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Economic impact and food security effects of trade disruptions in agricultural products for Sweden

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Abstract

The COVID-19 pandemic and geopolitical conditions in 2022–2023 highlighted the vulnerabilities of food supply chains to trade disruptions in agricultural inputs and foods, with the ensuing economic effects on producers and consumers. This study calculated the impact of various disruptions in the trade of agricultural inputs and outputs for Swedish producers and consumers and for food security. To this end, a mathematical programming model of the food sector with a spatial dimension was applied, which accounts for adjustments and interactions between producers and consumers of food. Food security is measured in terms of the self-sufficiency ratio, the ability to produce minimum dietary needs, and economic access for low-income households. The trade scenarios included disruptions to imports of agricultural inputs (fertilisers, fuel, feed, pesticides and foreign labour) and foods. The results showed that the economic effects for producers can be considerable, with a reduction in producer surplus by up to 75%. The decrease in consumer surplus is smaller, amounting to a maximum decrease of 21%. The self-sufficiency ratio and the ability to produce minimum dietary needs can be reduced by 55% and 61%, respectively, but may rise if the disruption to feed imports increases. Economic access to foods is slightly decreased in all scenarios. These results showing different impacts of trade disruptions on producers and consumers and food security metrics highlight the need to undertake extensive assessments to determine whether and how to prevent and mitigate their effects. The economic effects on producers and consumers and the associated impacts on food security are likely to differ, which affects the selection and targeting of policies, such as compensation for economic losses and promotion of food security.

Keywords Agriculture trade disturbances, Economic effects, Food security, Agricultural sector model

Introduction

The COVID-19 pandemic and geopolitical conditions highlighted vulnerabilities in the supply of agricultural inputs, such as fuel and fertilisers, and final consumption goods due to trade disruptions and delays [1, 2]. The associated economic effects on the agricultural sector and food (in)security are closely linked. The latter is a potential consequence of the economic impacts on agriculture, where rising production costs due to disruptions in inputs reduce the supply of food, with associated higher prices for consumers. The responses in many countries to mitigate the spread of COVID-19 during the pandemic resulted in disruptions to the international trade of important food products, which had negative effects on food security and the agricultural sector in several countries [3, 4]. The Russian invasion of Ukraine in February 2022 generated disturbances in the global

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markets for key food crops, energy and fertilisers, which increased economic vulnerability and food insecurity in the post-pandemic world [3, 4]. The problem was exacerbated by the climate impact of high temperatures in 2023, leading to lower crop yields and associated food shortages [5]. The policy responses by countries exposed to trade barriers included support for domestic agricultural production during the pandemic [6] and compensation for large increases in fuel prices due to the Russian invasion of Ukraine [7, 8]. However, to determine the type and magnitude of the policy response, it is important to understand the economic impacts of trade disruptions on the producers and consumers of food and on food security.

Like several small open economies, the agricultural sector in Sweden relies heavily on imports of fuel and fertiliser, and the cost of imports equates to approximately half of the country's total expenditure on food consumption [9]. Barriers to trade are therefore likely to have major economic and food security effects. Food security is generally split into four different dimensions: availability, access, utilisation and stability [10, 11]. Availability shows the supply side of food, which is determined by food production and net trade; access refers to consumers' economic and physical access to food; utilisation is the body's nutrient and calorie intake; and stability implies that the other three dimensions are ensured over time.

The role of international trade in food security has been analysed by a number of studies, but these have produced contradictory results. The positive effects of stability in international trade and decreases in trade barriers on the availability dimension of food security are emphasised by [12, 13], but [14, 15] highlight the volatility in international prices as a source of food insecurity from an access perspective. Calculations have been made for food availability due to disruptions in the global trade of wheat, for example, due to the Russian–Ukraine war [16] and disruptions to global trade due to the impacts of climate change [17]. A common approach in these studies was to base the calculations of vulnerability on the exposure to trade in a given year, without considering adjustments made by producers and consumers to the trade disruption.

Calculations of the economic and food security impacts require consideration of the responses and interactions of producers and consumers, since trade disturbances have economic effects and impacts on food security throughout many sectors of society [18]. For example, decreases in inputs such as fuel, feed and fertilisers reduce the production of food, which is transferred to consumers by increasing prices in the value chain. This, in turn, affects the composition of foods, which may mean that there is a risk that people will not have a sufficient nutrient intake.

Agricultural sector programming models are commonly used since they include the responses of producers and consumers to different types of exogenous events. Such models have often been applied to assess the economic effects on producers and consumers of changes in terms of trade and food policy reforms in several food markets [19, 20]. Other studies consider the economic impacts of tariff reductions in single markets, such as the sugar market [21]. A few studies have considered food security, but in different ways. Fathelrahman et al. [22] compared the effects on producer and consumer surplus of tariff reductions on foods, and addressed food security in terms of economic access (impacts on real incomes) for different countries. Mobarok et al. [23] calculated the effects of COVID-19 policies in Bangladesh on the economic performance of the rice sector, and food security in terms of rice availability. Lin et al. [24] calculated the food security and macroeconomic effects on a global scale of disruptions in wheat trade due to the Russia–Ukraine conflict. However, none of the studies has evaluated the economic impacts in a multimarket food sector and compared outcomes on food security in more than one dimension under different types of trade disruptions.

The purpose of the present study was to calculate the economic effects for producers and consumers in a multimarket food sector and for different food security metrics for Sweden under different scenarios regarding international trade barriers. To account for the interaction effects and spatial dimension, an existing mathematical programming model of the agricultural sector was applied that accounts for the dispersal effects of a trade disturbance in the production chain and for consumers [25]. Food security was introduced into the model in terms of availability and access. Availability was measured by a self-sufficiency ratio and the ability to produce minimum dietary needs. Economic access was measured by relating food expenditure to disposable income for low-income households. Calculations were performed for disruptions in the trade of different types of agricultural inputs (fuel, feed, fertilisers, pesticides and temporary labour) and in the imports of foods. Since Sweden is an elongated country with different climate conditions for the production of food, supply chains and food markets, calculations were made for the whole of Sweden and also separately for the country's northern and southern regions.

In the authors' view, the main contribution of this study to the literature is the systematic assessment of economic impacts and food security effects under different types of trade disruptions in agricultural inputs and foods. A further contribution is the use of a mathematical programming model of the agricultural sector that allows for producer and consumer adjustments to trade disruptions in the multimarket framework of the food sector. The study is organised as follows: "Conceptual framework" section describes the conceptual framework for estimating the economic impact and food security effects. The associated data retrieval and choice of crisis scenarios are described in "Data retrieval and scenarios" section. The results are presented in "Results" section and discussed in "Discussion" section, and the paper ends with a summary and conclusions in "Conclusion" section.

Conceptual framework

The ultimate aim of this study was to quantify the effects of trade disruptions on producers and consumers and on food security. Quantification of these impacts requires clear definitions of the concepts, which provide the basis for the subsequent data retrieval and understanding of the results. The conceptual analysis was based on microeconomic theory, which allows for the derivation of qualitative conclusions about the direction of the impacts of trade barriers on consumers and producers and on food security metrics.

Economic impacts on producers and consumers

The economic impacts for the producers and consumers of food were calculated as the differences in their economic welfare with and without the crisis, which is a common approach in economics for assessing the impacts of different types of disturbance on the agricultural sector [20, 26]. The economic welfare of the producers was calculated as producer surplus (PS), which shows the income from the sale of foods minus the production costs. Similarly, the welfare of the consumers was calculated as consumer surplus (CS), which is the consumers' valuation of the foods in excess of the purchasing cost.

For each producer $i=1,\dots,h$ in region $r=1,\dots,m$, income is determined by revenues from sales of food items, Q^{rfi}, where $f=1,\dots,n$ food items. The production of each food depends on the use of inputs, X^d, where $d=1,\dots,o$ inputs. Productivity differs between regions, for example due to climate conditions, such that $Q^{\mathrm{rfi}} = Q^{rf}(X^{1\mathrm{rfi}},\dots,X^{o\mathrm{rfi}})$. In addition, farmers in Sweden obtain incomes from different types of national and EU agricultural support, S^{riu}, where $u=1\dots,v$ types of support. The producer surplus for a region, PS^r, is then the sum of net incomes from all producers and foods, which is written as

$$\mathrm{PS}^r = \sum_f \sum_i (p^f Q^{\mathrm{rfi}} + \sum_u S^{\mathrm{riu}} - \sum_d \left(c^d X^{\mathrm{drfi}} + c^{\mathrm{dM}} X^{\mathrm{dMrfi}}\right) \quad (1)$$

where p^f is the unit sales price of the food, and c^d and c^{dM} are the unit costs of the domestic and imported inputs X^{drfi} and X^{dMrfi}, respectively. A reduction in imports of X^{dM} will increase the demand for domestic inputs, and hence raise the input price. The magnitude of the increase depends on the production technology and the availability of domestic inputs. This, in turn, raises the production cost and the output prices p^f, which reduces the demand for the foods. The magnitude of this depends on the changes in relative prices between the outputs and on price elasticities. The net effect for the producers then depends on the increase in p^f, which raises revenues, and the decrease in supply, which has the opposite effect [27].

Similarly, the total consumer surplus in a region, CS^r, includes the sum of utility of different food items minus the cost of purchases according to

$$\mathrm{CS}^r = \sum_f \left(U^f(Q^{\mathrm{rf}} + M^{\mathrm{rf}} - E^{\mathrm{rf}}) - p^f\left(Q^{\mathrm{rf}} - E^{\mathrm{rf}}\right) - p^{\mathrm{Mf}} M^{\mathrm{rf}}\right) \quad (2)$$

where $U^f(\cdot)$ is the utility of consuming available foods, which consists of domestic production, Q^{rf}, plus imports, M^{rf}, minus exports, E^{rf}. The unit price of imports, p^{Mf}, is likely to be higher than the domestic market price owing to transport costs. An increase in any output price will create a negative income effect since less food can be purchased at an unchanged income level [27]. The price increase and income effect give rise to adjustments in the food basket, with a decrease in the demand for the good, but an increase in the demand for a substitute good. For example, an increase in the price of pork reduces the demand for that food, but can increase the demand for chicken if it is a substitute.

In all scenarios, with and without trade disruptions, total welfare was calculated using a mathematical programming model of the agricultural sector, where the sum of producer and consumer surplus in all regions, i.e., $\sum_r \mathrm{PS}^r + \mathrm{CS}^r$, is maximised. Constraints are imposed on the maximisation, which includes the supply of farm-specific inputs, i.e., on X^{drfi} in Eq. (1), such as the maximum area of land and crop rotation requirements. Trade disruptions are introduced by constraints on the total supply of one or several imported inputs X^{dM} in Eq. (1) and on M^{rf} in Eq. (2), which are presented in Sect. 2.3.

The economic effects of a decrease in one or several X^d and/or M^{rf} were calculated as the difference in the maximum sum of PS and CS with and without trade disruption according to

$$\Delta PS = \sum_r \left(PS^r - PS^{r,ref}\right) > (<)0 \text{ and } \Delta CS = \sum_r \left(CS^r - CS^{r,ref}\right) < 0 \quad (3)$$

where the superscript *ref* denotes PS and CS without trade disturbance. While consumers' welfare always decreases from trade disturbances, the effect on producers is less clear. Decreases in inputs raise the producer cost and prices of foods, which in turn reduce demand. If the decrease in demand is sufficiently low, i.e., a low price elasticity, the producer surplus can increase compared with the reference case due to a higher sales price [27]. The producers always gain from trade disturbances in food imports since this implies an increase in demand and thus in prices of domestically produced food, but without raising the cost at given production levels.

Measuring food security

The concepts of food security and insecurity have been defined in various ways in the literature by different disciplines. A meta-analysis by [28] identified 52 different definitions. Sufficient food stocks to avoid temporary food shortages and famine were addressed in early studies, while economic access and physical food access were addressed in later studies [29]. There is a large body of literature on the measurement of food security in each of these categories, which is applied on the macro (global, regional, national) or micro scale (household, individual) [30].

The choice of metrics in this study was based on the availability of data obtained from the programming agricultural sector model and on commonly used metrics on national and regional scales in practice and in the literature [11, 29, 30]. The study then addressed two dimensions of the concept: availability and access. The availability dimension was measured by two indicators. One reflects the food self-sufficiency ratio (SSR) according to

$$SSR^r = \frac{\sum_f e^f \sum_i Q^{fri}}{\sum_f e^f \left(Q^{fr} + M^{fr} - E^{fr}\right)} \quad (4)$$

where e^f is the content of calories per unit of food item *f*. The numerator in Eq. (4) is the total production of calories in region *r*, and the denominator shows the consumption.

The second availability indicator is closely related to the SSR^r, but reflects a region's ability to meet minimum energy needs instead of actual energy needs. This is usually expressed in terms of minimum calories per day per person [31]. The denominator in Eq. (4) is then replaced by the total minimum calories consumed by the population, and the resulting expression measures the so-called dietary energy production (DEP^r), which is defined as

$$DEP^r = \frac{\sum_f e^f \sum_i Q^{fri}}{N^r * 365 * kcal^{Min}} \quad (5)$$

where N^r is the population size in region *r* and $kcal^{Min}$ is the minimum calorie intake per person per day.

The second dimension of food security reflects economic access by relating food expenditure to disposable income. This gives the average food expenditure (AFE^r). It originates from [32], who argued that the problem of food security is not food supply failure, but rather economic access to food. Food expenditure in relation to income for low-income households is widely used in the literature as an indicator of economic access [30], which is defined here as

$$AFE^r = 100 * \frac{\sum_f (p^f * Q^{lfr} + p^{Mf} M^{lfr})/H^r}{Y^r} \quad (6)$$

where Q^{lfr} and M^{lrf} are the purchases of domestic and imported foods by low-income households in region *r*, H^r is the number of low-income households, and *Y* is the disposable income per low-income household per year.

Similar to the calculations of changes in PS and CS, the impacts of trade disruptions on food security are calculated as the difference between the outcomes with and without the disruption, which are written as

$$\Delta SSR = \sum_r \left(SSR^{ref,r} - SSR^r\right) > (<)0 \quad (7)$$

$$\Delta DEP = \sum_r \left(DEP^{ref,r} - DEP^r\right) > (<)0 \quad (8)$$

$$\Delta AFE = \sum_r \left(AFE^{ref,r} - AFE^r\right) > (<)0 \quad (9)$$

The sign of the change cannot be determined for any food metric without empirical support. The sign of ΔSSR and ΔDEP depends on the strength of two counteracting forces: a decrease in the production of calories because of higher production costs and a decrease in the consumption of calories from reduced consumption owing to higher food prices. Similarly, the sign of ΔAFE is determined by the higher food prices (which increase expenditure) and lower food demand (which reduces expenditure).

Data retrieval and scenarios

Study area

Sweden is an elongated country in northern Europe covering a total area of approximately 41 million ha, with 6.4% of its land area used for agriculture [33]. Several rivers cross the land territory from its border with Norway in the west to the coast of the Baltic Sea. As the country is divided by rivers, bridges for crossing these rivers are essential for transport between northern and southern Sweden, which have quite different conditions regarding population (and thus demand for food), agricultural land, and the location of their food processing industries (see maps in Additional file 1: Figs. S1 and S2). Therefore, Sweden is divided into two main regions in this study: North and South. The division is presented in Additional file 1: Fig. S2.

Data retrieval

The exogenous variables presented in the conceptual framework include the choice of minimum dietary need ($kcal^{Min}$), calories per food unit (e^f), population (N^r), the number of low-income households (H^r) and disposable income (Y^r). The minimum dietary need is based on the recommendations of the Swedish Food Agency [34], which reports the minimum amounts of calories per person per day depending on age and gender for three dietary levels: low, middle and high. The middle dietary need is chosen as a constraint, and the total minimum calories are calculated based on the population demographics in 2021 [35]. This gives a minimum requirement of 2200 kcal per person per day on average, which can be compared with actual consumption of 3100 kcal per person per day in 2021. Data on e^f were obtained from the Swedish Food Agency [36].

Low-income households are defined as households that have an income below 60% of the median disposable income, which is a common measurement of relatively low economic standards in many countries [37]. In Sweden, the median disposable income per household per year differs between the two regions. The risk of poverty is at income levels below 22,200 euros and 30,900 euros in the North and South, respectively (Table 6 in Appendix). The incomes of approximately 15% of households are below these levels in each region. Food expenditure in the reference case was obtained from household budget surveys [38], according to which the average food expenditure accounts for 12.6% of the average disposable income. However, there are no data on expenditure shares at different income levels. Therefore, a meta-analysis of the elasticities of food demand with respect to disposable income was used, which shows an average elasticity of 0.5 for EU countries [39]. Food expenditure was then calculated based on average and low disposable incomes in each region (Table 6 in Appendix).

Endogenous variables were solved by maximising total producer and consumer surplus with the Swedish partial equilibrium model of several food markets, the Swedish agricultural sector model (SASM) [25]. The model identifies 95 different local regions in the country, with homogenous conditions regarding climate conditions (Additional file 1: Fig. S1). Each local region is represented as a large farm, with a maximum of 46 outputs and 41 production factors for conventional and ecological farms (Additional file 1: Table S1). The 95 local regions interact with each other and with consumers in six different market regions (Additional file 1: Fig. S2). The dairies and slaughterhouses are located in these market regions. Depending on the relationship between demand and supply, trade occurs between market regions and internationally. The six market regions are aggregated at a national level for trade in inputs, such as fertilisers and fuel.

SASM includes nine different EU and national support payments: income support, competence-enhancing support, regional compensation (particularly in northern Sweden), payment for cattle, ecological farming, grassland, animal welfare, catch crops and investment support for stable buildings. All supports and payments are associated with different types of conditions, which are considered in the model [40]. An implicit assumption in the study is that the Common Agricultural Policy and associated EU payments remain intact in the presence of a crisis affecting Sweden.

In total, the SASM model includes approximately 15,000 variables that consist of inputs and outputs of production by each farm, supplies to the processing industry in each market region, trade between market regions, consumption of foods in each market region, and exports and imports of inputs and foods. The data sources are presented in Additional file 1. The model is solved using the general algebraic modelling system (GAMS) code with the Conopt solver [41]. Data are available upon request.

Given the data on exogenous variables (Table 6 in Appendix) and the calculations of the producer and consumer surplus in the SASM model, the producer and consumer surplus and food security metrics in the reference case without any trade disturbances are as presented in Table 1.

The calculated total producer surplus of 1.08 billion euros is lower than the commonly used measurements of value added from the Economic Accounts for Agriculture (EAA), which ranged between 1.79 and 1.86 billion euros from 2019 to 2021 [42]. However, the EAA estimates do not include the costs of equity, land, existing buildings

Table 1 Producer and consumer surplus in billion euros and food security metrics in the reference case

Region	Producer and consumers surplus, billion euros[a]:			Food security metrics[b]:		
	PS^{ref}	CS^{ref}	Total	SSR^{ref}	DEP^{ref}	AFE^{ref}
Total Sweden	1.08	36.21	37.29	0.81	1.14	19.10
Regional division:						
North region	0.11	5.43	5.54	0.05	0.07	23.37
South region	0.97	30.78	31.75	0.96	1.34	18.57

[a] Calculations by the agriculture programming sector model SASM

[b] Table 6 in Appendix

or family labour. The estimates in SASM can then be compared with the EAA accounts by adding the cost of labour to the producer surplus in SASM, and the costs of employed labour, depreciation on buildings, rents and interests to the EAA calculation. The new measurement shows the total compensation for land, existing buildings and labour in agriculture, which amounts to 1.64 billion euros according to SASM and 1.80 billion euros according to the EAA calculation. Horticulture is included in the EAA calculation, but not in SASM. The total consumer surplus is of the same order of magnitude as the total expenditure on food (Table 6 in Appendix).

However, PS, CS and the production and consumption of calories are unevenly distributed between the North and South regions. This is mainly explained by the differences in population sizes and land use. Approximately 15% of the total Swedish population of 10 million people live in the North, with the remainder in the South, 12% of agricultural land is located there, and its processing industry is very small [35, 43]. Furthermore, the competitive disadvantage is compounded by the fact that crop yields for the major crops are substantially lower compared with the aggregate for Sweden. Forage and barley yields are approximately 20% and 40% lower in the North. The large difference in the SSR and DEP food security metrics between the regions may seem unexpected, but it is due to the large concentration of processing firms in the South. The AFE is higher in the North than in the South, which reflects the differences in median incomes. Both levels are far below the share of 0.5, which is regarded as a threshold for food insecurity with respect to economic access [44].

Trade barrier scenarios

The scenarios of disruptions to international trade were obtained from the literature with a focus on Sweden. Scenarios in the relatively early studies came from experiences during the Second World War [45, 46]. Sweden shares its experience of import constraints during the war with several other countries. The German occupation of Denmark and Norway in 1940, the British blockade of shipping traffic, and German mines in Skagerack led to the cessation of all imports and exports for a few months [47]. Swedish imports of food, crude oil, fuel and fertilisers fell by approximately 50% during the Second World War.

Both [45, 46] considered isolation with constrained imports of food by Sweden for a relatively long period of three years. Later studies, which mainly applied to developing countries, examined the impacts of different types of threats to food security, such as fluctuating prices in international trade, environmental disasters, transportation disturbances and pandemics, with different regional applications [14, 15, 48]. In general, the scenarios for trade blockades emerged from geopolitical considerations [45, 46, 49]. This was also highlighted by the Swedish Ministry of Defence [50] as a likely scenario due to geopolitical changes in the Baltic Sea region in the 2010s.

Similar to the two studies that applied to Sweden, the present study considered scenarios with trade blockades of different agricultural inputs and outputs. Regarding inputs, the main imports are fuel, fertilisers, pesticides, feed and labour. No fertilisers or pesticides are manufactured in Sweden, but there is some production of biofuel. Imports of feed consist mainly of soya protein, which accounts for approximately 40% of the value of the feed [42], and foreign labour is employed for short periods of high demand, e.g., harvest of crops. With respect to food consumption, approximately half of all food is imported [9]. The imports consist mainly of meat, dairy products, fruit and vegetables. Grain is the major export product.

With respect to the magnitude of the barriers to trade, this study considered relatively large impacts in which the imports of inputs and outputs are reduced by 50%, as experienced during World War II and analysed by [49]. It can be argued that the restrictions on trade are likely to affect imports of all inputs to the primary sector and food consumption goods. Therefore, a third type of scenario considers constraints in all international trade. All the scenarios are summarised in Table 2.

In total, there were eight different scenarios, six of which are trade decreases in single or all agricultural inputs. A basic assumption for all scenarios is the existence of sufficient time for adjustments by producers and consumers to these disruptions with the given production technologies, which implies a time perspective of one to three years. It should be noted that this may not coincide with the duration of the crisis since adjustments can take place long after the crisis ends.

Results

Total effects

As expected from the conceptual analysis in "Conceptual framework" section, consumers' welfare always decreases from trade disruptions, but that of producers can increase in some scenarios (Table 3).

The producers face the largest decrease in producer surplus in Scenario A.6 with simultaneous reductions in all inputs, which implies a decrease of 75% from the reference case. Given a separate decrease in one input, the reduction in producer surplus is greatest in the scenario with a fall in fuel imports. However, there is a slight increase in producer surplus with a decrease in imports of foreign labour. The reason is a relatively low cost increase because of the small share of foreign labour in the agricultural sector, which is more than compensated for by the increase in the price of foods due to the reduced supply.

According to the results of the conceptual analysis in "Conceptual framework" section, the producers gain from decreases in imports of food in Scenario B owing to the substitution of food demand from imports with domestic production. The producer surplus then increases by approximately 60%. Consumers face the largest welfare losses in Scenario C, with simultaneous decreases in all inputs and imports of foods because of the combined price impacts of increases in production costs and reduced supply from imports. The loss corresponds to 21% of the consumer surplus compared with the reference case.

The effects of trade barriers on food security metrics differ. Both the metrics that reflect availability, ΔSSR and ΔDEP, show relatively large differences between the trade scenarios. The decrease is largest for both metrics under scenario A.6, and corresponds to a reduction of 55% and 61% in SSR^{ref} and DEP^{ref}, respectively. The slight

Table 2 Summary of different scenarios of trade disruptions to agricultural inputs and consumption foods

Scenario	Description
A Agricultural input[a]	Separate and simultaneous 50% reduction in the import of fertilisers, pesticides, fuel and feed and in the supply of foreign labour
B Consumption[b]	50% reduction in imports of foods for consumption
C. Combination of A (all inputs) and B[b]	Simultaneous 50% reduction in trade in all inputs and foods for consumption

[a] [42, 49]; [b][49]

Table 3 Changes in producer surplus (ΔPS), consumer surplus (ΔCS) and food security metrics from the reference case under different scenarios with 50% import reductions

Scenario	Impacts on producers and consumers (billions of euros)			Food security		
	ΔPS	ΔCS	ΔTotal	ΔSSR	ΔDEP	ΔAFE
A. Agricultural inputs:						
1. Fertilisers	−0.26	−0.24	−0.50	−0.42	−0.60	0.12
2. Pesticides	−0.10	−0.04	−0.14	−0.23	−0.32	0.02
3. Fuel	−0.60	−0.31	−0.91	−0.38	−0.54	0.16
4. Feed	−0.15	−0.05	−0.20	0.12	0.17	0.02
5. Foreign labour	0.04	−0.02	0.02	−0.01	−0.02	0.01
6. Reduction in all inputs	−0.76	−4.23	−4.99	−0.45	−0.70	1.88
B. Consumption	0.59	−1.84	−1.25	−0.07	−0.15	0.92
C. A.6 and B	−0.41	−7.51	−7.92	−0.06	−0.39	2.30

increase in these metrics in scenario A.4 is explained by the substitution of imported soya feed with domestic cereals. Minimum dietary needs (DEP) are ensured by domestic production in Scenarios A.4 and A.5 only, and are below unity in all other scenarios, which can be seen by adding the changes in Table 3 to the reference level of 1.14 in Table 1. The AEF increases in all scenarios, which implies that economic access for low-income households decreases in all scenarios.

Regional effects

The effects of separate trade barriers for each input under Scenario A are relatively small, and regional effects on producer and consumer surplus and food security metrics are therefore presented for the A.6 and C scenarios. The impacts on producers and consumers differ between the two regions (Table 4).

According to the results shown in Table 4, the greatest effects on producers in the North occur in Scenario C, and on those in the South in Scenario A.6. The PS decreases by 73% in the North in Scenario C and by 72% in the South in Scenario A.6 compared with the respective reference cases. The smaller decrease in producer surplus in scenario C compared with Scenario A.6 in the South is explained by the gains from increases in domestic demand owing to the disruptions in food imports. Although the magnitude of decreases in consumer surplus differs between the regions, the change relative to the consumer surplus in the reference case is similar, with a decrease of approximately 6% in Scenario A.6 and a decrease of 20% and 21% in Scenario C in the North and South, respectively.

The availability metrics SSR and DEP are reduced by more than two thirds compared with the reference case under scenario A.6 for both regions, but are improved in the North in Scenario C (Table 5).

The SSR decreases by 80% and 53% compared with the reference case in the North and South regions, respectively. The availability metrics SSR and DEP are improved under Scenario C for the North, but are still lower than the reference case in the South. Similar to the national results, there are minor differences in the AFE metrics reflecting economic access, which deteriorate in both regions compared with the reference case owing to the relatively large increases in food prices.

Discussion

The main qualitative results of this study from the conceptual analysis were as expected. While consumer surplus always decreases from trade disruption, the net effect on producers depends on the relative magnitude of two counteracting forces: an increase in production cost and an increase in sales price. Similarly, the effects on the included food security metrics were all indeterminate, and depended on the adjustments made by producers and consumers to the trade disruptions. The application to Sweden of a 50% decrease in the import of inputs showed that the reductions in producer surplus and food security, as measured by the availability metrics, were largest for disruptions in the trade of fuel and fertilisers, but could improve with trade disruptions in feed.

It is somewhat difficult to compare the numerical results with other studies since similar calculations

Table 4 Changes in producer and consumer surplus in northern and southern Sweden under different scenarios with 50% import reductions (billions of euros)

Scenario	North Sweden			South Sweden		
	ΔPS	ΔCS	ΔTotal	ΔPS	ΔCS	ΔTotal
A.6 all inputs	−0.06	−0.63	−0.69	−0.70	−3.60	−4.30
C. A.6 and B	−0.08	−1.12	−1.20	−0.33	−6.39	−6.72

Table 5 Food security metrics in the North and South regions under different trade disturbance scenarios

Scenario	North Sweden			South Sweden		
	ΔSSR	ΔDEP	ΔAFE	ΔSSR	ΔDEP	ΔAFE
A.6 (all inputs)	−0.04	−0.05	2.30	−0.51	−0.80	1.79
C. A.6 and B	0.05	0.04	2.81	−0.07	−0.46	2.20

have not been undertaken. Some partial comparisons can be made regarding the decrease in the food security metrics reflecting availability. It is generally considered that high import dependency contributes to food insecurity [16, 17, 51]. This is supported by the results in the present study of large decreases in these security metrics for fuel and fertilisers with import shares of unity. However, despite the relatively high import share of feed (approximately 40%), food security improved from disruptions in imports owing to the substitution of soya protein with domestic forage crops.

The numerical results are based on a number of assumptions regarding the choice of method to calculate costs, parameterisation of supply and demand functions, capacity constraints in agriculture and the processing industry, and the magnitude of trade disturbance. The sensitivity of the assumptions concerning the construction of the SASM model has been discussed in [25]. Specific to the present study are the choice and magnitude of the imposed trade decreases in agricultural inputs and foods by 50%. A decrease in the magnitude of the disruption from 50% to 40% in Scenario C reduces the losses for consumers by 40%, but increases the losses for producers by 11% owing to the consumers' substitution of domestically produced food with imports. This, in turn, reduces the availability dimension of food security, as measured by the indices SSR and DEP, but improves economic access.

Partial agricultural programming models allow for interaction between producers and consumers in the food sector, but not with actors in other sectors. The magnitude of the costs for producers and consumers of the dispersal effects on the rest of the economy depends on the size of the food sector in the economy and the adjustments made to food trade disturbances in the entire economy [52, 53]. The agriculture and food processing industry in Sweden accounted for approximately 2% of GDP in 2021 [54], and the dispersal effects of trade disturbances on the rest of the economy may therefore be relatively small. Nevertheless, disruptions will reduce welfare for consumers, and have indeterminate effects on producers depending on their ability to pass on cost increases to consumers.

A basic assumption in agricultural sector models is that limited agricultural resources are allocated to their best uses in competitive markets [25]. However, if other allocation mechanisms were in place, such as imperfect markets in the value chain, the total cost would be higher [55]. The Swedish Competition Authority [56] has raised concerns about inadequate competition in the food industry, which is highly concentrated among a few companies. The use of the agricultural sector model can provide information about a lower limit to the cost of different trade disruptions. However, the static design of the agricultural sector model in the present study excludes, by definition, the dynamic impacts of the barriers and responses to them. The positive effects on producer surplus in the food sectors in the scenarios with barriers to trade of feed and foods may promote capital formation and enhance growth in the sector [57, 58].

Conclusions

The main findings of the conceptual analyses were that consumer surplus always decreases, irrespective of the type of trade disruption, but the impacts on producer surplus and food security are less clear. The results from the application to Sweden of a 50% decrease in the imports of different agricultural inputs and/or consumption foods showed that consumers are mainly affected by simultaneous disruptions in the import of agricultural inputs and foods, with a reduction in consumer surplus of at most 21%. Simultaneous disruptions in all inputs had the largest negative effects on producer surplus, with a 75% reduction. However, disruptions to food imports raised the producer surplus because of the increase in demand for domestically produced food.

The food security metrics reflecting availability fell drastically in the face of disruptions in fuel and fertilisers, but improved for feed owing to the substitution of soya feed with domestic forage crops. The economic access metric always showed a decrease in food security, with a maximum decrease of 10% compared with the reference case. Another finding was the unequal regional division of food security in particular. Whereas the production of food was close to or above the actual and minimum consumption of calories in the South, production was far below these levels in the North. Furthermore, economic access was lower in the North, where households spend a larger share of their disposable income on food. These regional differences were aggravated by trade disruptions.

The different economic impact and food security effects depending on the type of trade disruption highlight the need to assess these effects when deciding whether and how to prepare to mitigate the effects of different trade disruptions. The results of this study showed the importance of agricultural sector modelling, which accounts for producer and consumer responses in the food markets to the trade disturbances. This was manifested by the increases in producer surplus from trade disruptions in feed and foreign labour. Another example is that disruptions in the trade of feed, a seemingly vulnerable input with a large import share, improved food security in the availability dimension owing to the increased use of domestic forage crops.

However, the exact figures on the effects should be considered with caution owing to the different assumptions underlying the calculations with the agricultural sector model, as pointed out in "Discussion" section. There has been an ongoing development of mathematical programming for partial equilibrium models as a policy tool since its introduction in the 1950s [59]. The specific feature of the model used in the present study compared with other national sector models is the spatial resolution of trade between different regions in Sweden, which allowed for the assessment of regional differences in impacts. A relatively recent development is the meta-modelling approach, in which an agricultural sector model is combined with a general equilibrium approach to assess dispersal effects throughout the economy [19, 26]. Further improvements involve the consideration of uncertainty in production and consumption.

Nevertheless, the agricultural sector model simulations can offer guidance on whether and how to prevent and mitigate the impacts of trade disruptions. They provide indicative information about the negative effects on producers and consumers and the impact on food security, which can be mitigated by a number of different policies, such as compensation payments to households, the creation of storage reserves, enhanced food production and price regulations. The magnitude of the compensation payment to consumers can be obtained if there is an interest in mitigating the negative income distribution effects, as with the payments made in many countries owing to the high energy prices associated with the Russian military intervention in Ukraine in 2022. Similarly, the model can be used to assess the economic and food security effects of different mitigation measures, such as price regulations on crucial foods.

The World Bank [60] has shown that the cost of storage reserves for essential inputs and outputs in developing countries can correspond to 1.9% of their gross domestic product. In Sweden, [45, 46] have concluded that the cost of storage reserves in Sweden is relatively low for agricultural inputs in the short term, but sufficient capacity for livestock farming is cost-efficient in the long run. Rosenius [61] estimates that if there is a crisis, current food stocks in Sweden will be sufficient for 1 week. The quantitative results in this study highlight the need to consider the large differences in food security and economic impacts of trade disruptions in northern and southern Sweden. Calculations of the economic impact and food security effects using a mathematical programming model of the agricultural sector, as in this study, can then be useful when designing the cost-efficient allocation of storage reserves and production preparedness in agriculture to achieve food security targets in different regions.

Appendix

See Table 6.

Table 6 Population, households, disposable income, food expenditure and energy production and consumption in the reference case

Region	Population ('000)[a]	Households ('000)[a]	Low disposable income (euros/household)[b]	Food expenditure (euros/household)[c]	Energy Tcal[d], prod.	cons
Total Sweden	10,452	4831	29,612	5658	9557	11,834
North region	1476	723	22,213	5191	87	1799
South region	8976	4108	30,914	5740	9644	10,035

[a] Swedish Statistics [37]

[b] 60% of the median income of 37,022 euros and 51,524 euros in the North and South, respectively, and 49,721 euros for the whole of Sweden [15]

[c] Only national data, with 12.6% of average disposable income of 60,188 euros on food, giving 7,584 euros for the average household for the whole of Sweden [47]. Calculations of expenditure for each region, Exp^r, are based on the elasticity of food demand with respect to income of 0.5 as an average for the European Union [45], and calculated as $Exp^r = 7584*(1 + 0.5*((Y^{rl} - Y)/Y)$, where $Y = 60{,}188$ and Y^{rl} is low income levels in the table

[d] Calculations based on SASM, which is calibrated to actual 2021 levels

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40066-024-00483-3.

Additional file 1: Fig. S1. Sub-regions and classifications into production and public support regions in SASM. **Fig. S2.** Regional division of the regions in the present study, the SASM model, and counties in Sweden. **Table S1.** Outputs and production factors at the farm level (95 representative farms) in the SASM.

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Author contributions
IMG participated in the conceptualisation, writing of the original draft and formal analysis. HA participated in the conceptualisation, writing review and editing. LJ was responsible for data curation, software, writing review and editing. RK undertook project administration, participated in the conceptualisation, and in writing, reviewing and editing. All the authors read and approved the final manuscript.

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Availability of data and materials
Data are available upon request from the corresponding author.

Declarations

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Not applicable.

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The authors declare no competing interests.

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