt}$						0.23***
						(0.088)
BSE_{okt}	-1.32***	-1.28***	-1.34***	-1.28***	-1.28***	-1.28***
	(0.22)	(0.22)	(0.21)	(0.22)	(0.22)	(0.22)
BSE_{dkt}	0.052	0.075	0.053	0.076	0.078	0.081
	(0.11)	(0.12)	(0.11)	(0.12)	(0.12)	(0.12)
ASF_{okt}	-0.13	0.011	-0.12	-0.0042	-0.0025	-0.0084
	(0.11)	(0.12)	(0.11)	(0.12)	(0.12)	(0.12)
ASF_{dkt}	-0.32**	-0.38***	-0.32**	-0.37***	-0.36***	-0.37***
	(0.13)	(0.12)	(0.14)	(0.12)	(0.12)	(0.12)
CSF_{okt}	0.27***	0.30***	0.24***	0.30***	0.30***	0.29***
	(0.068)	(0.077)	(0.062)	(0.077)	(0.077)	(0.077)
CSF_{dkt}	0.32***	0.35***	0.31***	0.34***	0.34***	0.34***
	(0.099)	(0.098)	(0.10)	(0.098)	(0.098)	(0.097)
Constant	5.55***	5.51***	5.53***	5.50***	5.50***	5.50***
	(0.021)	(0.0053)	(0.0096)	(0.0053)	(0.0079)	(0.0050)
Observations	9,166	9,166	9,166	9,166	9,166	9,166

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Panel, origin-destination-year, and product-year fixed effects in all specifications. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

Table 6: Panel regression results by AW key issue, pork versus chicken

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
$gestAW_{okt}$	-0.35***					
	(0.092)					
$gestAW_{dkt}$	0.28**					
	(0.14)					
$lactAW_{okt}$		-0.23***				
		(0.083)				
$lactAW_{dkt}$		0.13				
		(0.096)				
$finiAW_{okt}$			-0.40***			
			(0.11)			
$finiAW_{dkt}$			0.0084			
			(0.082)			
$weanAW_{okt}$				0.45**		
				(0.20)		
$weanAW_{dkt}$				0.44***		
				(0.15)		
$tailAW_{okt}$					-0.58	
					(0.44)	
$tailAW_{dkt}$					-0.89*	
					(0.50)	
$manipAW_{okt}$						0.087*
						(0.046)
$manipAW_{dkt}$						-0.049
						(0.052)
FMD_{okt}	-0.038	0.0018	-0.047	0.0048	0.0052	0.0013
	(0.077)	(0.081)	(0.075)	(0.081)	(0.081)	(0.081)
FMD_{dkt}	-0.075	-0.013	-0.028	-0.0081	-0.011	-0.013
	(0.050)	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)
ASF_{okt}	-0.19**	-0.082	-0.18**	-0.089	-0.076	-0.076
	(0.082)	(0.083)	(0.084)	(0.082)	(0.082)	(0.083)
ASF_{dkt}	0.24**	0.17*	0.19	0.14	0.16	0.16*
	(0.11)	(0.097)	(0.12)	(0.096)	(0.097)	(0.097)
CSF_{okt}	0.14	0.14*	0.11	0.14*	0.14*	0.14*
	(0.089)	(0.087)	(0.083)	(0.086)	(0.087)	(0.087)
CSF_{dkt}	-0.084	-0.050	-0.052	-0.046	-0.045	-0.049
	(0.083)	(0.090)	(0.086)	(0.090)	(0.090)	(0.090)
Constant	5.46***	5.48***	5.50***	5.47***	5.51***	5.48***
	(0.023)	(0.0058)	(0.0081)	(0.0052)	(0.014)	(0.0049)
Observations	9,156	9,156	9,156	9,156	9,156	9,156

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Panel, origin-destination-year, and product-year fixed effects in all specifications. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

6.4 Event study regression results

The main results from the event study regression analysis are presented in Figures 3–5, including point estimates and 95 percent confidence intervals. We report up to seven pre-and post-treatment periods. The aggregate AW measures in the origin country ($AWsum_{okt}$) is the treatment variable in the first column of plots of Figure 3 (Panels A, C, and E). Aggregate AW in the destination country ($AWsum_{dkt}$) is the treatment variable in the second column of plots in Figure 3 (Panels B, D, and F). Panels A and B report the event study estimates using trade in pork only. The estimates using pork and chicken meat are reported in Panels C and D, while the estimates using pork and beef are reported in Panels E and F.

The results in Panel A of Figure 3 suggest a decline in exports around the time that AW stringency increases in the origin country when restricting the analysis to pork trade flows only. Exports tend to decrease a few years in advance of the legislation coming into force, which suggests that anticipation effects are at play. This is reasonable considering that many AW regulations require renovations to barns, which may be completed before the regulations enter info force.[3] The point estimates suggest that annual exports fall by around 30 million USD on average within 4 years after the legislation comes into force for a single key issue.

The results when using chicken or beef as the comparison group in Panels C and E of Figure 3 are roughly similar to those in Panel A, with a fall in annual exports by around 20 million USD on average following legislation for a single key issue coming into force. The results in Panels B, D, and F of Figure 3 do not suggest an effect of AW stringency on imports, as the pre-treatment and post-treatment effects are clearly not significantly different from each other.

Overall, the event study results in Figure 3 are in line with the panel regression results in Tables 3, 4, and 5, and suggest that exports respond to changes in overall AW stringency, but imports are not affected. The event study results also suggest that our earlier results with respect to impacts on exports in Tables 3, 4, and 5 were not driven by underlying trends or pre-treatment effects.

[3] In the case of laying hens, Mullaly and Lusk (2018) showed that the number of egg-laying hens in California began to fall as soon as the rules for minimum space requirements were passed, 20 months prior to entering into force in January 2015. Ferguson (2023) detected an increase in international trade in poultry-keeping equipment up to four years in advance of a ban on conventional battery cages for laying hens in EU countries.

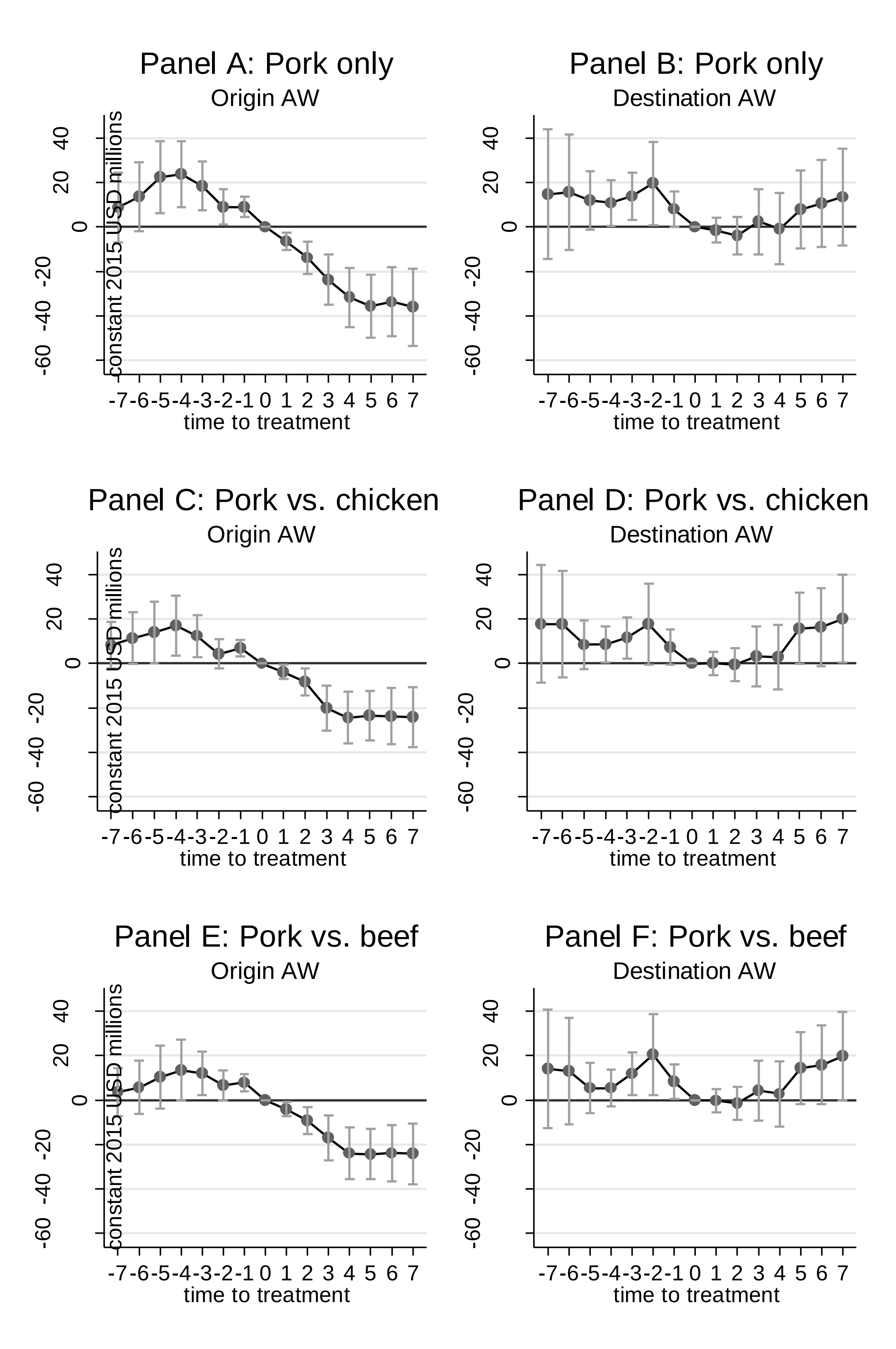

Figure 3: Event study results, impact of AW stringency in origin country exports and destination country imports.

Notes: The aggregate AW measures in the origin country ($AWsum_{okt}$) is the treatment variable in Panels A, C, and E. Aggregate AW in the destination country ($AWsum_{dkt}$) is the treatment variable in Panels B, D, and F.

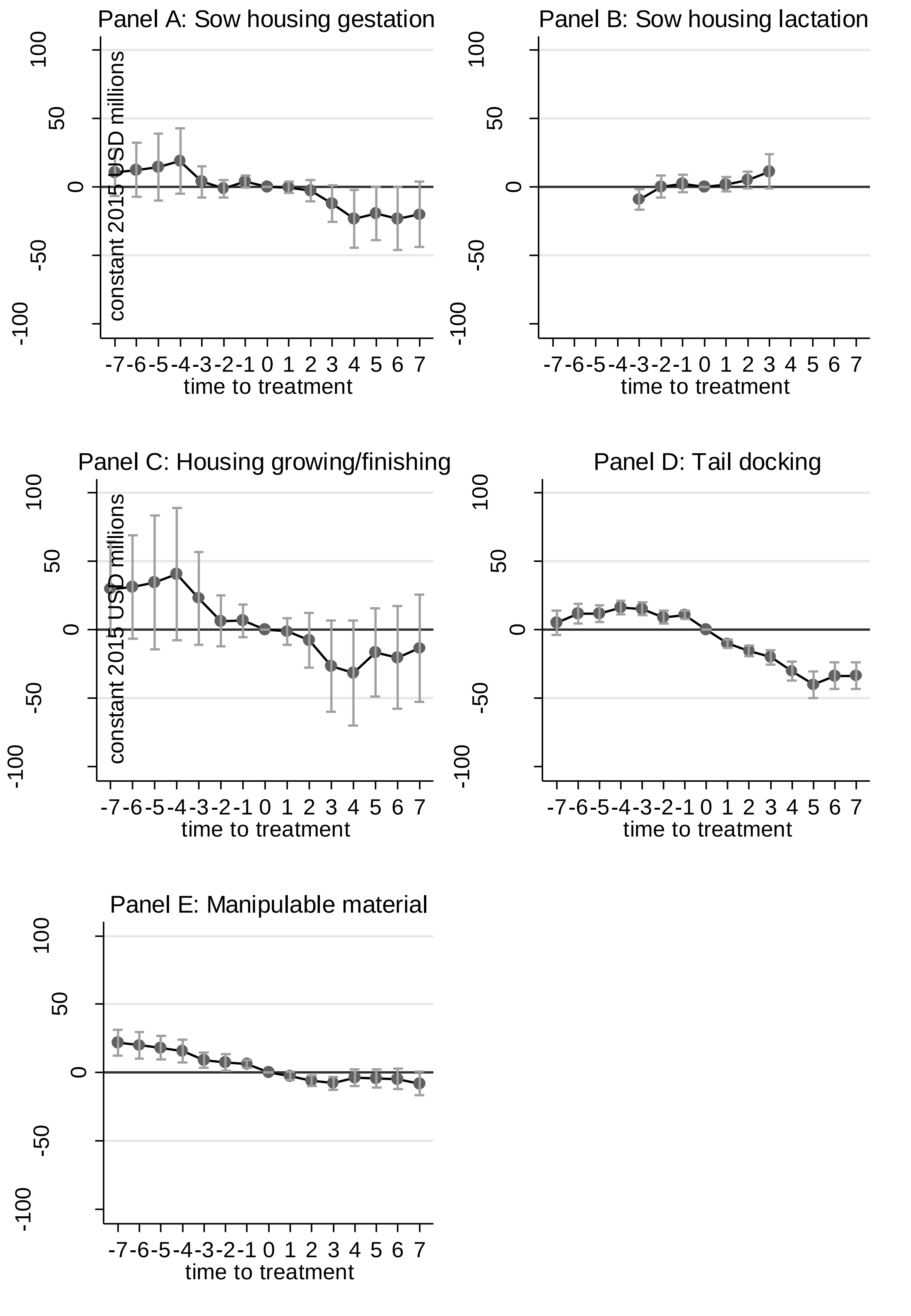

Figure 4: Event study results by AW key issue, origin country exports, pork vs. chicken

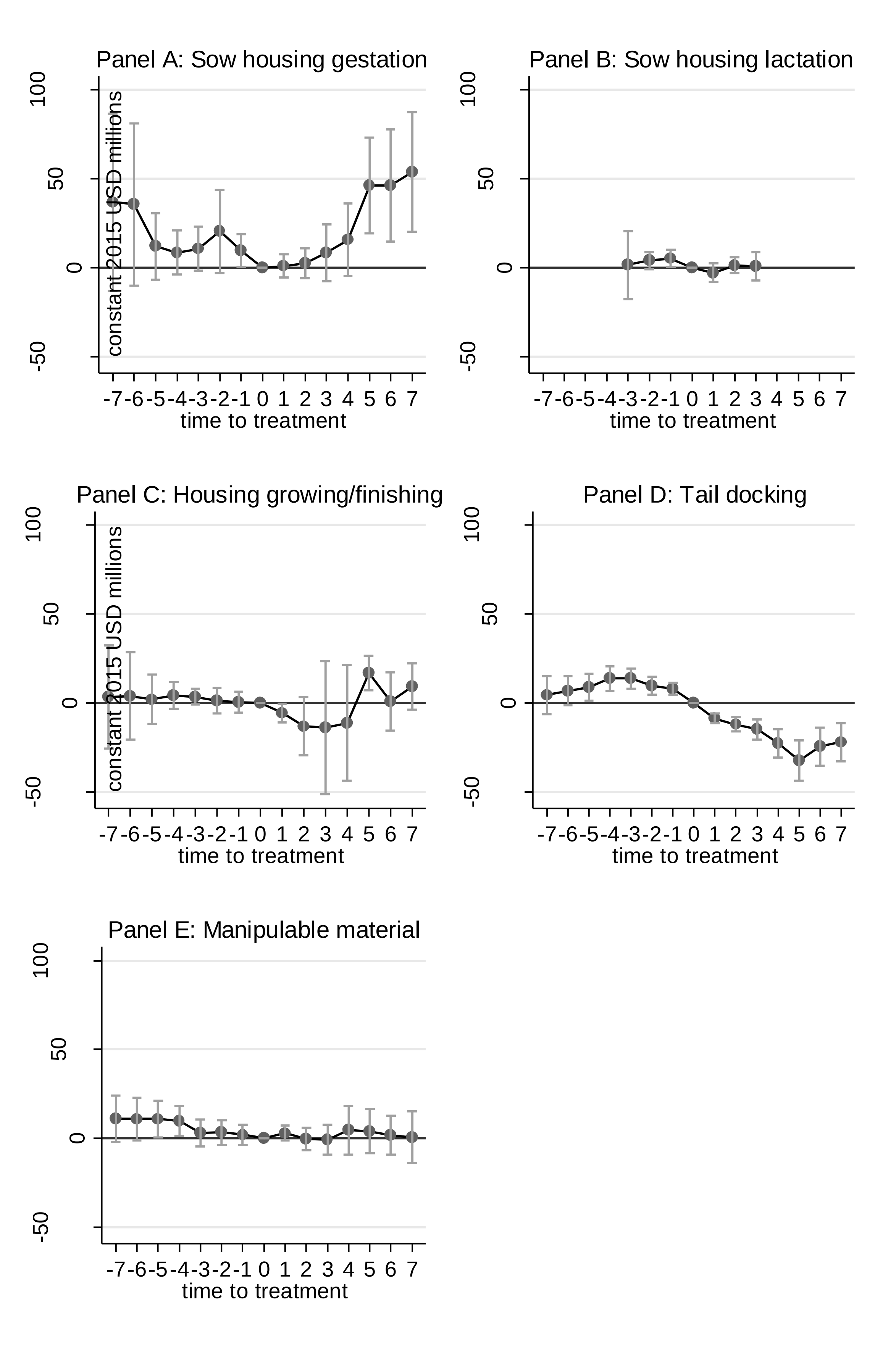

Figure 5: Event study results by AW key issue, destination country imports, pork vs. chicken

Event study results for each AW key issue in the origin country and destination country are reported in Figures 4 and 5 respectively. We focus on the results using trade in chicken meat as the comparison group, as it is arguably a more appropriate comparison group than beef. The results suggest that the effects vary substantially across different AW key issues, which may in part be due to constraints in the number of pre- and post-treatment effects that can be estimated. Treatment effects could be estimated separately for all AW key issues except weaning age.

The results in Figure 4 suggest that analysing the impact of single AW key issues in exports yields less consistent results, with less precision overall compared to the aggregate AW measures illustrated in Figure 3. Tail docking yields the largest and most precisely estimated effects, with the expected negative impact on exports in Panel D of Figure 4. However, the results in Panel D of Figure 5 reveal a negative impact of taildocking restrictions on imports, which is unexpected. The event study results by key issue in the origin and destination country and using beef as the comparison product are reported in Figures A.3 and A.4 in the appendix. The results using beef are generally similar to using chicken, but the pre-treatment period is less stable.

6.5 Robustness to alternative AW index

To check whether our results with respect to the aggregate AW measure are robust to alternative metrics, we construct an index that captures overall changes AW legislation, using the inverse covariance weighting method (Anderson, 2008). The inverse covariance weighted index assigns less weight to highly correlated components, thus maximizing the information contained in the index. We construct this AW index for the origin country in each trade flow observation ($AWindex_{okt}$) and a corresponding index for each destination country ($AWindex_{dkt}$). The results for the panel regressions and event study are reported in Table A.4 and Figure A.5 respectively in the appendix. We find that our results are robust to using this alternative measure of overall AW stringency.

6.6 Robustness to alternative fixed effects

As an additional robustness check, we build on our preferred specification in equation (2) and add destination-product-year fixed effects when estimating the impact of origin country AW stringency ($AWsum_{okt}$). Similarly, we include origin-product-year fixed effects when estimating the impact of AW stringency in the destination country ($AWsum_{dkt}$). These fixed effects effectively control for the “multilateral resistance terms” commonly included in gravity models of international trade (Anderson and van Wincoop, 2003; Head and Mayer, 2014; Yotov et al., 2016) for either the origin country or the destination country, depending on the specification. The results of this robustness check are reported in Table A.5 in the appendix. We find that our results are robust to including these additional fixed effects.

6.7 Robustness to alternative standard errors

The standard errors in the analysis are clustered at the country-pair-product level, as the origin-product level results in too few clusters (13 or 26, depending on whether a control product is used or not). In order to check if our results are robust to clustering at the treatment level (origin-product), we perform a wild bootstrap test of joint null (Roodman et al., 2019), then plot the histogram of bootstrapped t-statistics with our t-statistics clustering at the origin-product level. We perform this test on the estimates for $AWsum_o$ in our preferred specifications based on pork only, pork versus chicken, and pork versus beef (column (3) of Table 3, and columns (5) and (6) of Table 4). The results of this test are reported in Figure A.6 in the appendix, and suggest that the results are robust using these alternative standard errors.

6.7 Effects on trade with trade partners outside the study area

Our analysis so far has focused on trade between the 13 countries for which we have detailed data on AW stringency, and are a combination of countries that have had relatively stringent AW legislation for pigs, or are large exporters of pork. However, it is a valid question whether more stringent AW legislation vis-à-vis the EU minima has affected these countries' exports and imports with trade partners outside of the study area. Using the same sources for the bilateral trade data and other control variables, we estimate the impacts of AW stringency using our aggregated measure. The results of this analysis are reported in Table A.6 in the appendix, using either beef or chicken as the comparison product.

As we do not have data on the AW stringency on other countries, we can instead subsume all unobserved product-country-year covariates using fixed effects, following the approach used in Table A.3. We include destination-product-year fixed effects when estimating the impact of origin country pig AW stringency ($AWsum_{okt}$) on exports to all other countries. Likewise, we include origin-product-year fixed effects when estimating the impact of destination country pig AW stringency ($AWsum_{dkt}$) on imports from all other countries. The results in Table A.6 suggest that additional pig AW stringency beyond EU minima have not affected exports or imports of pork to countries outside of the study area.

7 Discussion and policy implications

Overall, our first robust finding is that AW regulation stringency has a strong and negative impact on a country's exports. This result is consistent across the panel regressions and the event study. The negative relationship between AW regulation and exports could be driven by several mechanisms. One possible mechanism is that more stringent AW regulations lead to lower exports if the competitiveness channel dominates. Another possible mechanism is that more stringent pig AW regulations are more feasible in countries with a less export-oriented domestic pork industry. For example, countries such as Finland and Sweden, which have relatively stringent AW regulations for pork production, have historically exported relatively little pork.

The other main finding in both the panel and event study analyses is that we do not detect a consistent impact of AW regulations on imports. When studying AW key issues individually, we find positive effects of weaning age legislation (Table 6) and tail docking legislation (Figure 6) on imports. One interpretation of these results is that AW regulations reduce competitiveness in export markets, but do not necessarily reduce competitiveness in the domestic market. One possible explanation is that consumers in the domestic market may have stronger preferences for AW, which can also explain the introduction of more stringent regulation. The lack of a robust effect on imports could also suggest that national AW policies do not diverge greatly from domestic consumers' preferences for AW.

The lack of an effect on imports implies that higher AW stringency is not always leading to a problem of leakage from "low AW havens". This lack of import response to higher cost pork due to AW regulations could be driven by a combination of consumer preferences for AW or a general home bias in pork, whereby domestic consumers prefer to consumer domestic pork produced with higher AW standards, despite the higher cost.

The policy implications of our findings hinge on whether or not our findings can be interpreted as a causal effect of AW regulations. If stricter AW regulations with respect to sow housing during gestation indeed reduce exports among the EU countries studied, then policies that subsidize the fixed and variable costs of group sow housing may reduce the adverse impact on exports. Quantifying the economic benefits of such a policy would require an extensive economic welfare analysis, which is beyond the scope of this study.

As we do not detect a robust adverse impact of AW regulations on imports, our findings also suggest that import restrictions may not always be an appropriate policy measure in order to protect pork producers in countries with more stringent AW regulations among these EU countries. Indeed, our findings suggest that tail docking regulations may have a pro-competitive effect via decreased imports of pork. Our nuanced results with respect to imports could have potentially important implications and deserves further attention, especially given the many calls to require equivalent AW standards for imported meat.

An important caveat of our results is that they are based differences in stringency relative to EU minima for the 13 countries included in the analysis, and not the impact of EU pig AW directives in general. EU directives could affect trade patterns, particularly with respect to countries outside the EU, given that most other countries in the world have less stringent AW standards than the EU minimum levels. Imports from the rest of the world made up less than one percent of total imports by the 13 countries included in our study in 2020 (see Figure A.1), suggesting that EU directives have a small potential impact on pork imports. However, exports to the rest of the world comprise 42 percent the study area's total pork exports, so there is more scope for EU pig AW directives to affect extra-EU pork exports. We leave the study of the impact of EU minimum standards on pork trade for future research.

8. Conclusions

While the welfare of farm animals remains an important issue for humans in their roles both as citizens and consumers, it is an important empirical question whether more stringent AW regulation has reduced the competitiveness of pork producers. We study this question using trade as an indicator of competitiveness, using detailed data on bilateral trade flows of meat for several European countries during the period 1991–2020, a period where EU directives and national initiatives substantially affected the way pigs are raised. We take advantage of the fact that some countries' AW regulations for pigs went further than EU directives, while some countries only achieved the EU minimum standards. We perform this analysis using a novel dataset of pig AW-regulation stringency that considers several dimensions of AW that have important cost implications for pork producers.

In both the panel and event study regression analyses we find that the relative stringency of pig AW regulations has a large and negative impact on exports. We find that more stringent AW for pigs is associated with significantly lower pork exports, compared to beef and chicken. In contrast, we do not detect an effect on pork imports. These results suggest that stricter AW regulations for pigs in the six key issues that we study are associated with a decrease in countries' competitiveness in export markets, but not in the domestic market.

Although our results suggest a strong association between pig AW regulation stringency and exports, we cannot make a causal claim regarding this effect. We thus leave an analysis of the causal effects of AW regulations on comparative advantage for future research. We hope that this study inspires further research on the implications of AW regulations on competitiveness in animal production.

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Appendix

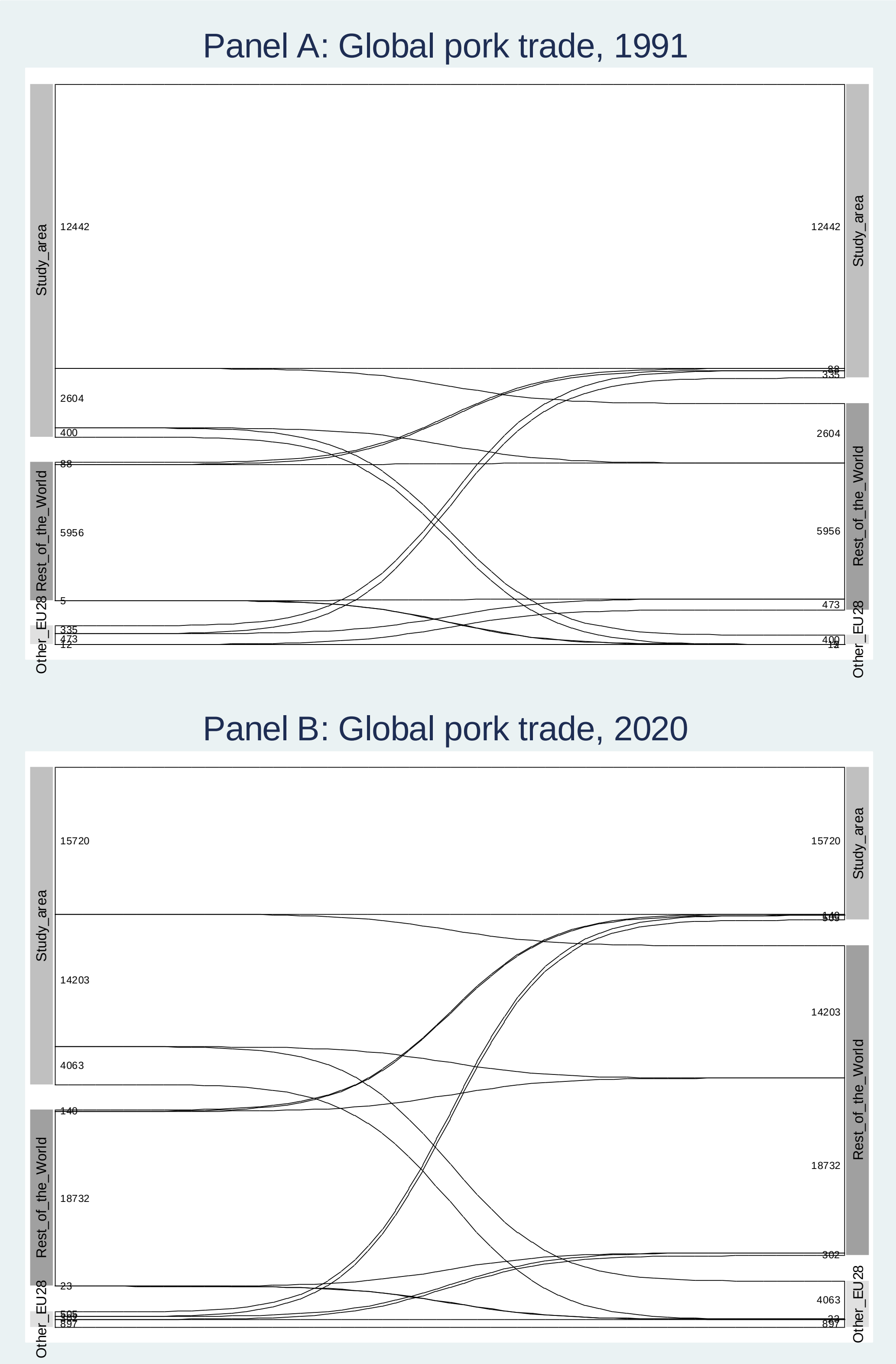

Figure A.1 Sankey diagram of global pork trade in 1991 and 2020 for countries included in the analysis, other EU-28 countries, and the rest of the world, constant 2015 USD millions. Source: FAOstat

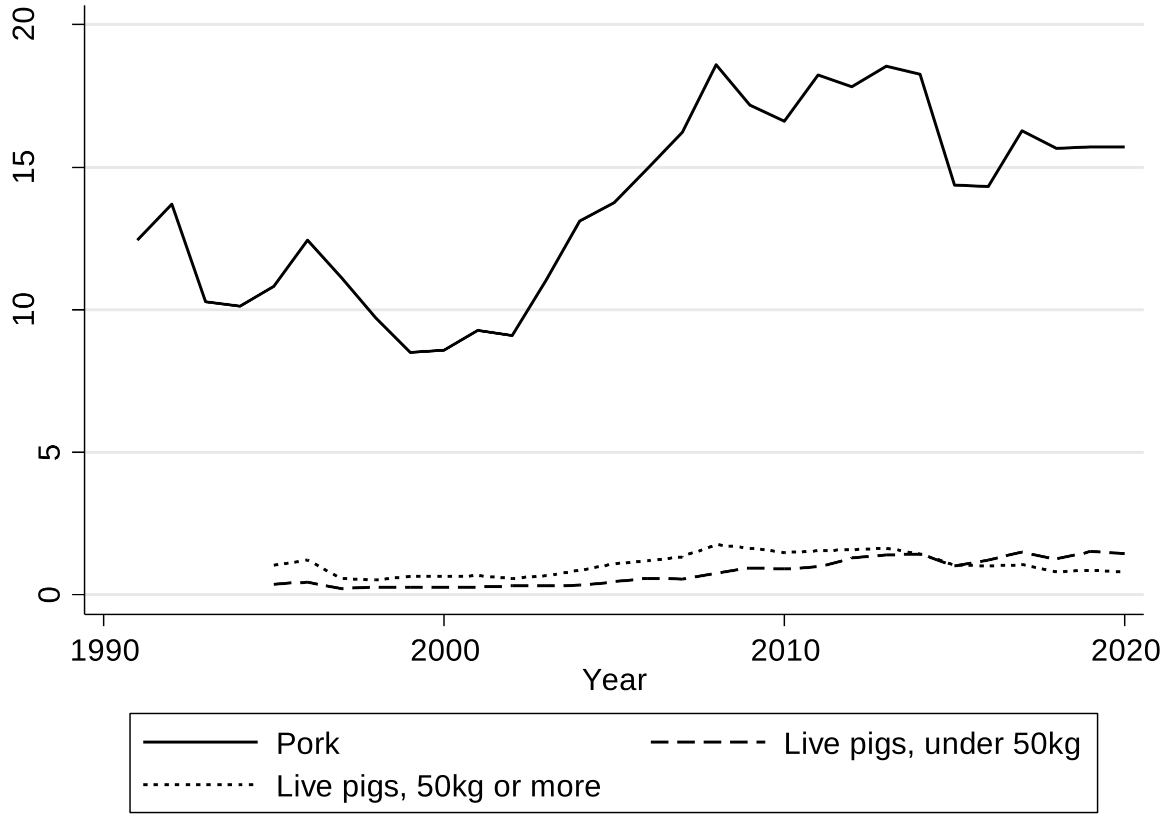

Figure A.2: Total annual trade in pork between the countries included in the analysis, 1991–2020, and total trade in live pigs by weight category (HS010391, “Swine; live, other than pure-bred breeding animals, weighting less than 50kg”, and HS010392, “Swine; live, other than pure-bred breeding animals, weighting 50kg or more”), 1995–2020. Source: FAOstat and CEPII BACI database.

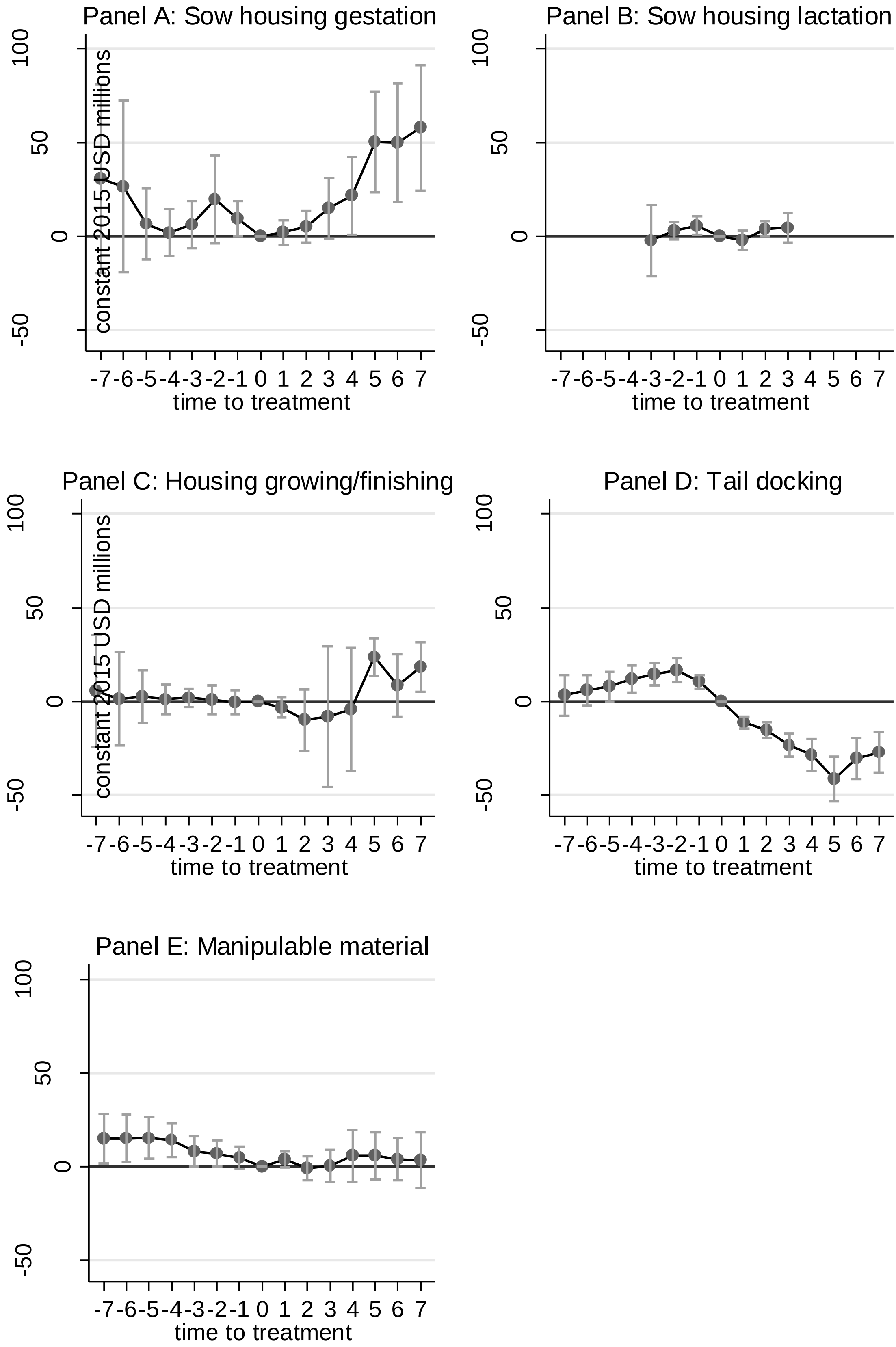

Figure A.3: Event study results by AW key issue, origin country exports, pork vs. beef

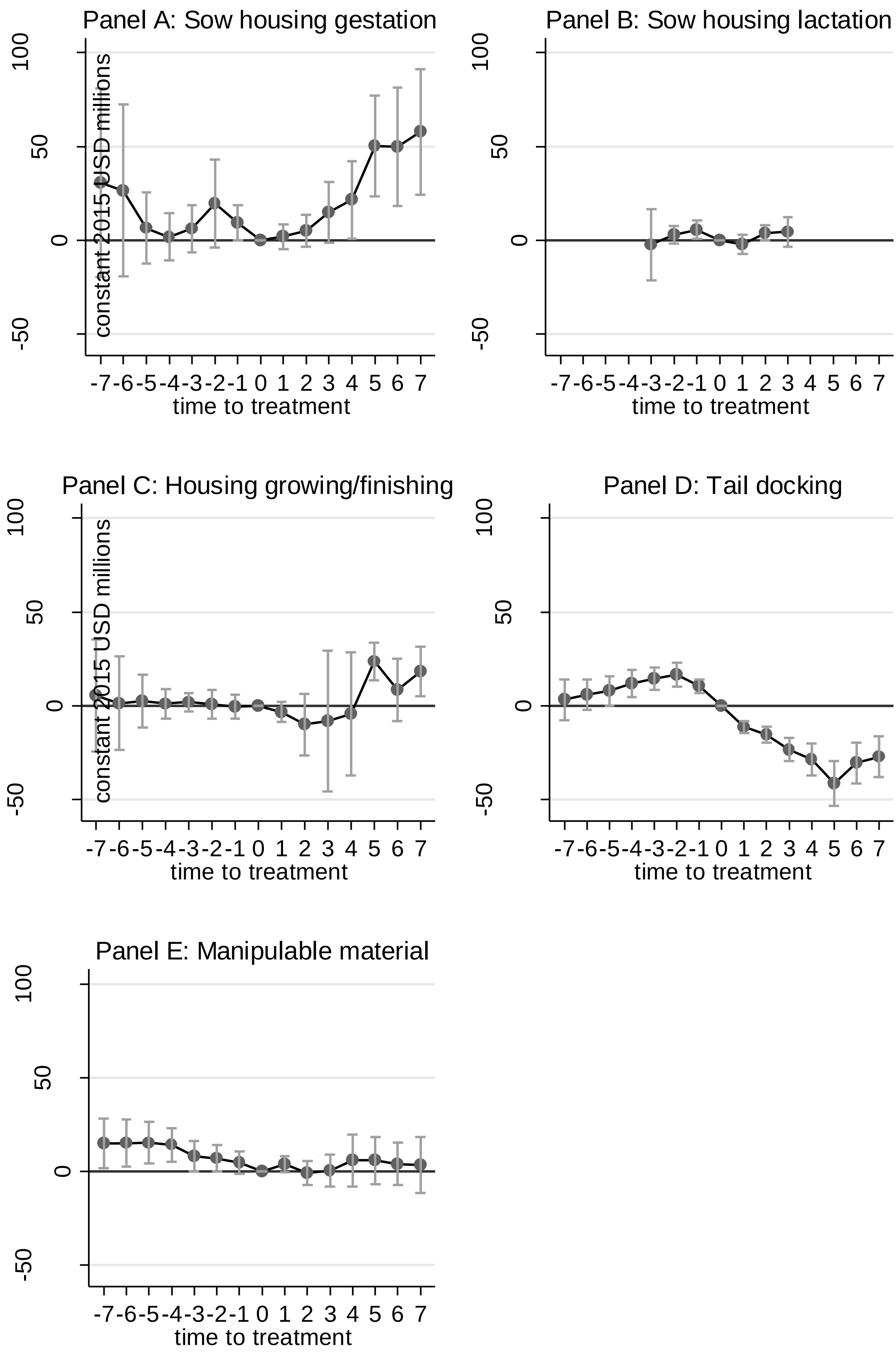

Figure A.4: Event study results by AW key issue, destination country imports, pork vs. beef

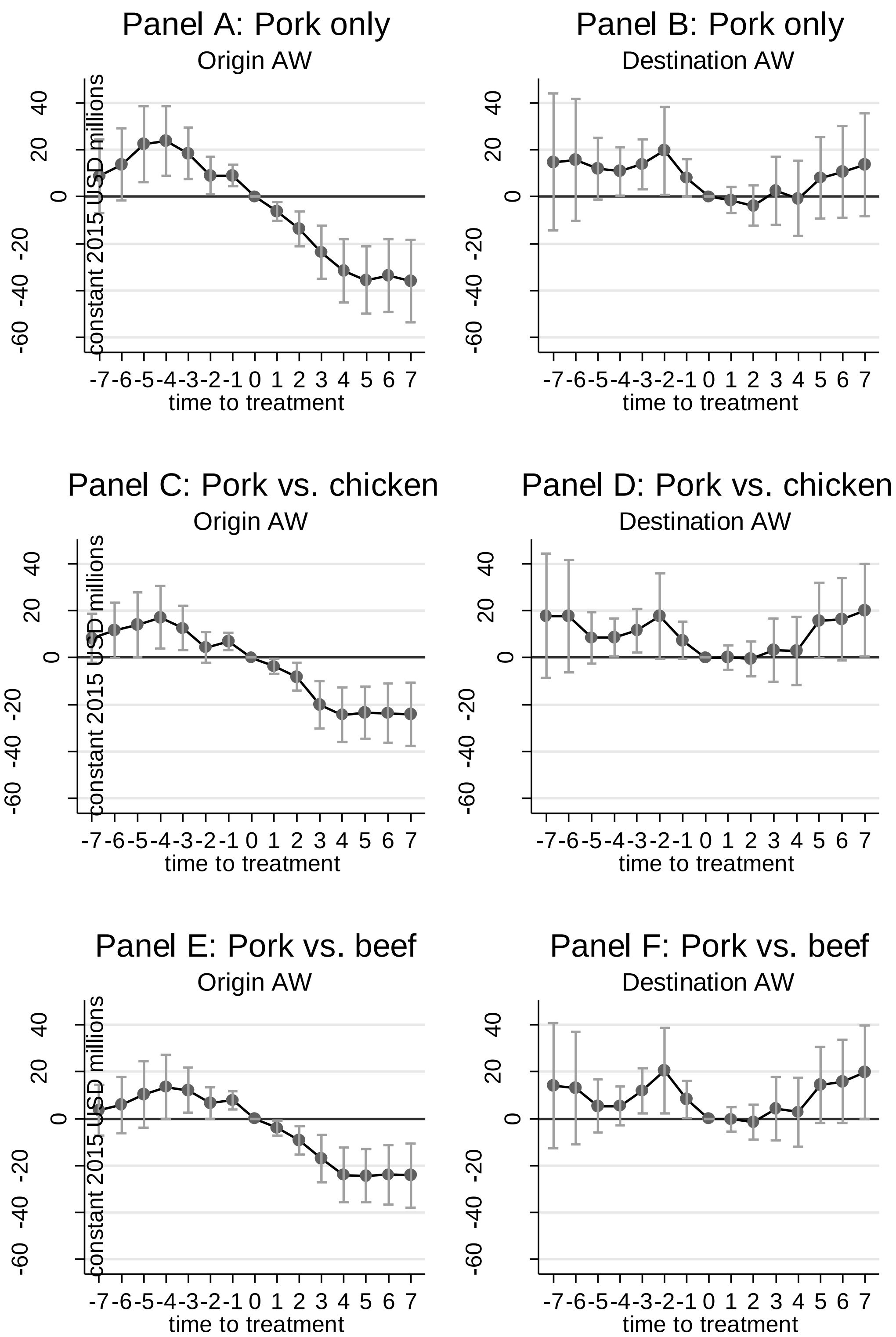

Figure A.5: Robustness: Event study results, impact of AW stringency in origin country exports and destination country imports, using alternative AW index.
Notes: The inverse covariance weighted AW index for the origin country ($AWindex_{okt}$) is the treatment variable in Panels A, C, and E. The corresponding AW index for the destination country ($AWindex_{dkt}$) is the treatment variable in Panels B, D, and F.

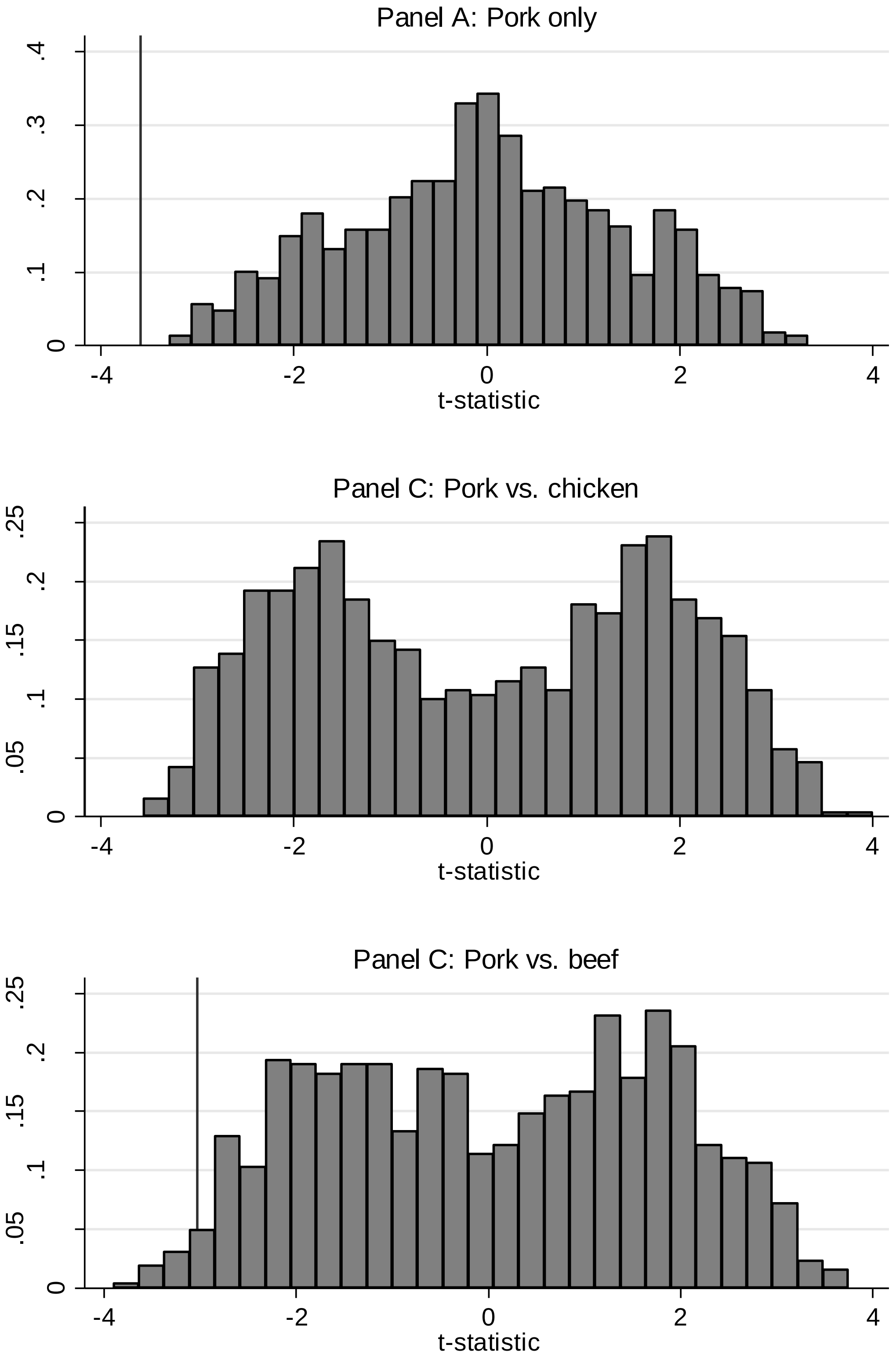

Figure A.6: Robustness to clustering standard errors at the origin-product level, $AWsum_o$
Notes: Histogram of bootstrapped t-statistics and estimated t-statistic (vertical line) for *AWsum* clustering at the origin-product level, based on a wild bootstrap test of joint null (Roodman et al., 2019). Panel A report the results based on column (3) of Table 3. Panels B and C report the results based on columns (5) and (6) of Table 4 respectively.

Table A.1: List of FAO products included in analysis

FAO product code	Description
Pork:	
1035	Meat of pig with the bone, fresh or chilled
1036	Edible offal of pigs, fresh, chilled or frozen
1037	Fat of pigs
1038	Meat of pig boneless, fresh or chilled
1039	Pig meat, cuts, salted, dried or smoked (bacon and ham)
1041	Sausages and similar products of meat, offal or blood of pig
1042	Pig meat preparations
1043	Pig fat, rendered
Beef:	
867	Meat of cattle with the bone, fresh or chilled
868	Edible offal of cattle, fresh, chilled or frozen
869	Cattle fat, unrendered
870	Meat of cattle boneless, fresh or chilled
875	Beef and veal preparations not elsewhere specified
Chicken:	
1058	Meat of chickens, fresh or chilled
1059	Edible offals and liver of chickens and guinea fowl, fresh, chilled or frozen
1061	Poultry meat preparations

Source: FAOstat

Table A.2: Pairwise correlation coefficients, aggregate AW measure and other control variables

	AWsum	EUmember	GDP	GDP	BSE	FMD	ASF	CSF
$EUmember_{ot/dt}$	-0.02							
$ln\_GDP_{ot/dt}$	-0.07	0.26						
$ln\_GDPpc_{ot/dt}$	0.13	0.51	0.06					
$BSE_{ot/dt}$	-0.02	0.03	0.13	0.03				
$FMD_{ot/dt}$	0.00	0.02	0.05	0.04	0.09			
$ASF_{ot/dt}$	-0.02	0.03	-0.01	-0.11	-0.01	-0.01		
$CSF_{ot/dt}$	-0.02	0.02	0.02	-0.01	-0.01	-0.01	-0.01	
$EnvPol_{ot/dt}$	0.10	0.31	0.22	0.42	-0.08	-0.07	0.07	-0.07

Note: The panel is strongly balanced, implying that the correlation coefficients for the origin-year and destination-year variables are identical, hence the “ot/dt” notation.

Table A.3 Average annual imports and exports within the study area, per country, 1991–2020

	Constant 2015 USD, millions	
	imports	exports
Austria	371	300
Belgium	620	1630
Denmark	394	2464
Finland	91	29
France	1692	1006
Germany	3007	2764
Ireland	248	417
Italy	2363	861
Netherlands	704	2259
Poland	796	298
Spain	327	1304
Sweden	391	76
United Kingdom	2741	339

Table A.4: Robustness to inverse covariance weighted AW index

	(1) pork vs beef	(2) pork vs chicken	(3) pork vs beef	(4) pork vs chicken	(5) pork vs beef	(6) pork vs chicken
$AWindex_{okt}$	-0.18**	-0.23**	-0.14*	-0.13**	-0.12	-0.13***
	(0.083)	(0.091)	(0.074)	(0.057)	(0.079)	(0.050)
$AWindex_{dkt}$	0.066**	0.035	0.023	0.049	0.029	0.065*
	(0.030)	(0.037)	(0.033)	(0.050)	(0.035)	(0.034)
$EUmember_{ot}$	1.43***	1.56***				
	(0.30)	(0.24)				
$EUmember_{dt}$	0.68***	0.71***				
	(0.19)	(0.16)				
ln_GDP_{ot}	-1.30	-3.38**				
	(1.31)	(1.54)				
ln_GDPpc_{ot}	2.15	4.43***				
	(1.56)	(1.72)				
ln_GDP_{dt}	0.34	1.20				
	(1.23)	(1.19)				
ln_GDPpc_{dt}	2.09	0.89				
	(1.29)	(1.26)				
BSE_{okt}	-1.35***		-1.33***		-1.29***	
	(0.25)		(0.24)		(0.22)	
BSE_{dkt}	-0.14		0.061		0.071	
	(0.095)		(0.11)		(0.12)	
FMD_{okt}	-0.23**	-0.030		-0.053		-0.021
	(0.10)	(0.079)		(0.093)		(0.078)
FMD_{dkt}	0.085*	0.12**		-0.044		-0.035
	(0.051)	(0.051)		(0.097)		(0.057)
ASF_{okt}	0.098	-0.022	-0.013	-0.15	-0.034	-0.13
	(0.12)	(0.11)	(0.13)	(0.11)	(0.12)	(0.083)
ASF_{dkt}	-0.064	-0.066	-0.32***	0.079	-0.35***	0.17*
	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.10)
CSF_{okt}	0.21***	0.33***	0.28***	0.14	0.29***	0.14
	(0.068)	(0.071)	(0.084)	(0.13)	(0.073)	(0.086)
CSF_{dkt}	0.054	0.068	0.35***	0.013	0.34***	-0.052
	(0.078)	(0.072)	(0.097)	(0.099)	(0.100)	(0.086)
$EnvPol_{ot}$	-0.34***	-0.44***				
	(0.091)	(0.092)				
$EnvPol_{dt}$	-0.026	0.094				
	(0.073)	(0.078)				
Fixed effects	Panel and year		Panel, origin-year, destination-year, product-year		Panel, origin-destination-year, product-year	
Constant	-33.9***	-37.9***	5.47***	5.45***	5.49***	5.47***
	(9.61)	(10.5)	(0.0087)	(0.012)	(0.0093)	(0.0079)
Observations	9,360	9,360	9,360	9,360	9,166	9,156

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

Table A.5: Robustness to alternative fixed effects

	(1) pork vs beef	(2) pork vs chicken	(3) pork vs beef	(4) pork vs chicken
$AWsum_{okt}$	-0.23***	-0.23***		
	(0.059)	(0.040)		
BSE_{okt}	-1.55***			
	(0.20)			
ASF_{okt}	-0.078	-0.16**		
	(0.11)	(0.081)		
CSF_{okt}	0.25***	0.13*		
	(0.067)	(0.071)		
FMD_{okt}		0.064		
		(0.087)		
$AWsum_{dkt}$			-0.017	0.12**
			(0.058)	(0.051)
BSE_{dkt}			0.20*	
			(0.12)	
ASF_{dkt}			-0.29***	0.20**
			(0.11)	(0.10)
CSF_{dkt}			0.26***	-0.075
			(0.065)	(0.064)
FMD_{dkt}				0.0045
				(0.048)
Fixed effects:	Panel, origin-destination-year, destination-product-year		Panel, origin-destination-year, origin-product-year	
Constant	5.53***	5.52***	5.52***	5.46***
	(0.0051)	(0.0046)	(0.013)	(0.015)
Observations	9,166	9,156	9,166	9,138

Notes: The dependent variable is the value of trade in constant 2015 USD millions. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.

Table A.6: Effects on trade with trade partners outside the study area

	Exports from study area		Imports to study area	
	(1)	(2)	(3)	(4)
	pork vs beef	pork vs chicken	pork vs beef	pork vs chicken
$AWsum_{okt}$	-0.12	0.074		
	(0.097)	(0.070)		
BSE_{okt}	-1.47***			
	(0.45)			
ASF_{okt}	-0.63***	-0.79***		
	(0.21)	(0.16)		
CSF_{okt}	-0.22*	-0.20*		
	(0.12)	(0.12)		
FMD_{okt}		-0.32**		
		(0.14)		
$AWsum_{dkt}$			-0.048	0.011
			(0.051)	(0.077)
BSE_{dkt}			0.044	
			(0.13)	
ASF_{dkt}			-0.17	-0.024
			(0.13)	(0.12)
CSF_{dkt}			0.35***	0.088
			(0.082)	(0.094)
FMD_{dkt}				0.027
				(0.093)
Fixed effects:	Panel, origin-destination-year, destination-product-year		Panel, origin-destination-year, origin-product-year	
Constant	4.37***	4.30***	5.12***	5.04***
	(0.015)	(0.012)	(0.0081)	(0.014)
Observations	99,099	98,197	113,882	110,924

Notes: The estimates in columns 1 and 2 are restricted to bilateral trade flows from the study area countries to all other countries in the world. The estimates in columns 3 and 4 are restricted to bilateral trade flows from all other countries in the world to the study area countries. The dependent variable is the value of trade in constant 2015 USD millions. Estimates clustered at the panel-level in all specifications. ***p<0.01, **p<0.05, *p <0.1.