Policy-Induced Expansion of Organic Farmland: Implications for Food Prices and Welfare

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Abstract

Public policies increasingly support the expansion of organic agriculture as part of a menu of food and environmental initiatives. A little-studied yet crucial element of such expansion, especially in light of scientific evidence on lower yields of organic crops, is its impact on overall food production and food prices, especially for poorer households. In this paper, we first establish a positive empirical relationship between countries' propensity to produce and consume organic foods and their per capita income. Such correlation suggests that, even if rich countries' consumers can benefit from an increase in the organic farmland share, poor countries' consumers would likely face higher conventional food prices. We then develop and calibrate a model of world food demand and supply to assess the implications of a policy-driven expansion in organic farmland. Our results for four major grains and oilseeds show that raising the organic cropland share in rich countries from 3% to 15% will increase food prices in poor countries by up to 2.7%, with a central value of about 1.2% and a commensurate reduction in consumer welfare. Model parameterizations indicate that farmers in poor countries would benefit from higher food prices, as would, in some instances, consumers in rich countries. In all cases, poor countries' consumers bear most of the distortion burden. In our preferred parameterization, a 3% increase in cropland in rich countries would offset the food price increase in poor countries.

JEL Codes: Q11, Q13, Q18

Keywords: organic food, credence attribute, consumer welfare, food prices

1 Introduction

Foods certified as organic must comply with production standards intended to yield better environmental and human-health outcomes and make agriculture more sustainable relative to conventional production (Seufert and Ramankutty, 2017; Meemken and Qaim, 2018). Public policies in many countries support expanded production of organic foods in pursuit of these goals. Key examples are the European Commission's goal of a 25% organic farmland share by 2030 (European Commission, 2021) as part of its Farm-to-Fork (F2F) strategy,[1] Japan's goal of tripling organic production and number of organic farmers by 2030 under its Basic Plan for Agricultural Production and Management (Japanese Ministry of Agriculture, Forestry, and Fisheries, 2020), or the United States Department of Agriculture's new Organic Transition Initiative intended to reverse the declining trend of farms transitioning to organic and increase organic food production in the United States (United States Department of Agriculture, 2022).

The production characteristics associated with organic foods represent "credence-attributes" that cannot be discerned by consumers either through search or consumption (Darby and Karni, 1973; Emons, 2001). Organic foods are also associated with yield decrements, in the range of 20% or more relative to their conventional counterparts (de Ponti, Rijk, and van Ittersum, 2012; Ponisio et al., 2015; Seufert and Ramankutty, 2017), making it essential for organic producers to have access to credible signalling schemes when marketing their generally costlier products.

Public policies often support production of other credence-attribute products associated with yield decrements or cost increments, e.g., bans by some European and African countries on the production of bioengineered products and production restrictions related to animal welfare in several Northern European countries. Private policies enacted by supply-chain intermediaries have also contributed to expanding the share of credence-attribute products in food markets (Henson and Humphrey, 2010; Saitone, Sexton, and Sumner, 2015).[2]

As production of foods embodying organic and other credence claims has expanded, so too has economic research into various questions regarding them. Much of this work has focused on demand-side issues including consumer acceptance of and motivations to purchase such products (Goddard et al., 2013), consumer confidence in the veracity of credence claims (Janssen and Hamm, 2012; Lassoued and Hobbs, 2015), determinants of consumer willingness to pay (WTP) for foods embodying credence claims (Lagerkvist and Hess, 2011; Katt and Meixner, 2020), and the divergence between consumers' stated WTP for credence-attribute foods and their actual shares in the market

[1] The European Union supports organic farming through subsidies under the second pillar of the Common Agricultural Policy (CAP) as a means to achieving this goal. Under the CAP, member states must include subsidies for organic farming, including conversion or support payments (European Parliament, 2022).

[2] Adoption of such production standards by market intermediaries may be motivated by factors not directly related to consumer demand such as corporate image or interest-group pressure (Baron, 2011; Saitone, Sexton, and Sumner, 2015).

place (Lusk, 2018). The literature review by Katt and Meixner (2020) lists 138 journal papers published from 1999–2019 on consumer WTP for organic foods alone.

Other work has studied the mechanisms for certification of credence attributes (Sheldon, 2017) and appropriate labeling schemes (Roe and Sheldon, 2007; Bonroy and Constantatos, 2008). Certification and labeling have been generally understood to create vertical product differentiation within a supply chain, which carries the potential to affect price competition among sellers (Shaked and Sutton, 1982), with attendant implications for economic welfare (Roe and Sheldon, 2007; Bonroy and Constantatos, 2008; Bonroy and Constantos, 2015).

Although many studies have investigated the yield and cost impacts of organic and other credence-attribute production relative to the conventional alternative, little has been done to translate these effects into their impacts on the supply side of markets and overall food production and prices, despite calls to do so (Meemken and Qaim, 2018). Yet these impacts are of great practical importance amidst policy-driven expansion of such production. The salience of these questions is heightened by projections of rapidly growing food demand due to rising world population and income convergence between rich and poor countries (Gouel and Guimbard, 2019; Fukase and Martin, 2020) and by challenges to expansion of food supplies due to climate change (Challinor et al., 2014), pest resistance to traditional treatments (Gould, Brown, and Kuzma, 2018), and a slowdown of agricultural productivity growth (Pardey and Alston, 2021).

The goal of the present paper is to address this void through analysis of the implications of policy-driven expansion of the organic farmland share for organic, conventional, and overall food prices and the distribution of economic welfare within and across rich and poor countries. The prior work most closely related to ours has focused on the price and production impacts of the European Union's F2F strategy, a central component of the European Green Deal that proposes substantial reductions in the inputs utilized in agricultural production, including pesticides, fertilizers, and land. According to this work, the F2F strategy will result in significant production declines and price increases within the EU for most food categories (Beckman et al., 2020; Barreiro-Hurle et al., 2021; Beckman, Ivanic, and Jelliffe, 2022), with specific results depending on trade patterns and whether other countries adopt policies similar to F2F. Food insecurity is also projected to increase, especially within low- and middle-income countries (Baquedano et al., 2022). Wesseler (2022) provides a useful summary of this work.[3]

Our work differs from these prior studies in its focus on price and distributional impacts of policy-induced expansion of organic production worldwide, and its development of a distinctive modeling approach relative to more traditional computable general equilibrium models. The foun-

[3]The F2F strategy includes other policy goals intended to counterbalance the lower food production associated with reducing agricultural input use. Such strategies include expanded investment in agricultural technology, reduced food waste, and dietary changes to de-emphasize consumption of animal products (Barreiro-Hurle et al., 2021; Wesseler, 2022).

dations of our analysis are two key facts regarding organic production that are shared with many other credence-attribute foods: (i) they are more costly to produce and market per unit output than the conventional alternative, yet consumers typically view them as different goods, hence their presence in the market; and (ii) they are consumed mainly by wealthier consumers and within wealthier countries.

In what follows, we provide evidence regarding these foundations, first recounting the literature on yield and productivity decrements associated with organic production relative to the conventional alternative and then providing econometric evidence to support the proposition that organic foods are produced and consumed mainly within wealthier countries. We then set forth a prototype model of regional food production and consumption with international trade in crops to assess the potential consequences of policy-driven expansion in organic cropland on food prices and economic welfare in rich and poor countries. We approximate world production, consumption, and trade of four major grains and oilseeds (rice, wheat, corn, and soybeans) that comprise two-thirds of world calorie consumption.

Importantly, our inference does not rely on assumptions regarding conventional and organic yields, which vary across crops and would need to be complemented by information about consumers' preferences for organic vs. conventional foods to permit proper welfare comparisons.[4] Instead, we study utility generated per unit of resource use for conventional and organic foods. We develop an equilibrium model architecture for which observable land, cost, production, trade, and expenditure shares, together with a small number of key elasticities, are shown to be sufficient for welfare counterfactuals. Thus, although our empirical question is partially motivated by the yield gap between organic and conventional crops, our modelling approach does not directly rely on estimates of such gap; nor does it rely on estimates of willingness to pay for organic foods, which is often context-specific and may overstate actual behavior (Lusk, 2018).

The current organic land share in rich countries, as defined for purposes of this paper,[5] is about 3%. The organic share in some rich countries is considerably higher—for example, it was estimated to be 9.1% in the EU in 2020 (Eurostat, 2022). Our results show that a five-fold increase in the organic cropland share of the four crops under consideration in rich countries, an expansion consistent with some of these countries' stated policy goals, would result in higher overall food prices, primarily in poor countries which consume mainly the conventional variant. There, the overall food price rises by up to 2.7% depending on model parameterizations, with a central value of about 1.2%. The price of food may rise in rich countries too, but to a much lesser extent, given the higher expenditure share on organic food in these countries. For some model parameterizations,

[4] We do use an estimate of the yield gap to recover a missing trade flow for organic crops, but we do not rely on it to calibrate the production technology itself.

[5] Rich countries in our model include EU countries and others such as the US, Canada, and Japan. See Section 4.8 for a full discussion.

the overall food price even declines in rich countries, highlighting the generally regressive nature of the organic farmland expansion across consumer types. Land rents are predicted to increase in aggregate, with gains concentrated in poor countries.

Finally, we show that the agricultural land base in these four crops would need to expand by about 0.8–6.8% in rich countries, with most estimates around 3%, to offset the higher food price in poor countries, given the simulated expansion of the organic cropland share. Extensification of agriculture, however, is well understood to contribute to biodiversity loss and climate change (Foley et al., 2011), even though policies to expand organic production are based in large part upon beliefs that organic production improves environmental outcomes including reducing pollution and lowering carbon emissions. In this context, our paper illuminates important tradeoffs between environmental stewardship, food security, and greenhouse gas emissions from land use change.

2 Yield and productivity decrements of organic production relative to the conventional alternative

Most farmers operate as perfect competitors and are driven to adopt the most efficient production practices in order to survive in the long run. Thus, diverging from conventional farming practices in order to produce the organic variant or other credence-attribute products must increase production costs per unit of output and/or reduce yields from a given land base. If it did not, and instead led to cost savings, such practices would be widely adopted, even without a credible way to inform consumers about them.

The scientific evidence to support this proposition is vast. Cost and yield differences for an organic product relative to its conventional alternative have been studied extensively. Meta studies have established this gap to be in the range of 19–25% (de Ponti, Rijk, and van Ittersum, 2012; Ponisio et al., 2015; Seufert and Ramankutty, 2017), with the gap tending to be lower for forage crops and legumes and higher for cereals and tubers (Kniss, Savage, and Jabbour, 2016a,b; Seufert and Ramankutty, 2017).[6] The organic-conventional yield gap has been studied most extensively with experimental plots, and the available evidence suggests that the commercial yield gap is even wider (Kniss, Savage, and Jabbour, 2016a,b; Kravchenko, Snapp, and Robertson, 2017; Kirchmann, 2019). For example, with correction, Kniss, Savage, and Jabbour (2016a,b) find that organic yields averaged across crops in the US are 67% of conventional yields. A similar commercial yield gap is reported by Kirchmann (2019) for Sweden. Barreiro-Hurle et al. (2021, table 13) report yield gaps

[6]The yield gap between genetically modified (GM) crops and non-GM crops is similar. A meta-study by Klümper and Qaim (2014) involving hundreds of observations found an average 21% yield decrement for the non-GM crop, with the yield impact being greatest in developing countries. Areal, Riesgo, and Rodriguez-Cerezo (2013) found similar results in a meta-study focusing specifically on Bt cotton and maize and herbicide-tolerant soybean.

in this range or higher for cereals, oilseeds, vegetables, wheat, and fruit in Central and Northern Europe. The reported gaps are lower in Southern Europe and for maize and non-fruit permanent crops.

The larger yield gap for commercial organic operations is due in part to crop-rotation issues that are generally ignored in crop-by-crop organic vs. conventional comparisons. For example, rotation on an organic operation may include production of non-harvested "green manures" or inclusion of low-yielding legume crops in the rotation for biological nitrogen fixation (Kirchmann, 2019).

Looking ahead, the yield decrement may change with increasing shares of production in the organic variant. The yield gap may widen because the most efficient converters from conventional to organic will be the first converters, so policy-driven expansions in the organic share of production will require incentivizing farms to make the transition that are less efficient at doing so. In crop production, for example, the most efficient and, hence, first converters to organic production are operations less prone to pest pressures and with fertile soils that can be productive without application of chemical fertilizers. A second factor supporting a yield decrement that increases in the organic land share is that critical inputs into organic farming such as organic manures may become limiting (de Ponti, Rijk, and van Ittersum, 2012). Arguments that the yield gap may decline over time are based on the potential for soil-restoration practices required for organic production to improve yields of organic lands over time (Schrama et al., 2018) and for "learning by doing" and improved organic seed varieties and other organic technologies that emerge as the organic market share expands (Ponisio et al., 2015).

2.1 Impacts of credence-attribute products on the costs of food marketing

Although impacts of credence-attribute production on supply-chain costs downstream from the farm are often ignored, processing and marketing costs are generally higher than for the conventional alternative because credence attributes create product differentiation at the farm level, which must be preserved throughout the supply chain. Although farm products produced through conventional means are differentiated in terms of physical characteristics such as sweetness or brix in fruits, protein content in grains, and fat content in animal products, the products are typically commingled in processing and handling, and mixing of heterogeneous products is often desirable to achieve specific final-product characteristics. Credence-attribute products such as organic must, however, have their identity preserved throughout the supply chain in order to be labeled and sold to consumers as distinct products.

Because market intermediaries will typically handle both the credence-attribute product and its conventional counterpart, incremental costs associated with handling the credence good will be due to product segregation, inefficiencies associated with transitioning between processing conventional and credence-attribute product, compliance testing, and traceability (Saitone, Sexton, and Sumner, 2015; Matthews and Sumner, 2015). Costs in credence-good supply chains are also higher due to the need for suppliers to attain certification and labeling of the presence of the credence-good attribute throughout the supply chain in a way that is credible to consumers and can be documented in the event of litigation.

Information on incremental food-marketing costs associated with credence goods is understandably more limited than is the cost and yield information for farm production. The best information to date pertains to incremental processing costs for animal products with credence attributes. Lee, Sexton, and Sumner (2021) estimated such costs to be about 8% more than for conventional products to preserve identity throughout the supply chain of hogs compliant with California's housing standards for breeding sows. Similar segregation and identity-preservation requirements through the supply chain apply as well to other credence-attribute products, so we might anticipate incremental processing and marketing costs of the same order of magnitude as found by Lee, Sexton, and Sumner (2021) to apply in these cases as well.

3 Consumer income and organic food production and consumption

Most studies of consumer WTP for credence goods have relied upon surveys or experiments instead of actual purchase behaviors and are subject to the limitations of such methodologies (Breidert, Hahsler, and Reutterer, 2006). With few exceptions, these studies show that consumer income is a positive determinant of WTP for these products. This outcome is documented for organic foods in the U.S. in studies by Dimitri and Dettmann (2012) and McFadden and Huffman (2017).[7] The meta study by Lagerkvist and Hess (2011) establishes the same point for animal-welfare attributes.

Given the paucity of published research on the link between organic food production and consumption and income, we conduct our own analyses at the global scale. First, we examine the share of agricultural land in organic production by country. Land in organic production is an imperfect proxy for consumption due to trade and yield differences across countries (Lohr, 2001), but organic production data are available for more countries than is organic consumption data.

[7] Dimitri and Dettmann (2012) use limited-dependent variable models to show an increasing likelihood of purchasing organic milk, fruits, and vegetables for higher-income categories. McFadden and Huffman (2017) utilize an experimental auction to assess consumer WTP for conventional and organic apples, eggs, and broccoli and find WTP for organic to be increasing in income. The income–WTP relationship for organic food is less clear for Europe based on the work of Kriwy and Mecking (2012) and Bazoche et al. (2014).

Table 1: Organic farmland share as a function of GNI per capita

	Organic Farmland Share (%)					
	Cross Section: 2018		Panel Model: 2016–2020			
	(1)	(2)	(3)	(4)	(5)	(6)
Log GNI	2.436***	1.616***	1.716***	0.754***	1.912***	1.105***
per capita	(0.450)	(0.490)	(0.230)	(0.269)	(0.250)	(0.316)
Continent FE		✓		✓		✓
Year FE			✓	✓		
Continent-by-Year FE				✓		
Observations	111	111	555	555	555	555
Number Censored	12	12	88	88	88	88

Notes: Share (%) is percent of total farmland in organic production. Robust standard errors are reported in parentheses in columns (1) and (2); observed information matrix (OIM) standard errors are reported in parentheses in columns (3) through (6).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Organic land share data come from statistics compiled by the Research Institute of Organic Agriculture (FiBL) (`https://statistics.fibl.org/world/area-world.html`). FiBL collects country-level data from national sources, certifiers, and Eurostat. We also leverage data from the Food and Agriculture Organization (FAO) of the United Nations in cases of missing FiBL data for a handful of countries.[8] This dataset covers 190 countries and areas of the world from 2016 to 2020. To avoid biases due to the inclusion of countries with insignificant land allocated to agriculture, we only include countries with at least 1,000,000 ha of agricultural land, a total of 111 countries. In addition, to account for the truncation of the organic land share at zero, we estimate the model as a Tobit.

Due to concerns regarding outliers and measurement error for single-year observations, we average each country's percentage organic land share over the five years 2016–2020 to construct the main dependent variable. For regressors, the main variable of interest is the log of a country's Gross National Income (GNI) per capita for 2018 (the midpoint of the organic land-share average) obtained from Human Development Reports of the United Nations Development Programme (UNDP).

Results for this cross-sectional analysis without and with continent fixed-effects are reported in columns (1) and (2) of Table 1. As a robustness check, we also estimated a random-effects model using the full five-year country panel. Both continent and year fixed-effects are considered in

[8] We compute the organic land share by calculating the ratio of "Cropland area under organic agriculture" to "Cropland", with both series coming from the FAOSTAT Land Use domain: `https://www.fao.org/faostat/en/#data/RL`. The numbers obtained from the FAOSTAT source are only used for certain countries/areas in certain years when the FiBL data on organic land shares are not available. This complementary source adds one observation to the 2016-2020 panel for each of the following countries/areas: Jamaica, New Caledonia, Kuwait, New Caledonia, Mauritius, Cook Islands, Grenada, and Switzerland.

Table 2: Organic farmland share as a function of development indicators

	Organic Farmland Share (%)					
	Cross Section: 2018		Panel Model: 2016–2020			
	(1)	(2)	(3)	(4)	(5)	(6)
Log GNI per capita	1.463** (0.727)	0.848 (0.569)	1.150*** (0.427)	0.002 (0.359)	1.140*** (0.404)	0.514 (0.413)
Log Life Expectancy at Birth	1.967 (4.783)	8.375 (5.248)	6.834** (3.183)	11.131*** (2.463)	4.857 (2.962)	4.759 (3.006)
Log Expected Years of Schooling	4.443 (2.743)	1.079 (2.412)	1.237 (1.411)	1.320 (1.276)	3.325** (1.445)	1.979 (1.406)
Continent FE		✓		✓		✓
Year FE			✓	✓		
Continent-by-Year FE				✓		
Observations	110	110	550	550	550	550
Number Censored	11	11	83	83	83	83
P-value from F test	p<0.01	0.011	p<0.01	p<0.01	p<0.01	p<0.01

Notes: Share (%) is percent of total farmland in organic production. Robust standard errors are reported in parentheses in columns (1) and (2); observed information matrix (OIM) standard errors are reported in parentheses in columns (3) through (6).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

these models, with results reported in columns (3) through (6). Our analysis shows that per capita income has a positive overall impact on the share of land devoted to organic production across all specifications considered. While we have significance with p < 0.01 across all specifications, a 10% increase in GNI per capita is associated with an increase in organic land share in the range of 0.075 (column (3)) to 0.244 (column (1)) percentage points. Given a mean organic share in the sample of 2.40%, these values correspond to a percent increase in the organic share of 3.13% to 10.17%. Organic land shares are highest in Europe and Oceania relative to the default region, Africa.

Organic production may also be correlated with indicators of a country's level of development other than GNI per capita. To investigate this possibility, we added additional measures of economic development to the regression model—life expectancy at birth and expected years of schooling.[9] Including these variables provides a more comprehensive understanding of the factors influencing the organic land share.

Results with these additional variables are presented in Table 2. The interpretation of the

[9]Prior literature has yielded conflicting results regarding the impact of education on organic food consumption. For example, Ghorbani and Hamraz (2009) found a negative relationship in Iran, while Bhatta, Doppler, and Bahadur (2010) and Smith, Huang, and Lin (2009) found a positive relationship for Nepal and the United States, respectively.

Table 3: Organic per capita consumption as a function of GNI per capita

	Log Organic Consumption per capita					
	Cross Section: 2018		Panel Model: 2016–2020			
	(1)	(2)	(3)	(4)	(5)	(6)
Log GNI	2.807***	2.783***	2.282***	2.237***	2.497***	2.351***
per capita	(0.373)	(0.485)	(0.321)	(0.375)	(0.340)	(0.416)
Continent FE		✓		✓		✓
Year FE			✓	✓		
Continent-by-Year FE				✓		
Observations	50	50	233	233	233	233
R^2	0.686	0.764	0.712	0.752	0.711	0.755

Notes: Robust standard errors are reported in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

columns in Table 2 is similar to that in Table 1.[10] Per capita income has a positive effect on the organic land share across the various specifications, even after controlling for life expectancy and years of schooling, and the range of statistically significant coefficients, 1.140 (column (5)) to 1.463 (column (1)), falls within that of Table 1. Adding continent fixed effects reduces the magnitude and statistical significance of GNI per capita as it arguably removes a large share of the cross-sectional variation in that variable. In addition, there is high collinearity between GNI per capita and life expectancy (correlation coefficient $\rho = 0.788$) and between GNI per capita and expected year of schooling ($\rho = 0.806$), which contributes to imprecision in the estimates of individual regressor effects. An F-test shows that the three development indicators are jointly significant in all model specifications. Although in what follows we retain our focus on income and classify regions as "rich" and "poor," an alternative characterization of "developed" and "developing" would serve the same purpose, given the difficulties in separating indicators of economic development due to their high correlations.

A direct analysis of organic consumption is possible for a smaller sample covering 50 countries from 2016 to 2020, for which FiBL provides organic per capita food consumption expenditure (`https://statistics.fibl.org/world/retail-sales.html`). Figure 1 shows a direct relationship between the logarithm of organic food consumption per capita and the logarithm of GNI per capita.

Regression results are provided in Tables 3 and 4. As in Table 1 and 2, columns (1) and (2) use the logarithm of organic consumption per capita averaged over years 2016–2020; columns (3) through (6) report results from a random-effects panel regression model using annual log organic

[10] We lose observations for Somalia because it doesn't report expected years of schooling.

Figure 1: Organic per capita consumption versus GNI per capita

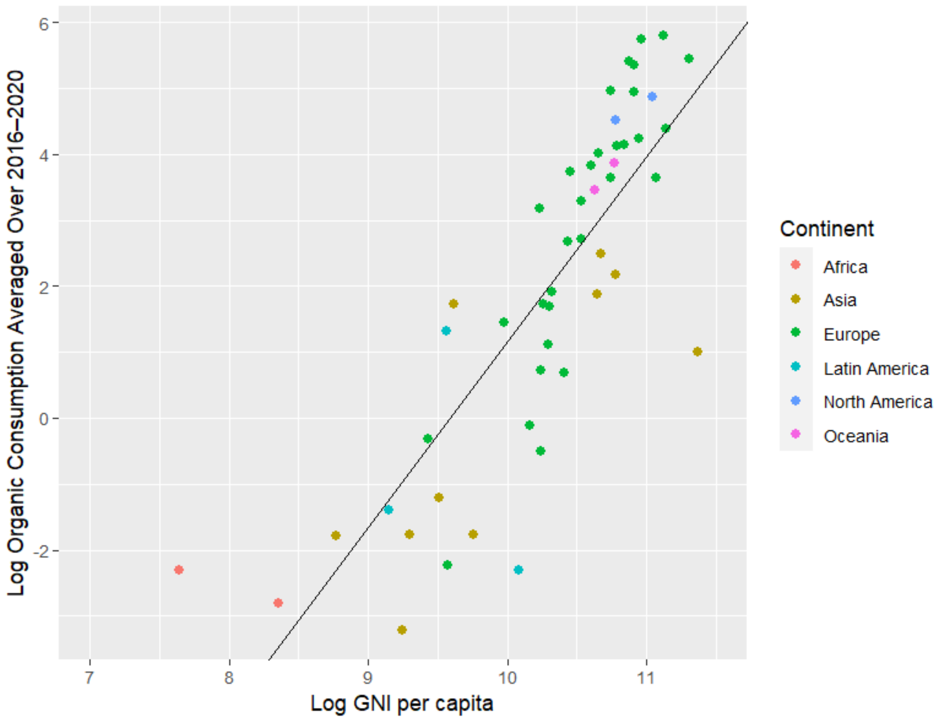


Table 4: Organic per capita consumption as a function development indicators

	Log Organic Consumption per capita					
	Cross Section: 2018		Panel Model: 2016–2020			
	(1)	(2)	(3)	(4)	(5)	(6)
Log GNI per capita	2.778*** (0.766)	2.307*** (0.757)	2.155*** (0.327)	2.065*** (0.385)	2.511*** (0.366)	2.359*** (0.424)
Log Life Expectancy at Birth	3.217 (7.771)	10.565 (7.408)	2.728** (1.295)	4.057* (2.123)	-0.425 (1.130)	0.082 (1.150)
Log Expected Years of Schooling	-1.319 (2.543)	-2.104 (2.435)	-0.569 (0.837)	-0.697 (0.930)	0.098 (0.874)	-0.109 (0.828)
Continent FE		✓		✓		✓
Year FE			✓	✓		
Continent-by-Year FE				✓		
Observations	50	50	233	233	233	233
R^2	0.688	0.776	0.714	0.762	0.711	0.755
P-value from F-test	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01

Notes: Robust standard errors are reported in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

consumption per capita as the dependent variable.[11] The effect of GNI per capita on organic consumption per capita is significant in all specifications with $p < 0.01$ and indicates a highly income elastic demand for organic food in the range of 2.24–2.81 in Table 3 and 2.07–2.78 in Table 4, revealing that organic food is a luxury good based on the standard definition.

Our regression models, as well as the preponderance of the published literature, thus support the proposition that organic foods are produced and consumed mainly in wealthy countries and by wealthier consumers within them. It is worth noting that incomes have been rising more rapidly in the developing world than in the West in recent decades (Fukase and Martin, 2020), meaning that over time the developing world is likely to consume increasing amounts of income-elastic credence goods including organic.

4 Quantitative model of the effect of expanded organic farmland

In this section, we develop and calibrate a model of regional crop supply, food production, and food demand, with trade in crops. We use it to assess the consequences for food prices and welfare of policy-driven expansions in the land area dedicated to organic production. Our approach borrows from the works of Costinot, Donaldson, and Smith (2016) and Gouel and Laborde (2021), notably in the way we model land heterogeneity and trade costs and the fact that we rely on an "exact hat algebra" for counterfactual analysis (Dekle, Eaton, and Kortum, 2008; Costinot and Rodríguez-Clare, 2014). The parsimony of our model has tangible benefits in terms of exposure and permits transparent counterfactuals as well as comprehensive sensitivity analysis along key structural parameters.

We calibrate the model specifically for organic agriculture. However, our approach can be applied to other credence-attribute products, such as non-GMO foods, that compete for productive inputs and consumer demand with conventional variants.

4.1 Summary of model features

Consistent with the empirical results reported in Section 3, we specify two world regions: "Poor" and "Rich," which differ in their taste for organic foods, their cropping technology, and their food processing technology. In each region, a fixed resource is allocated to two competing production systems: conventional and organic. We call this factor "land" and calibrate our model to land

[11] Since the organic consumption data reported by FiBL are strictly positive and we apply a log transformation to them, we do not use a Tobit model here. We should expect $50 \times 5 = 250$ observations in the full panel, but 17 observations are missing from the FiBL data, resulting in 233 observations.

use data, but it could conceptually capture an aggregate of the various resources dedicated to agricultural production, including water and farm labor, which may be supplied in finite quantities at broad regional levels.

We allow for trade in conventional and organic crops between regions. Like Costinot, Donaldson, and Smith (2016), we assume iceberg trade costs, that is, if one unit of crop is shipped from one region, less than one unit arrives at destination; but departing from the Armington assumption, we specify that imported crops are perfectly substitutable for domestic crops, conditional on the variant. A consequence is that in equilibrium, trade in a crop variant must be unidirectional.[12] We deal with bidirectional trade flows between Poor and Rich by computing net exports and using that information to calibrate model parameters.

Production of food in our model involves the transformation of aggregate crop output available at regional level into consumable calories, via a Leontief technology assumed to be variant-specific. Since the consumption good is an aggregate of foods produced from crops, it is meant to include, albeit implicitly, foods derived from animal products.

Although we specify production and utility functions as primitives of our model, it is a partial equilibrium model as we assume quasi-linearity with respect to food consumption. In addition, the price of the non-food numeraire consumption good and the price of the aggregate input used to transform crops into foods are treated as exogenous. Our calibrating information comports with expectations: Rich has a higher relative preference for organic food than Poor; its food processing technology is less crop-intensive; and Rich is a net exporter of the conventional crops, while Poor is a net exporter of the organic crops.

4.2 Preferences and demand

We assume the existence of a representative consumer in each of two world regions, Poor (P) and Rich (R). In region $i = P, R$, preferences over food (C^i) and a numeraire good (C_0^i) have the following quasilinear form:

$$U^i = C_0^i + \left(\beta^i\right)^{\frac{1}{\epsilon^i}} \frac{\left(C^i\right)^{1-\frac{1}{\epsilon^i}}}{1-\frac{1}{\epsilon^i}}$$

where $\beta^i > 0$ captures the strength of preferences for food relative the numeraire, $0 < \epsilon^i < 1$ represents the absolute demand elasticity for food, and C^i is a CES food aggregate defined over conventional ($v = 1$) and organic ($v = 2$) food variants as

$$C^i = \left[\sum_v \left(\beta_v^i\right)^{\frac{1}{\sigma^i}} \left(C_v^i\right)^{\frac{\sigma^i-1}{\sigma^i}}\right]^{\frac{\sigma^i}{\sigma^i-1}}$$

[12] Another consequence is that our model cannot be used to investigate policies that would reverse trade flows.

with $\sigma^i > 0$ denoting the elasticity of substitution between food variants, $\beta_v^i \geq 0$ for $v = 1, 2$, and $\sum_v \beta_v^i = 1$ as normalization.

Utility maximization given prices $p_0 \equiv 1$ for the numeraire and p_v^i for food variant v in region i implies the following demand functions for food variants:

$$C_v^i = \beta^i \beta_v^i \left(P^i\right)^{\sigma^i - \epsilon^i} \left(p_v^i\right)^{-\sigma^i} \tag{1}$$

where $P^i \equiv \left[\sum_v \beta_v^i \left(p_v^i\right)^{1-\sigma^i}\right]^{\frac{1}{1-\sigma^i}}$ is the food price index in region i. A standard result is that the demand for the food aggregate can then be written as a sole function of the food price index, namely

$$C^i = \beta^i \left(P^i\right)^{-\epsilon^i} \ .$$

4.3 Land allocation, crop supply, and food production

Crops of variant v are used to produce food of variant v according to a Leontief technology, with one unit of crop giving rise to one unit of food. We denote by c_v^i the processing cost per unit of crop variant v in region i, and by q_v^i the price of crop variant v paid by the processing sector in region i. Competition among processing firms implies that in equilibrium the consumer price, p_v^i, equals the farm price, q_v^i, plus the unit processing cost, c_v^i:

$$p_v^i = q_v^i + c_v^i \ . \tag{2}$$

In each region i, a fixed regional land base $L^i > 0$ is used to grow conventional and organic crop variants.[13] Production costs per unit land are assumed identical between variants, though they may differ between regions. Therefore, differences in returns between variants are solely due to different crop prices and yields. We denote by A_v^i the average yield of variant v in region i. Land in region i is described by a continuum of parcels ω, with parcel-level yields $A_v^i(\omega)$ distributed according to the following joint Fréchet cumulative distribution function:

$$\Pr\left(A_v^i(\omega) \leq a_v, v = 1, 2\right) = \exp\left\{-\eta^i \left[\sum_v \left(\frac{a_v}{A_v^i}\right)^{-\frac{\theta^i}{1-\rho^i}}\right]^{1-\rho^i}\right\} ,$$

with $\rho^i \in [0, 1)$, $\theta^i > 1$, and parameter η^i such that the unconditional yield of variant v in region i is precisely equal to A_v^i. As shown for instance in Costinot, Donaldson, and Smith (2016), this

[13] Although the land base in agriculture can be expanded through extensification of production, it is well understood that extensification through deforestation or other means is a significant source of greenhouse gas emissions (Burney, Davis, and Lobell, 2010; Foley et al., 2011). Limiting such land expansion is a key goal of climate-change policies, making it important to consider the implications of policy-induced expansion of land share in organic production holding the land base constant.

is achieved by setting $\eta^i = \Gamma\left(\frac{\theta^i - 1}{\theta^i}\right)^{-\theta^i}$, where $\Gamma(\cdot)$ denotes the gamma function. Note that yields of variants need not be independently distributed within regions: as long as $\rho^i > 0$, parcels with higher conventional yields also have higher organic yields. The limit value $\rho^i = 0$ corresponds to independence.

The use of a Fréchet distribution for yields, in addition to capturing land heterogeneity in a parsimonious fashion, affords a very simple and intuitive expression for the share of land grown in each variant under the assumption of profit maximization. In the absence of any policy on variant acreage, arbitrage between variants on each parcel of land implies that in region i, the share, π_v^i, of land dedicated to variant v is simply[14]

$$\pi_v^i = \frac{\left(q_v^i A_v^i\right)^{\frac{\theta^i}{1-\rho^i}}}{\sum_u \left(q_u^i A_u^i\right)^{\frac{\theta^i}{1-\rho^i}}} \tag{3}$$

with attendant crop supply:

$$Y_v^i = L^i A_v^i \left(\pi_v^i\right)^{1-\frac{1-\rho^i}{\theta^i}} \quad . \tag{4}$$

Equation (3) makes apparent that if $\frac{\theta^i}{1-\rho^i} \to +\infty$, parcels become completely homogeneous and only the variant providing the highest average return is grown. In contrast, $\frac{\theta^i}{1-\rho^i} \to 1$ represents the extreme of land heterogeneity, where each variant is grown no matter how small its average revenue is relative to that of other variants (though it is still the case, of course, that variants with higher average returns have a higher land share).

Under a mandatory acreage policy, land is assumed to be allocated so that total land rents are maximized subject to the acreage constraint. This is what would obtain if, for instance, the organic acreage expansion were achieved by way of a subsidy for organic crops. Thus, Equation (4) still describes the supply of variants in a region where land shares are mandated rather than the result of competitive arbitrage, since conditional on acreage (π_v^i), supply (Y_v^i) is independent of crop prices (q_v^i).

4.4 Trade in crop variants and market clearing

We assume that crop (not food) variants are traded, and that crop variants from different origins are perfect substitutes in processing and ultimate consumption in their destination region. Trade in crop variant v from region i to region j is subject to iceberg trade costs (Samuelson, 1954; Krugman, 1991; Costinot, Donaldson, and Smith, 2016) denoted $\tau_v^{ij} \geq 1$, with strict inequality if and only if $j \neq i$. Denoting by X_v^{ij} the quantity of crop variant v from region i that is made available in region

[14] See Appendix A for the derivation of Equations (3) and (4).

j (with X_v^{ii} denoting the quantity of crop variant v remaining in region i), we have:

$$Y_v^i = \sum_j \tau_v^{ij} X_v^{ij} \ , \tag{5}$$

$$X_v^{ji} X_v^{ij} = 0 \quad v = 1,2 \quad i,j = P,R \quad i \neq j \ , \tag{6}$$

$$\left(q_v^i - \tau_v^{ji} q_v^j\right) X_v^{ji} = 0 \quad v = 1,2 \quad i,j = P,R \ , \tag{7}$$

and

$$\sum_j X_v^{ji} = C_v^i \quad v = 1,2 \quad i = P,R \ . \tag{8}$$

Equation (5) indicates that the sum of shipments of a crop variant to all destination regions must equal the origin region's total production of that variant. Note that shipments exceed quantities at destination due to positive trade costs. Equation (6) indicates that since crop variants from different origin regions are perfect substitutes and trade costs are positive, trade in a given variant must be unidirectional. Equation (7) indicates that whenever a crop variant is shipped from region j to i (i.e., $X_v^{ji} > 0$), its farm price at destination must exceed that in its origin region by a factor precisely equal to the trade cost. Finally, Equation (8) indicates that the total quantity of a variant available for consumption in a region is the sum of variants from all origins (including itself) present in that region.

4.5 Policy analysis and equilibrium in relative changes

We investigate the consequences of a policy-driven rise in the share of land dedicated to the organic variant in the rich region, that is, an exogenous increase in π_2^R. Such policy could take the form of a binding mandate or, perhaps more likely, an explicit subsidization of returns to organic farmland. In either case, in the new equilibrium the social value of land is no longer equated between variants in region R, and Equation (3) becomes irrelevant for that region. In addition, Equation (4) implies that a mandated increase in π_2^R is equivalent to an increase in the organic crop production Y_2^R, though due to $\rho^i < 1$ and $\theta^i > 1$ the increase in quantity is less than proportional to the increase in acreage.

We denote with the use of a "prime" the new equilibrium value of a variable and with the use of a "hat" the relative change in a variable, defined as the new equilibrium value divided by the initial equilibrium value. For example, $\hat{Y}_2^R \equiv \frac{Y_2^{R\prime}}{Y_2^R}$ denotes the relative increase in organic crop production in region R.

Because the regional land base is fixed, we have

$$\pi_1^i \hat{\pi}_1^i + \pi_2^i \hat{\pi}_2^i = 1 \quad i = P,R \ , \tag{9}$$

with $\hat{\pi}_2^R$ treated as exogenous due to policy. Changes in land shares directly translate into changes in crop variant supply:

$$\hat{Y}_v^i = \left(\hat{\pi}_v^i\right)^{1-\frac{1-\rho^i}{\theta^i}} \quad i = P, R \quad v = 1, 2 \; . \tag{10}$$

In the poor region, land allocation is driven by market returns between variants, thus Equation (3) continues to hold in the new equilibrium, leading to the relative change:[15]

$$\hat{\pi}_1^P = \frac{\left(\hat{q}_1^P\right)^{\frac{\theta^i}{1-\rho^i}}}{\sum_u \pi_u^P \left(\hat{q}_u^P\right)^{\frac{\theta^i}{1-\rho^i}}} \; . \tag{11}$$

Changes in regional crop output have consequences on crop shipments. Denoting $\chi_v^{ij} \equiv \frac{\tau_v^{ij} X_v^{ij}}{Y_v^i}$ the share of region i's production of crop variant v that is shipped to region j, we have

$$\hat{Y}_v^i = \sum_{j | X_v^{ij} > 0} \chi_v^{ij} \hat{X}_v^{ij} \quad i = P, R \quad v = 1, 2 \; . \tag{12}$$

Equation (7) implies that whenever a variant is traded between regions, crop prices must move in proportion in these regions, that is,

$$\hat{q}_v^P = \hat{q}_v^R \quad v = 1, 2 \; . \tag{13}$$

If, to the contrary, trade in variant v ceases between region i and region j, then $\hat{q}_v^i$ and $\hat{q}_v^j$ are no longer related, but then the equality $\hat{X}_v^{ij} = 0$ must hold, so arbitrage across markets imposes one equality for each crop variant.

At the processing stage, Equation (2) implies that

$$\hat{p}_v^i = \phi_v^i \hat{q}_v^i + 1 - \phi_v^i \quad i = P, R \quad v = 1, 2 \; , \tag{14}$$

where $\phi_v^i \equiv \frac{q_v^i}{p_v^i}$ denotes the initial crop share of the food dollar for variant v in region i.

Finally, relative changes in crop availability at the region level must be matched by equivalent changes in consumption, themselves brought about by changes in food prices. Denoting $\gamma_v^{ji} \equiv \frac{X_v^{ji}}{\sum_k X_v^{ki}}$ as the share of variant v's total availability in region i originating from region j, Equations (1) and (8) together imply that

$$\sum_{j | X_v^{ji} > 0} \gamma_v^{ji} \hat{X}_v^{ji} = \left(\hat{P}^i\right)^{\sigma^i - \epsilon^i} \left(\hat{p}_v^i\right)^{-\sigma^i} \quad i = P, R \quad v = 1, 2 \; , \tag{15}$$

[15]The value of $\hat{\pi}_2^P$ is given by Equation (9) for $i = P$.

where the changes in food price indexes are

$$\hat{P}^i = \left[\sum_v b_v^i \left(\hat{p}_v^i \right)^{1-\sigma^i} \right]^{\frac{1}{1-\sigma^i}} \qquad i = P, R \ , \tag{16}$$

with $b_v^i \equiv \frac{p_v^i C_v^i}{P^i C^i} = \frac{p_v^i C_v^i}{\sum_v p_v^i C_v^i}$ denoting the budget share on variant v in region i.

Equations (9)–(16) represent a system of 23 equations in 23 unknowns, namely $\hat{\pi}_1^R$, $\hat{\pi}_v^P$ ($v = 1, 2$), $\hat{Y}_v^i$ ($v = 1, 2$ and $i = P, R$), $\hat{X}_v^{ij}$ ($v = 1, 2$ and $i, j = P, R$), $\hat{q}_v^i$ ($i = P, R$ and $v = 1, 2$), $\hat{p}_v^i$ ($i = P, R$ and $v = 1, 2$), and $\hat{P}^i$ ($i = P, R$), that together describe the market's adjustment to a policy-driven increase in the share of land devoted to organic production. (Note that due to the unidirectionality of trade, there are only 6 unknowns amongst the $\hat{X}_v^{ij}$ variables, namely the four values of non-shipped crop variants $\hat{X}_v^{ii}$ plus two potentially non-zero values $\hat{X}_v^{ij}$ with $i \neq j$, one for each variant. That is, we do not allow for trade creation, though we allow for trade disappearance.)

Qualitatively, policy-driven organic acreage expansion in region R is expected to have the following consequences: conventional acreage contracts in R which tends to reduce conventional supply and increase the price of conventional food in R but also in P since conventional prices are linked through trade. In addition, the increase in organic supply in R lowers organic crop returns and increases conventional crop returns through the demand effect. To the extent that crop prices in the two regions are linked through international trade, the organic crop price decreases relative to the conventional crop price in P as well, inducing a conversion of land from organic towards conventional, which partially offsets the price effects in R, and may eliminate trade in organic crops towards R. In both regions, the food price is thus expected to decrease for organic and to increase for conventional. To the extent that consumers in R spend a higher expenditure share on organic food, they should be hurt relatively less than consumers in P, and could even benefit. Given that Poor is a net exporter of organic crops and a net importer of conventional crops, and the price of conventional crops rises while that of organic crops decreases, the Poor region is unambiguously hurt by the organic acreage expansion in R. This does not mean that farmers in the Poor region are hurt, as they receive higher prices for conventional crops and, thus, face offsetting impacts as producers and consumers. Indeed, in our parameterizations land rents always increase in the Poor region.

Note that in region R, the fact that the changes in acreage are driven by policy implies that marginal returns to crop production are no longer equated across variants in that region. In particular, nothing in the model prevents $q_2^{R'}$ from becoming negative. Specifically, if the consumer price needed to clear the market for organic food is sufficiently low that it will not cover the processing cost for the organic variant, then processors would not pay a positive price to procure the organic product from farmers and returns from organic acreage would become negative. The practical significance of this point is that policy-mandated expansions of land share in production of a credence-attribute product must generally be accompanied by a redistribution scheme that compensates farmers for the lower returns per unit land associated with producing a credence-attribute product, such as an organic crop, in order to incentivize the necessary conversion. Since we focus mainly on consumer and total welfare effects in this paper, we abstract from modeling such redistribution in our simulations.

4.6 Welfare effects

We consider exogenous changes in organic acreage that leave consumers' incomes unaffected. Unlike changes in prices and quantities, relative changes in welfare measures are defined here as the difference between final and initial values, divided by some normalizing baseline value. In each region $i = P, R$, the change in consumer surplus relative to baseline food expenditures can be shown to be equal to:[16]

$$\frac{\Delta \mathrm{CS}^i}{P^i C^i} = \frac{\Delta U^i}{P^i C^i} = \frac{1 - \left(\hat{P}^i\right)^{1-\epsilon^i}}{1-\epsilon^i} \approx 1 - \hat{P}^i \ , \tag{17}$$

where the approximation holds for values of $\hat{P}^i$ close to one. One can also write the change in region i's consumer surplus as a share of the total value of food consumption across regions:

$$\frac{\Delta \mathrm{CS}^i}{\sum_j P^j C^j} = \frac{\alpha^i}{1-\epsilon^i}\left[1 - \left(\hat{P}^i\right)^{1-\epsilon^i}\right] \approx \alpha^i \left(1 - \hat{P}^i\right) \ , \tag{18}$$

where $\alpha^i \equiv \frac{P^i C^i}{\sum_j P^j C^j}$ denotes the share of region i in total food expenditures.

The change in total consumer surplus relative to total food expenditures across both regions is then

$$\frac{\sum_i \Delta \mathrm{CS}^i}{\sum_i P^i C^i} = \sum_i \frac{\alpha^i}{1-\epsilon^i}\left[1 - \left(\hat{P}^i\right)^{1-\epsilon^i}\right] \ . \tag{19}$$

Regional land rents, LR^i, in this model are the total revenues from sales of farm output, that is, $\mathrm{LR}^i \equiv \sum_v q_v^i Y_v^i$.[17] Therefore the relative change in land rents in region i is

$$\frac{\Delta \mathrm{LR}^i}{\mathrm{LR}^i} = \sum_v \delta_v^i \left(\hat{q}_v^i \hat{Y}_v^i - 1\right) = \left(\sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i\right) - 1 \ , \tag{20}$$

where $\delta_v^i \equiv \frac{q_v^i Y_v^i}{\sum_u q_u^i Y_u^i}$ represents the share of variant v in crop value in region i. For comparison with demand-side effects, one may also write the change in land rents relative to the total value of

[16] See Appendix B for this derivation and that of the change in land rents.

[17] In our model, agricultural costs are borne per unit of land and are independent of the variant. Accounting for such costs would reduce the land rents, but it would not affect our calculation of the change in regional land rents since cropland is utilized fully.

consumption as

$$\frac{\Delta \mathrm{LR}^i}{\sum_j P^j C^j} = \phi \delta^i \left[\left(\sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i \right) - 1 \right] \ , \tag{21}$$

where $\delta^i \equiv \frac{\sum_v q_v^i Y_v^i}{\sum_j \sum_v q_v^j Y_v^j}$ represents the share of region i in total value of crop production and $\phi \equiv \frac{\sum_i \sum_v q_v^i Y_v^i}{\sum_i P^i C^i}$ represents the overall crop share of the food dollar across variants and regions. The aggregate land rent effect is then

$$\frac{\sum_i \Delta \mathrm{LR}^i}{\sum_i P^i C^i} = \phi \left[\left(\sum_i \delta^i \sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i \right) - 1 \right] \ . \tag{22}$$

Adding Equations (19) and (22) gives the change in social welfare relative to the total value of consumption, that is, the social cost of the organic acreage policy.

4.7 Model identification

We assign values to the demand parameters ϵ^i, σ^i, and the heterogeneity ratio $\frac{\theta^i}{1-\rho^i}$ based on elasticity estimates found in the economic literature and use data to identify the share parameters of our model. First note that, due to the assumption of equal costs per acre between crop variants, we must have $\delta_v^i = \pi_v^i$.[18] Second, there exist inherent relationships between land shares and the ultimate expenditure shares. Using the definitions of χ_v^{ij} and γ_v^{ij}, we can write:

$$\begin{aligned} \chi_v^{ij} = \frac{\tau_v^{ij} X_v^{ij}}{Y_v^i} &= \frac{\tau_v^{ij} \gamma_v^{ij} \sum_k X_v^{kj}}{Y_v^i} \\ &= \frac{\tau_v^{ij} q_v^i \gamma_v^{ij} C_v^j}{q_v^i Y_v^i} \\ &= \frac{\gamma_v^{ij} q_v^j C_v^j}{q_v^i Y_v^i} \\ &= \frac{\gamma_v^{ij} \phi_v^j p_v^j C_v^j}{q_v^i Y_v^i} \\ &= \frac{\gamma_v^{ij} \phi_v^j b_v^j P^j C^j}{\delta_v^i \sum_u q_u^i Y_u^i} \\ &= \frac{\gamma_v^{ij} \phi_v^j b_v^j \alpha^j \sum_i P^i C^i}{\delta_v^i \delta^i \sum_k \sum_u q_u^k Y_u^k} \\ &= \frac{\gamma_v^{ij} \phi_v^j b_v^j \alpha^j}{\delta_v^i \delta^i \phi} \ , \end{aligned}$$

[18] This can be seen by using Equations (3) and (4). Appendix C shows the derivation.

from which, using $\delta_v^i = \pi_v^i$, we deduce

$$\phi \delta^i \pi_v^i \chi_v^{ij} = \alpha^j b_v^j \phi_v^j \gamma_v^{ij} \quad i,j = P,R \quad v = 1,2 \ . \tag{23}$$

Summing over i on both sides and using $\sum_i \gamma_v^{ij} = 1$, we obtain:

$$\phi \sum_i \delta^i \pi_v^i \chi_v^{ij} = \alpha^j b_v^j \phi_v^j \quad j = P,R \quad v = 1,2 \ . \tag{24}$$

Suppose that one observes, ϕ, δ^i, π_v^i, χ_v^{ij}, α^j, and b_v^j. Then, one may use Equation (24) to deduce the value of ϕ_v^j, and then use Equation (23) to deduce the value of γ_v^{ij}.

Thus, apart from elasticity parameters, the only information needed to calibrate the model is that represented by the share parameters ϕ, δ^i, π_v^i, χ_v^{ij}, α^i, and b_v^i.

Note that we can use Equation (23), together with the equations describing the equilibrium in relative changes, to rewrite the aggregate land rent impact in Equation (22) as a function of the demand-side, rather than supply-side, variables:[19]

$$\frac{\sum_i \Delta \mathrm{LR}^i}{\sum_i P^i C^i} = \sum_i \alpha^i \left[\left(\hat{P}^i \right)^{1-\epsilon^i} - 1 \right] - \sum_i \alpha^i \sum_v b_v^i \left(1 - \phi_v^i\right) \left(\hat{C}_v^i - 1 \right) \tag{25}$$

where $\hat{C}_v^i = \left(\hat{P}^i \right)^{\sigma^i - \epsilon^i} \left(\hat{p}_v^i \right)^{-\sigma^i}$. Using Equations (19) and (25), we can then write the aggregate social welfare effect as

$$\frac{\Delta \mathrm{W}}{\sum_i P^i C^i} = \sum_i \frac{\alpha^i \epsilon^i}{1 - \epsilon^i} \left[1 - \left(\hat{P}^i \right)^{1-\epsilon^i} \right] - \sum_i \alpha^i \sum_v b_v^i \left(1 - \phi_v^i\right) \left(\hat{C}_v^i - 1 \right) \ . \tag{26}$$

4.8 Calibrating information

We calibrate the model to rice, wheat, corn, and soybean land use, trade, and expenditure data. Rich countries are defined according to the UN classification of developed economies in 2018, which includes the United States, Canada, Australia, Japan, New Zealand, EU-15 countries, EU-13 countries, Iceland, Norway, and Switzerland (United Nations, Department of Economic and Social Affairs, 2018).[20] All other countries are assigned to the Poor region.

[19] See Appendix B for the derivation.

[20] EU-15 countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom. EU-13 countries are Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia.

4.8.1 Land and expenditure shares

We compute the land shares π_v^i based on the country-level organic land share data introduced in Section 3 as well as data on the harvested area for the four crops under consideration from the UN FAOSTAT crops and livestock products domain (`https://www.fao.org/faostat/en/#data/QCL`). As in Section 3, the organic land share is constructed as a simple average over the years 2016–2020 for robustness concerns. The crop-specific harvested area is measured in 2018, the midpoint of the organic land-share average.

We multiply the area in these four crops by the organic land share to obtain an estimate of the organic cropland area in each country. Thus, for lack of better information, we implicitly assume that for a given country the overall organic land share is representative of the organic share in these crops. We then compute the land shares π_v^i as the ratio of the total organic cropland area in region i to the total cropland area in that region. This calculation shows that about 3% (resp. 0.7%) of cropland is organic in R (resp. P).

Calculation of the expenditure shares relies on retail sales data from FiBL (`https://statistics.fibl.org/world/retail-sales.html`), population data from the FAOSTAT food balances domain (`https://www.fao.org/faostat/en/#data/FBS`), GNI per capita data from UNDP (`https://hdr.undp.org/data-center/documentation-and-downloads`), and food expenditures per capita data from USDA (`https://www.ers.usda.gov/topics/international-markets-u-s-trade/international-consumer-and-food-industry-trends/`). All these data pertain to the year 2018.

We only have food expenditure per capita data for a subset of 99 countries. Using that sample of countries, we regress per capita food expenditures on a quadratic function of GNI per capita and continent dummies. The R-squared is equal to 0.83, indicating that the explanatory power of the regression model is good. We use it to predict food expenditures per capita for 178 countries. We then predict these countries' total food expenditures by multiplying predicted per capita food expenditures by population, and add up country-level predicted expenditures to obtain each region's total food expenditures. We use FiBL's organic per capita consumption data to compute country and regional organic food expenditures and deduce expenditures on conventional foods by subtracting expenditures on organic foods from total food expenditures. These expenditures are then used to construct the shares α^i and b_v^i. Because our expenditure shares are constructed from retail-level data, they implicitly reflect the value of the four crops processed for ultimate food use, including those fed to livestock.

Table 5 summarizes the values of the region-level land and expenditure shares.

Table 5: Land and expenditure share parameters

Parameter	Definition	Value
π_1^P	Share of total land dedicated to the conventional variant in Poor	0.993
π_1^R	Share of total land dedicated to the conventional variant in Rich	0.970
α^P	Share of Poor in total food expenditures	0.670
b_1^P	Budget share on the conventional variant in Poor	0.997
b_1^R	Budget share on the conventional variant in Rich	0.960

4.8.2 Production and trade shares

The parameter δ^i, representing region i's share in the total value of crop production, is calibrated using data from the UN FAOSTAT value of agricultural production domain (`https://www.fao.org/faostat/en/#data/QV`). We first sum up the gross production value of the four crops by region, and then calculate shares by dividing by the total value across regions. Our data indicate that $\delta^P = 0.78$.

Calibration of the trade parameter χ_v^{ij} is more complex as we do not observe trade in crop variants, only overall trade in crops. The data we use are the export quantity, the import quantity, and the production quantity of each crop for each country from the UN FAOSTAT crops and livestock products domain (`https://www.fao.org/faostat/en/#data/TCL`). To first identify production of the organic variant, we leverage the conditional yield gap of each crop c, defined as

$$\kappa_c^i = \frac{Q_{c1}^i / L_{c1}^i}{Q_{c2}^i / L_{c2}^i}$$

where Q_{cv}^i, $v = 1, 2$ represents the quantity of variant v of crop c produced in region i, and L_{cv}^i the associated land area. Based on Ponisio et al. (2015), we assign the following values to κ_c^i: $\frac{1}{0.89}$ for maize, $\frac{1}{0.94}$ for rice, $\frac{1}{0.92}$ for soybeans, and $\frac{1}{0.73}$ for wheat in both regions. We then estimate organic production of crop c in region i as

$$Q_{c2}^i = \frac{Q_{c1}^i + Q_{c2}^i}{\frac{Q_{c1}^i}{Q_{c2}^i} + 1} = \frac{Q_{c1}^i + Q_{c2}^i}{\frac{\pi_1^i}{\pi_2^i}\kappa_c^i + 1} ,$$

assuming that the regional crop-level land allocation between variants matches the regional breakdown across all crops. The conventional production Q_{c1}^i is recovered as the difference between total production and organic production. We then transform the conventional and organic crop quantities into calories using the caloric conversion rates used by Roberts and Schlenker (2009) and Williamson and Williamson (1942). We thus end up with only one conventional and one organic crop quantity for each region, corresponding to the baseline values of Y_v^i in our model.

The variant shipments $\tau_v^{ij} X_v^{ij}$ are recovered using information on net crop exports (in calories, inclusive of both variants), an estimate of trade costs, and an estimate of the share of total world organic crop that is used to produce organic food consumed in Rich, a parameter defined as $\psi \equiv \frac{\tau_2^{PR} X_2^{PR} + X_2^{RR}}{Y_2^P + Y_2^R}$.

Using the numbers reported in Table 5, we first compute Rich's share of organic food expenditures, defined as $\alpha_2^R \equiv \frac{b_2^R \alpha^R}{b_2^P \alpha^P + b_2^R \alpha^R} \approx 0.87$. Importantly, this share pertains to processed food values, not crop quantity. Since processing costs are likely higher in Rich than in Poor and would be reflected in food values, we set a default value for ψ of 0.80 and explore an alternative value of 0.75 in sensitivity analysis. Multiplying ψ by world organic crop production gives Rich's total use of organic crops, which is always larger than its own organic crop production; hence, Poor exports organic crops to Rich. Subtracting Rich's own organic production gives the organic shipment from Poor to Rich, $\tau_2^{PR} X_2^{PR}$.

Table 6: Trade shares (χ_v^{ij})

	Conventional	Organic
Poor to Rich	0	0.545
Rich to Poor	0.160	0

Note: values are reported for $\psi = 0.80$ and $\tau_2^{PR} = 1.05$

Since Rich has positive net crop exports in the data, and is importing organic crops, it must export conventional crops. We recover the conventional shipment from Rich to Poor, $\tau_1^{RP} X_1^{RP}$, as the sum of X_2^{PR} and Rich's net crop exports. This requires an assumption regarding the value of τ_2^{PR}, since what is identified so far is the product $\tau_2^{PR} X_2^{PR}$. We estimate the average trade cost by dividing Rich's net crop exports (which are positive) by the negative of Poor's net crop exports (which are negative). We obtain an average trade cost of 1.036, implying that about 4% of crop shipments are lost in transit across variants. We assign $\tau_2^{PR} = 1.05$ based on the expectation that organic crops are more perishable than conventional ones. Organic shipments from Poor are exceedingly small relative to Rich's net crop exports, however, thus the particular value of τ_2^{PR} turns out to be immaterial to our simulations. For the sake of brevity, we thus abstain from reporting sensitivity analysis results along that dimension of our calibration. The resulting trade shares are reported in Table 6.

4.8.3 Average crop share of the food dollar

According to the USDA, the 2020 farm share of the consumer food expenditure in the U.S. was 0.16 (see `https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=103547`). On the one hand, this value likely overestimates the crop share of the consumer dollar, as it pertains to the value of all farm output, including animal products which are arguably produced by combining crop and non-crop inputs. On the other hand, it likely underestimates the average crop share across all regions, as developed economies like the U.S. tend to process crops to a much larger extent than developing economies.

Table 7: Crop share of the food dollar by variant and region (ϕ_v^i)

	Conventional	Organic
Poor	0.303	0.309
Rich	0.141	0.181

Note: values are reported for $\phi = 0.25$ and $\psi = 0.80$

We set ϕ, the average crop share of the food dollar across variants and regions, equal to 0.25, and perform sensitivity analysis along this dimension of the parameter space. As explained in Section 4.7, the remaining share parameters determine the breakdown of this average value across variants and regions. Table 7 reports the implied values of ϕ_v^i for our baseline parameterization. As expected, the crop share is larger for organic than for conventional, though the difference is small, and it is much larger in Poor than in Rich.

4.8.4 Elasticities

We set our baseline price elasticities of demand at $\epsilon^P = 0.6$ and $\epsilon^R = 0.3$ to incorporate the fact that consumers in Poor regions are more price-sensitive than those in Rich regions.[21] We investigate the sensitivity of our results to alternative demand elasticity values.

Estimates of substitution elasticities between organic and conventional foods are, to no surprise, sparse in the literature. (Fourmouzi, Genius, and Midmore, 2012) estimate cross-price elasticities for conventional and organic fruits and vegetables for London, UK, reporting a compensated cross-price elasticity of the organic variant with respect to the conventional price of 0.85 for fruits and 1.35 for vegetables. We take the average of these two values, 1.1, to represent the compensated cross-price elasticity of organic food with respect to the price of conventional food in Rich and convert the cross-price elasticity to the equivalent substitution elasticity between organic and conventional food as follows:[22]

$$\sigma^R = \epsilon^R + \frac{1.1}{b_1^R} = 0.3 + \frac{1.1}{0.96} \approx 1.45 \ .$$

[21] These base values are consistent with the empirical literature. For example, Blanciforti and Green (1983) estimate the price elasticity of demand for all food in the U.S. to be -0.32. More recently, estimates in the comprehensive study by Okrent and Alston (2011) imply an all-food demand elasticity for the U.S. in the range of -0.33 to -0.35. Dunne and Edkins (2008) estimate a value of -0.50 for South Africa (classified as middle income by the United Nations). The comprehensive empirical study by Seale et al. (2003) provides country-level own-price demand elasticities for food, beverages, and tobacco combined. The central value for high-income countries is -0.32, that for medium-income countries is -0.59, and that for low-income countries is -0.74.

[22] See Appendix D for the derivation.

We thus use $\sigma^R = \sigma^P = 1.5$ as the central value, with 0.1, 0.5, and 2.5 as alternative values.

The last parameter to set is the ratio $\frac{\theta^i}{1-\rho^i}$, which represents the degree of parcel heterogeneity within a region as it pertains to relative yields between the conventional and the organic variants. It is thus conceptually distinct from the land heterogeneity parameter in Costinot, Donaldson, and Smith (2016) and Gouel and Laborde (2021), as land in these studies is allocated across different crops, rather than different crop variants, and the authors do not explicitly model spatial correlation in yields across crops. Given the proximity between crop variants relative to that across different crops, we would expect our overall land heterogeneity to be smaller, that is, the parameter to be larger than that considered in those studies.[23] As explained in Gouel and Laborde (2021), the land heterogeneity parameter is directly related to the elasticity of supply of crop variants. Using Equations (3) and (4), this elasticity can be written as

$$\frac{\partial \ln Y_v^i}{\partial \ln q_v^i} = \left(\frac{\theta^i}{1-\rho^i} - 1\right)\left(1 - \pi_v^i\right) \ .$$

The acreage shares π_v^i are observed in the data, therefore information on the supply elasticity of crops of a given variant is sufficient for calibration. This supply elasticity is to be interpreted as one for overall crops of given variant, holding acreage across the set of crops and variants constant. Given the hurdles associated with transitioning to organic production, we would expect such elasticity to be relatively small, though it may become larger in the long run. Our central value is based on the assumption that the elasticity of supply of organic crops in Rich, holding cropland constant, is equal to 0.5. The acreage share $\pi_2^R = 0.03$ implies a value for the land heterogeneity ratio of about 1.52. The implied elasticity of supply for conventional crops is then much smaller, namely 0.016, which is expected since conventional crops already occupy a large share of available cropland. We use the same heterogeneity ratio of 1.52 in the Poor region and explore alternative values of 1.1, 2.5, 5.0, and 10.0 in sensitivity analysis. In comparison, Gouel and Laborde (2021) set $\rho^i = 0$, and their assumed value for θ^i ranges from 1.05 to 1.2.[24]

4.9 Results

We investigate the effects of a five-fold increase in the share of organic cropland in the Rich region, from 3 to 15%. An expansion of this magnitude over the next 10–15 years, although admittedly ambitious, is not unrealistic given the stated goals for expansion of organic production by the EU and many other Western countries, as noted previously.

Across all model parameterizations, we find that the policy leads to moderate increases in

[23]This intuition is reinforced by the fact that we are dividing θ^i by $1 - \rho^i$, which explicitly accounts for the correlation between the yields of crop variants.

[24]Gouel and Laborde (2021) discuss issues with the estimation of θ^i in Costinot, Donaldson, and Smith (2016).

food prices in the Poor region.[25] Price effects in the Rich region range from very small increases to moderate decreases. The policy often leads to a complete disappearance of organic crop trade from Poor to Rich. In contrast, trade in conventional crops from Rich to Poor, although reduced, never vanishes. To provide further perspective, we also compute the increase in cropland in the Rich region needed to offset the food price increase in the Poor region.[26]

For each parameterization, we report several measures of welfare impacts: on overall food prices in each region $\hat{P}^i$ (which are directly informative about impacts on regional consumer surplus due to Equation (17)), on regional land rents $\frac{\Delta \text{LR}^i}{\text{LR}^i}$, and on aggregate consumer surplus, land rents, and social welfare. Importantly, impacts on land rents need not reflect farmer welfare impacts, as farmers in Rich would likely be incentivized financially to convert farmland to organic production under the policies to expand the organic share of farmland.

Table 8 summarizes our findings. Across all model parameterizations, the food price index increases in the Poor region, by a magnitude that ranges from 0.3–2.7%, with most estimates close to 1.2%. The largest price increases obtain for models with more inelastic food demand in Poor, more homogeneous land productivity, and less substitutability between variants in consumption. In contrast, in most parameterizations the food price index in Rich remains stable, except in the models with more homogenous land or less variant substitutability, where it decreases by an amount of similar magnitude as that of the price increase in Poor, suggesting that the organic policies in Rich countries may be highly regressive, benefiting consumers in Rich while hurting those in Poor.

In all cases, consumers in Poor bear relatively more of the burden of the organic expansion than those in Rich. The key reason is that the conventional food price rises whereas the organic food price decreases, and consumers in Rich countries spend a higher share of food expenditures on organic food. Although consumers in Rich only spend 4% of their food expenditures on organic food, the decrease in the organic price is sufficient to offset most of the increase in the price of conventional food, generally leading to muted consumer welfare effects in that region. For example, in our baseline parameterization (first line of Table 8), the price of conventional food increases by 0.6% while the price of organic food decreases by 11%.

Mirroring price index effects, the change in consumer surplus relative to baseline food expenditure in Poor varies between -0.3% and -2.7%, while that in Rich varies between -0.6% and +2.7%. Notably, this contrast is not due to the differing values of demand elasticities in the two regions: when both are assumed equal to -0.3, consumer welfare decreases by 2.3% in Poor against

[25] Appendix E provides the GAMS code used to obtain our results.

[26] This counterfactual exercise requires a slight modification of the land availability and crop supply relationships in the Rich region. Denoting by $\hat{L}_v^R$ the relative change in the area of variant v in Rich, Equation (9) becomes $\pi_1^R \hat{L}_1^R + \pi_2^R \hat{L}_2^R = \hat{L}^R$, and Equation (10) becomes $\hat{Y}_v^R = \left(\hat{L}^R\right)^{\frac{1-\rho^R}{\theta^R}} \left(\hat{L}_v^R\right)^{1-\frac{1-\rho^R}{\theta^R}}$. In addition, the five-fold exogenous increase in the share of organic cropland in Rich translates to $5 = \frac{\hat{L}_2^R}{\hat{L}^R}$.

Table 8: Price and welfare effects of a five-fold increase in the organic farmland share in the Rich region

ϵ^P	ϵ^R	σ^i	$\frac{\theta^i}{1-\rho^i}$	ϕ	ψ	$\hat{X}_2^{PR}$	$\hat{P}^P$	$\hat{P}^R$	$\frac{\Delta\text{CS}}{V}$ (%)	$\frac{\Delta\text{LR}^P}{\text{LR}^P}$ (%)	$\frac{\Delta\text{LR}^R}{\text{LR}^R}$ (%)	$\frac{\Delta\text{LR}}{V}$ (%)	$\frac{\Delta\text{W}}{V}$ (%)	$\hat{L}^R_{\hat{P}^P=1}$
0.6	0.3	1.5	1.52	0.25	0.80	0	1.012	1.001	-0.833	3.850	-1.378	0.675	-0.158	1.029
0.6	0.1	1.5	1.52	0.25	0.80	0	1.012	1.001	-0.838	3.871	-1.355	0.680	-0.158	1.028
0.3	0.3	1.5	1.52	0.25	0.80	0	1.023	1.006	-1.734	7.477	2.098	1.573	-0.161	1.029
0.6	0.3	0.1	1.52	0.25	0.80	0	1.018	0.973	-0.301	5.697	-20.000	0.011	-0.290	1.045
0.6	0.3	0.5	1.52	0.25	0.80	0	1.014	0.993	-0.712	4.435	-6.250	0.521	-0.191	1.034
0.6	0.3	2.5	1.52	0.25	0.80	0.118	1.011	1.002	-0.823	3.660	-0.676	0.676	-0.147	1.027
0.6	0.3	1.5	1.10	0.25	0.80	0.856	1.003	1.000	-0.232	1.061	-0.285	0.191	-0.041	1.008
0.6	0.3	1.5	2.50	0.25	0.80	0	1.020	0.991	-1.008	6.389	-11.017	0.640	-0.368	1.048
0.6	0.3	1.5	5.00	0.25	0.80	0	1.025	0.982	-1.041	8.106	-22.555	0.340	-0.701	1.062
0.6	0.3	1.5	10.00	0.25	0.80	0	1.027	0.977	-1.021	8.877	-30.113	0.075	-0.946	1.068
0.6	0.3	1.5	1.52	0.20	0.80	0	1.012	1.001	-0.843	4.897	-1.189	0.712	-0.131	1.030
0.6	0.3	1.5	1.52	0.30	0.80	0.033	1.012	1.001	-0.817	3.164	-1.629	0.633	-0.184	1.029
0.6	0.3	1.5	1.52	0.25	0.75	0	1.012	0.999	-0.768	3.913	-2.853	0.606	-0.162	1.029

Notes: $\psi = \frac{\tau_2^{PR} X_2^{PR} + X_2^{RR}}{Y_2^P + Y_2^R}$, $V = P^P C^P + P^R C^R$, $\Delta\text{LR} = \Delta\text{LR}^P + \Delta\text{LR}^R$, $\Delta\text{W} = \Delta\text{CS} + \Delta\text{LR}$. Relative changes in regional consumer surplus can be obtained as $\frac{\Delta U^i}{P^i C^i} \approx 1 - \hat{P}^i$. The column labeled $\hat{X}_2^{RP}$ indicates the change the in the quantity of organic crops grown in Poor available in Rich. The column labeled $\hat{L}^R_{\hat{P}^P=1}$ indicates the relative change in the land area in Rich that would leave the food price in Poor unchanged.

0.6% in Rich. This parameterization corresponds to the lowest value of the food demand elasticity in Poor, which consumes the most food. Not surprisingly then, the acreage shift is absorbed by relatively large increases in food prices and the largest decrease in overall consumer surplus, -1.7% relative to total food expenditures.

Across all parameterizations, land rents increase in the aggregate, reflecting an overall decrease in food production. Such a result is indeed a likely outcome of policy-induced expansions of production of credence-attribute products. Such policies tend to harm consumers as they distort the product mix. Since the food price index is a sufficient statistic for consumer welfare effects (see Equation (17)), the food price must increase. With inelastic food demand, an increase in the food price will tend to also increase returns to scarce factors such as land. This effect can be seen in the first term of Equation (25), which is positive for $\epsilon^i < 1$.[27] Regionally, land rents always increase in Poor, and decrease in Rich in all but one parameterization. Land rent effects in Rich, however, need to be interpreted with caution as they ignore any redistribution scheme used to incentivize organic conversion.

Net social welfare effects are the sum of the change in consumer welfare and land rents, and are small, less than 1% of the aggregate value of initial food expenditures. In summary, the organic land-share expansion in Rich mostly transfers welfare from consumers in Poor and landowners in Rich (absent redistribution) towards landowners in Poor, and, possibly, consumers in Rich, especially if land conversion is elastic with respect to relative returns.

Our simulations also suggest that disappearance of organic trade from Poor to Rich countries is a likely outcome of the organic expansion process in Rich. Our model does not consider a reversal of trade with Rich becoming an exporter of organic crops to Poor. Such trade reversal is unlikely due to discontinuous costs associated with reversing importer-exporter roles and the fact that such trades of a subsidized commodity would likely be challenged under WTO rules (Gulotty, 2022).

The last column of Table 8 reports the relative increase in Rich's cropland area that would offset the food price increase in Poor.[28] Across parameterizations, this value ranges from 0.8% to 6.8%, with a central value of about 3%. Not surprisingly, the increase in Rich's cropland is largest for values of $\frac{\theta^i}{1-\rho^i}$ reflecting more homogeneous land, as reductions in conventional output then more closely follow reductions in conventional acreage. Note that our model treats the additional area as being of the same nature as that already used as cropland in the baseline; in particular the joint distribution of crop yields is assumed to be identical in terms of average yields, yield heterogeneity, and the correlation between variant yields. While it is difficult to assess the extent to which yield heterogeneity and yield correlation would compare between baseline and additional

[27] The second term reflects changes in food processing costs across variants, and vanishes if $\phi_v^i = 1$.

[28] Note that this analysis is intended only as an illustration of how policy-driven organic expansion could impact the landbase in agriculture. We do not propose that land expansion solely in Rich would be an equilibrium outcome from expansion of organic production.

cropland, one could reasonably posit that average yields would be lower in newly claimed areas. If so, the cropland increase indicated by our model would represent a lower bound to the actual increase needed to offset consumer effects in Poor. Conversion of existing land into cropland entails adverse environmental effects, notably in terms of greenhouse gas emissions from land-use change (Burney, Davis, and Lobell, 2010).

Another way to describe welfare impacts while conveying the uncertainty surrounding our estimates is to draw parameter values from a prior distribution and report the distribution of the calculated effects. We perform this exercise by drawing 10,000 values of each of the six key parameters listed in Table 8 from independent distributions. We choose these distributions so that their expectation is equal to the central values reported in the first line of Table 8. The demand elasticities ϵ^i are drawn from Fréchet distributions with shape parameter equal to 1.5. This choice leads to about 90% (resp. 96%) of the demand elasticity values in Poor (resp. Rich) being less than one, reflecting our prior that demand for food is generally inelastic. The substitution elasticities σ^i and the land heterogeneity parameters $\frac{\theta^i}{1-\rho^i}$ are also drawn from Fréchet distributions, with shape parameter equal to 2.0. The location parameter for $\frac{\theta^i}{1-\rho^i}$ is set to one to ensure that all values are strictly greater than one, as required by the model. Finally, the parameters ϕ and ψ, which represent shares, are drawn from beta distributions $\text{Beta}(10, 30)$ (expectation 0.25) and $\text{Beta}(40, 10)$ (expectation 0.80), respectively. The resulting probability density functions are depicted in Figure F.1 in Appendix F.

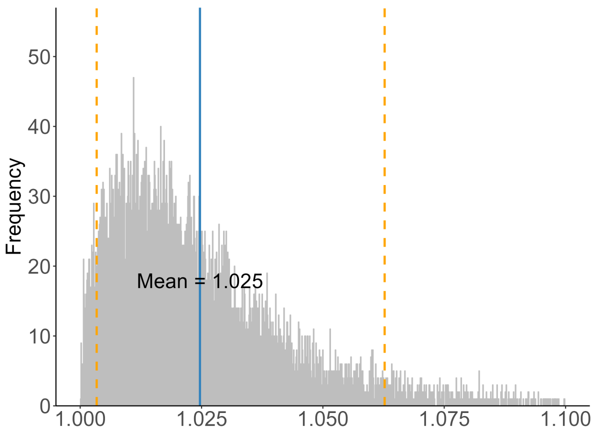
Table 9: Key statistics of the empirical distributions

	(a) $\hat{P}^P$	(b) $\hat{P}^R$	(c) $\frac{\Delta\text{LR}^P}{\text{LR}^P}$ (%)	(d) $\frac{\Delta\text{LR}^R}{\text{LR}^R}$ (%)	(e) $\frac{\Delta\text{W}}{V}$ (%)	(f) $\hat{L}^R_{\hat{P}^P=1}$ (%)
5th percentile	1.003	0.991	0.010	-0.109	-0.004	1.013
Mean	1.025	1.004	0.087	0.012	-0.002	1.027
Median	1.020	1.003	0.065	0.011	-0.001	1.024
95th percentile	1.063	1.018	0.239	0.127	-0.001	1.049

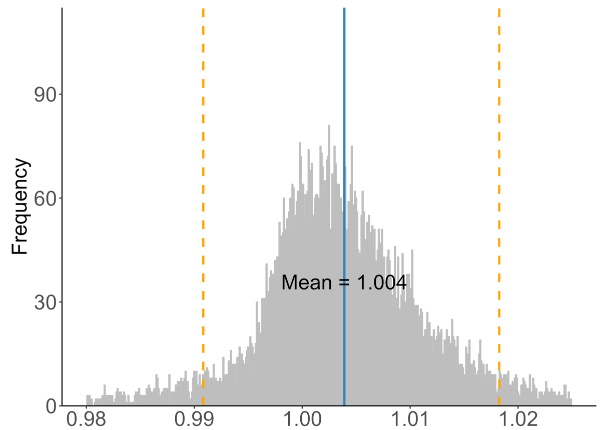
The empirical distributions of the price and welfare impacts are depicted in Figure 2, and their mean, median, and 5th and 95th percentiles are reported in Table 9. Food price changes and land rent changes for Poor and Rich regions are presented in Figure 2 panels (a) through (d), while the overall social welfare changes and the new acres in Rich needed to offset the food price increase in Poor are reported in panels (e) and (f). Since Equation (17) implies that regional consumer welfare changes are approximately equal to one minus the regional price changes, panels (a) and (b) also reflect the regional consumer welfare changes.

Our Monte Carlo simulation offers straightforward insights into significant discrepancies in

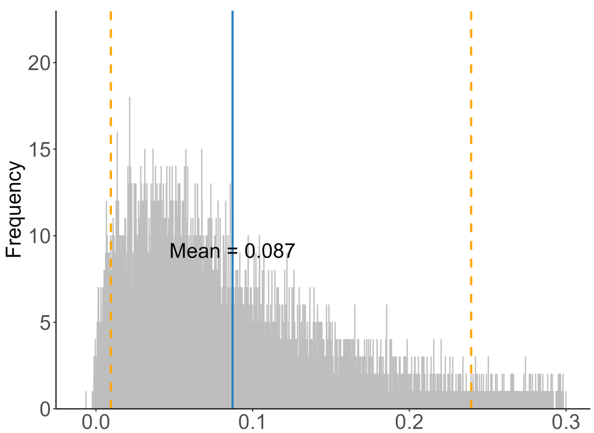
Figure 2: Empirical distributions of price and welfare effects



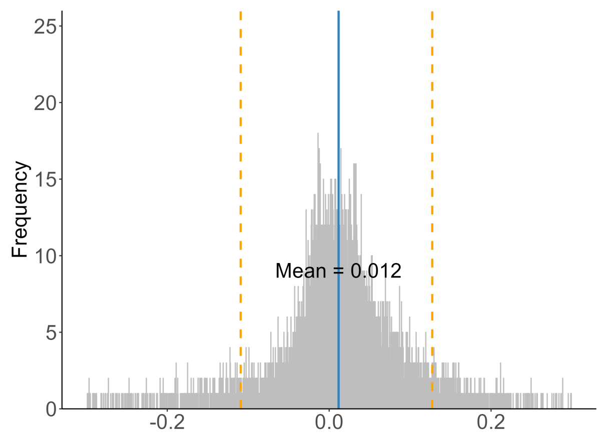
(a) Price changes in Poor



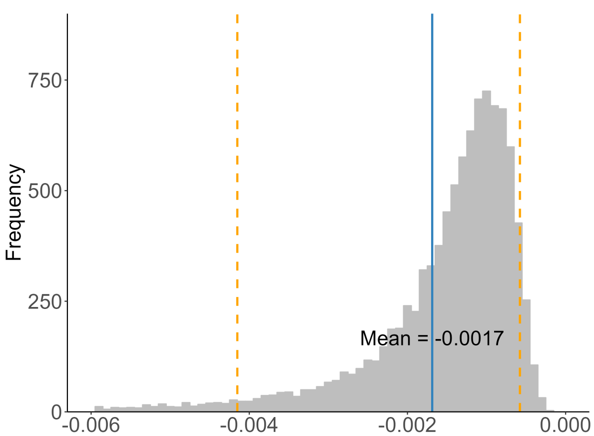
(b) Price changes in Rich



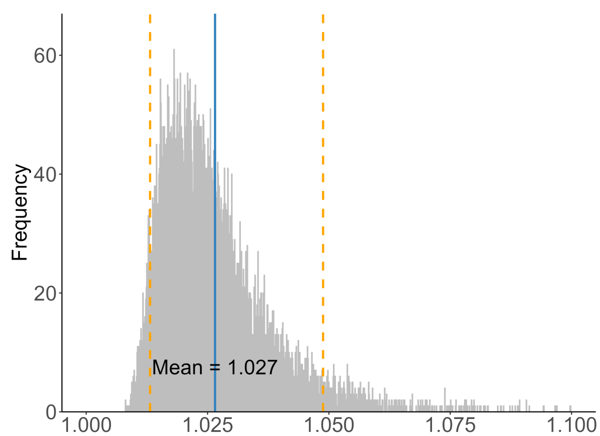
(c) Land rent changes in Poor



(d) Land rent changes in Rich



(e) Social welfare changes



(f) New acres in Rich

Note: Blue solid line indicates the mean. Dashed yellow lines indicate 5th and 95th percentiles. All empirical distribution are generated from a Monte Carlo Simulation with 10,000 Iterations and are plotted using a bin width of 0.0001.

the economic impacts of the hypothetical organic expansion on Poor and Rich regions. Consistent with the findings summarized in Table 8, the statistics reported in Table 9 underscore a substantial sensitivity of the Poor region to these shocks, as evidenced by an average price increase of 2.5% compared to a mere 0.4% in the Rich region. Land rent changes also exhibit a pronounced disparity, with an average surge of 8.7% in Poor and a small increase of 1.2% in Rich.

Despite certain negative impacts on consumers and positive ones on producers in the Poor region, uncertainty characterizes price and welfare changes in the Rich region, creating ambivalent scenarios for consumers and producers alike. Should a group incur losses, compensatory measures will be necessary. For instance, escalation in food prices could necessitate an expansion of nutrition programs for economically disadvantaged groups in Rich. Simultaneously, the prospect of reduced income could drive farmers in these countries to advocate for increased agricultural subsidies, especially when land rents decrease by 10.9% in the 5th percentile case. Such uncertainty may rationalize compensation for both consumers and producers, and thus drive up the social cost of organic expansion in rich countries.

A key implication of our study is the ripple effect triggered by organic expansion in rich countries. By reducing conventional production and, consequently, crop exports to the Poor region, it exacerbates food scarcity, driving up both food prices and land rents there. In our simulation, we find a 38.5% chance of observing a complete suppression of organic exports from Poor to Rich. However, these outcomes may not represent the full extent of potential consequences. The escalated land rents could incentivize farmers in Poor to expand agricultural land usage, potentially triggering severe environmental repercussions. Alternatively, to counterbalance the price escalations in Poor, our model suggests that the Rich region would need to expand cropland by 2.7% on average, and up to 4.9% in the 95th percentile case. This finding, while offering a potential solution to the higher food price, also calls for a comprehensive assessment of its environmental implications.

5 Conclusion

The introduction and policy-driven expansion of organic and other foods with credence-attribute characteristics has been among the major developments in the food system in the last few decades. The phenomenon has stimulated considerable economic research into various aspects impacting consumer demand for these products and their effects on market competition. The impacts of their expanding share of the agricultural land base on food prices, land rents, and consumer welfare have, however, been little studied despite calls to do so (Meemken and Qaim, 2018), and amidst growing concerns about our ability to expand food production to meet growing demands without substantial expansion of the land base in agriculture or significantly higher food prices (Hertel et al., 2016).

This study addresses this void in the literature, focusing specifically on production and consumption of organic foods. We first documented two essential facts regarding organic foods: their production and marketing are associated with higher unit costs and/or reduced yields relative to the conventional alternative, and they are produced and consumed mainly by wealthier consumers in wealthier countries. We then developed a prototype model of world food production and demand in regions designated as Rich and Poor. The model was calibrated specifically to reflect organic and conventional production, consumption, and trade of wheat, rice, corn, and soybeans, commodities that jointly comprise about two-thirds of world calorie consumption.

Our simulation analysis of a five-fold expansion in rich countries of the organic share of the land area in these commodities from our estimated baseline of about 3% found increases in the food price in Poor countries ranging from 0.3–2.7%, with most estimates near 1.2%, and commensurate reductions in consumer welfare. Results from a more systematic Monte Carlo simulation yielded larger price changes in Poor on average—about a 2.5% increase. Consumers in Rich regions were on average little impacted because a small increase in the conventional food price was largely offset by a larger decrease in the organic price. Overall land rents increased due to reduced total food production caused by the expansion of the organic land share. We also estimated that the land base in agriculture in the Rich region would need to expand by 0.8–6.8%, with most estimates around 3%, to avoid higher food prices in the Poor region from the expansion of the land base in organic production.

One limitation of our model is that it does not allow us to calculate impacts for individual countries. Indeed, significant heterogeneity remains, both in terms of agricultural productivity and consumption patterns, within the Poor region, meaning that different countries within that region could experience very different impacts. Calibrating a more granular model, both geographically and with respect to crops and food products, would require more detailed information about the trade of organic crops than that currently available. We note, however, that the model architecture utilized here could easily be extended to accommodate such refinement. Another extension could consider trade in foods, in addition to trade in crops, especially if individual countries, rather than broad regions, were chosen as the unit of analysis.

The push for expanded production of organic foods relies upon many justifications, but primary among them is the view that organic production is better for the environment than the conventional alternative due to eliminating chemical fertilizers and pesticides, mandating practices to improve soil health, and contributing to improved biodiversity (Reganold and Wachter, 2016; Seufert and Ramankutty, 2017). These claims themselves are both uncertain and controversial (Seufert and Ramankutty, 2017; Meemken and Qaim, 2018),[29] but such debates generally ignore

[29]Impacts on human health from consuming organic versus conventional foods have also been studied extensively, with some, but not all, studies finding evidence of improved nutrition from eating organic foods, but with no agreement among experts as to whether the reported differences are meaningful (Reganold and Wachter, 2016).

the impacts of expanded production of organic foods on total food production due to their higher unit costs and/or lower yields.

Unless food prices are allowed to rise, along with attendant increases in hunger and malnutrition, or significant reductions in food waste and consumption of animal proteins are achieved, the land base in agriculture will need to expand into natural habitats that are essential for carbon storage and other ecosystem services. Indeed, incentives for such expansion will be created by the higher food prices that will accompany increased production of organic and other credence-attribute products.

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Appendices

A Derivation of land shares and crop supplies

To ease notation, we omit the region superscript. Since per area costs are assumed identical for the two crop variants, land allocation decisions are based on gross revenue, that is, one can write the organic land share as:

$$\begin{aligned}
\pi_2 &= \Pr\left\{q_2 A_2(\omega) \geq q_1 A_1(\omega)\right\} \\
&= \int_0^{+\infty} \Pr\left\{A_1(\omega) \leq \frac{q_2 a_2}{q_1}, A_2(\omega) = a_2\right\} da_2 \\
&= \int_0^{+\infty} \frac{\eta\theta}{a_2}\left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}} \left[\left(\frac{q_2 a_2}{q_1 A_1}\right)^{-\frac{\theta}{1-\rho}} + \left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\right]^{-\rho} e^{-\eta\left[\left(\frac{q_2 a_2}{q_1 A_1}\right)^{-\frac{\theta}{1-\rho}} + \left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho}} da_2 \\
&= \int_0^{+\infty} \frac{\eta\theta}{a_2}\left(\frac{a_2}{A_2}\right)^{-\theta} \left[\left(\frac{q_2 A_2}{q_1 A_1}\right)^{-\frac{\theta}{1-\rho}} + 1\right]^{-\rho} e^{-\eta\left(\frac{a_2}{A_2}\right)^{-\theta}\left[\left(\frac{q_2 A_2}{q_1 A_1}\right)^{-\frac{\theta}{1-\rho}} + 1\right]^{1-\rho}} da_2 \\
&= \frac{(q_2 A_2)^{\frac{\theta\rho}{1-\rho}}}{\left[(q_1 A_1)^{\frac{\theta}{1-\rho}} + (q_2 A_2)^{\frac{\theta}{1-\rho}}\right]^{\rho}} \int_0^{+\infty} \frac{\eta\theta}{a_2}\left(\frac{a_2}{A_2}\right)^{-\theta} e^{-\eta (q_2 A_2)^{-\theta}\left[(q_1 A_1)^{\frac{\theta}{1-\rho}} + (q_2 A_2)^{\frac{\theta}{1-\rho}}\right]^{1-\rho}\left(\frac{a_2}{A_2}\right)^{-\theta}} da_2 \\
&= \frac{(q_2 A_2)^{\frac{\theta}{1-\rho}}}{(q_1 A_1)^{\frac{\theta}{1-\rho}} + (q_2 A_2)^{\frac{\theta}{1-\rho}}} \left[e^{-\eta (q_2 A_2)^{-\theta}\left[(q_1 A_1)^{\frac{\theta}{1-\rho}} + (q_2 A_2)^{\frac{\theta}{1-\rho}}\right]^{1-\rho}\left(\frac{a_2}{A_2}\right)^{-\theta}}\right]_0^{+\infty} \\
&= \frac{(q_2 A_2)^{\frac{\theta}{1-\rho}}}{(q_1 A_1)^{\frac{\theta}{1-\rho}} + (q_2 A_2)^{\frac{\theta}{1-\rho}}},
\end{aligned}$$

which leads to Equation (3).

Using Bayes' theorem, the regional supply or organic crop is then

$$\begin{aligned}
Y_2 &= L\pi_2\mathbb{E}\left[A_2(\omega)|q_2A_2(\omega)\geq q_1A_1(\omega)\right] \\
&= L\pi_2\int_0^{+\infty} a_2\frac{\Pr\left\{A_1(\omega)\leq \frac{q_2a_2}{q_1}, A_2(\omega)=a_2\right\}}{\Pr\left\{q_1A_1(\omega)\leq q_2A_2(\omega)\right\}}da_2 \\
&= L\int_0^{+\infty} a_2\Pr\left\{A_1(\omega)\leq \frac{q_2a_2}{q_1}, A_2(\omega)=a_2\right\}da_2 \\
&= L\int_0^{+\infty}\eta\theta\left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\left[\left(\frac{q_2a_2}{q_1A_1}\right)^{-\frac{\theta}{1-\rho}}+\left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\right]^{-\rho} e^{-\eta\left[\left(\frac{q_2a_2}{q_1A_1}\right)^{-\frac{\theta}{1-\rho}}+\left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho}} da_2 \\
&= L\eta\theta\frac{\left(q_2A_2\right)^{\frac{\theta\rho}{1-\rho}}}{\left[\left(q_1A_1\right)^{\frac{\theta}{1-\rho}}+\left(q_2A_2\right)^{\frac{\theta}{1-\rho}}\right]^{\rho}}\int_0^{+\infty}\left(\frac{a_2}{A_2}\right)^{-\theta} e^{-\eta\left[\left(\frac{q_2a_2}{q_1A_1}\right)^{-\frac{\theta}{1-\rho}}+\left(\frac{a_2}{A_2}\right)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho}} da_2 \\
&= L\eta\theta\left(\pi_2\right)^{\rho}\int_0^{+\infty}\left(\frac{a_2}{A_2}\right)^{-\theta} e^{-\eta\left(\pi_2\right)^{\rho-1}\left(\frac{a_2}{A_2}\right)^{-\theta}} da_2\ .
\end{aligned}$$

Proceed with the change of variable $u\equiv\eta\left(\pi_2\right)^{\rho-1}\left(\frac{a_2}{A_2}\right)^{-\theta}$, which implies that $\left(\frac{a_2}{A_2}\right)^{-\theta}=\eta^{-1}\left(\pi_2\right)^{1-\rho}u$, $a_2=A_2\eta^{\frac{1}{\theta}}\left(\pi_2\right)^{\frac{\rho-1}{\theta}}u^{-\frac{1}{\theta}}$, and thus

$$da_2=-\frac{1}{\theta}A_2\eta^{\frac{1}{\theta}}\left(\pi_2\right)^{\frac{\rho-1}{\theta}}u^{-1-\frac{1}{\theta}}\ .$$

We can then write

$$Y_2=LA_2\left(\pi_2\right)^{1-\frac{1-\rho}{\theta}}\eta^{\frac{1}{\theta}}\int_0^{+\infty}u^{-\frac{1}{\theta}}e^{-u}du\ .$$

Since the parameter η is set equal to $\Gamma\left(\frac{\theta-1}{\theta}\right)^{-\theta}$, where $\Gamma(t)=\int_0^{+\infty}u^{t-1}e^{-u}du$, we have that $\eta^{\frac{1}{\theta}}=\Gamma\left(\frac{\theta-1}{\theta}\right)^{-1}=\left(\int_0^{+\infty}u^{-\frac{1}{\theta}}e^{-u}du\right)^{-1}$ and therefore $Y_2=LA_2\left(\pi_2\right)^{1-\frac{1-\rho}{\theta}}$. This gives Equation (4).

B Derivation of welfare effects

In this appendix we show the steps in the derivation of Equations (17), (20), (21), and (25) in the main text. Since consumer incomes do not change, from Walras' Law the change in consumption of the numeraire is $C_0^{i\prime} - C_0^i = P^i C^i - P^{i\prime} C^{i\prime}$. Therefore, we have

$$\begin{aligned}
\Delta U^i &= U^{i\prime} - U^i \\
&= \frac{\left(\beta^i\right)^{\frac{1}{\epsilon^i}}}{1-\frac{1}{\epsilon^i}} \left[\left(C^{i\prime}\right)^{1-\frac{1}{\epsilon^i}} - \left(C^i\right)^{1-\frac{1}{\epsilon^i}}\right] + P^i C^i - P^{i\prime} C^{i\prime} \\
&= \frac{\left(\beta^i\right)^{\frac{1}{\epsilon^i}} \left(C^i\right)^{1-\frac{1}{\epsilon^i}}}{1-\frac{1}{\epsilon^i}} \left[\left(\hat{C}^i\right)^{1-\frac{1}{\epsilon^i}} - 1\right] + P^i C^i \left(1 - \hat{P}^i \hat{C}^i\right) \\
&= \frac{P^i C^i}{1-\frac{1}{\epsilon^i}} \left[\left(\hat{C}^i\right)^{1-\frac{1}{\epsilon^i}} - 1\right] + P^i C^i \left(1 - \hat{P}^i \hat{C}^i\right)
\end{aligned}$$

where we have used the fact that $C^i = \beta^i \left(P^i\right)^{-\epsilon^i}$. Therefore,

$$\begin{aligned}
\frac{\Delta U^i}{P^i C^i} &= \frac{\left(\hat{C}^i\right)^{1-\frac{1}{\epsilon^i}} - 1}{1-\frac{1}{\epsilon^i}} + 1 - \left(\hat{P}^i\right)^{1-\epsilon^i} \\
&= \frac{\left(\hat{P}^i\right)^{1-\epsilon^i} - 1}{1-\frac{1}{\epsilon^i}} + 1 - \left(\hat{P}^i\right)^{1-\epsilon^i} \\
&= \frac{1 - \left(\hat{P}^i\right)^{1-\epsilon^i}}{1-\epsilon^i} .
\end{aligned}$$

For values of $\hat{P}^i$ close to one, which is typically the case in our simulations, this last expression is close to $1 - \hat{P}^i$. Indeed, $\left(\hat{P}^i\right)^{1-\epsilon^i} = \exp\left((1-\epsilon^i)\ln \hat{P}^i\right) \approx \exp\left((1-\epsilon^i)(\hat{P}^i - 1)\right) = \sum_{k=0}^{+\infty} \frac{\left((1-\epsilon^i)(\hat{P}^i-1)\right)^k}{k!} \approx 1 + (1-\epsilon^i)(\hat{P}^i - 1)$, giving the result.

Since the consumer utility is quasilinear and income does not change, the change in utility is equal to the change in consumer surplus, the compensating variation, and the equivalent variation for the price changes.

On the production side, the change in land rents is

$$\begin{aligned}
\Delta \mathrm{LR}^i &= \sum_v q_v^{i\prime} Y_v^{i\prime} - q_v^i Y_v^i \\
&= \sum_v q_v^i Y_v^i \left(\hat{q}_v^i \hat{Y}_v^i - 1\right)
\end{aligned}$$

and therefore

$$\begin{aligned}\frac{\Delta \mathrm{LR}^i}{\mathrm{LR}^i} &= \sum_v \frac{q_v^i Y_v^i}{\sum_u q_u^i Y_u^i}\left(\hat{q}_v^i \hat{Y}_v^i - 1\right)\\ &= \sum_v \delta_v^i \left(\hat{q}_v^i \hat{Y}_v^i - 1\right)\\ &= \left(\sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i\right) - 1\end{aligned}$$

where the last equality obtains from $\sum_v \delta_v^i = 1$. One may also express the change in land rents relative to the total value of food expenditures,

$$\begin{aligned}\frac{\Delta \mathrm{LR}^i}{\sum_j P^j C^j} &= \frac{\Delta \mathrm{LR}^i}{\mathrm{LR}^i}\frac{\mathrm{LR}^i}{\sum_j \mathrm{LR}^j}\frac{\sum_j \mathrm{LR}^j}{\sum_j P^j C^j}\\ &= \phi \delta^i \left[\left(\sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i\right) - 1\right] .\end{aligned}$$

Summing over regions, we obtain the aggregate land rent effect:

$$\frac{\sum_i \Delta \mathrm{LR}^i}{\sum_i P^i C^i} = \phi \left[\left(\sum_i \delta^i \sum_v \delta_v^i \hat{q}_v^i \hat{Y}_v^i\right) - 1\right] .$$

This expression can be rearranged to reflect changes on the consumption side. First note that, using the convention $\hat{X}_v^{ij} = 1$ whenever $X_v^{ij} = 0$ (in which case $\chi_v^{ij} = \gamma_v^{ij} = 0$), we can write

$$\sum_{j|X_v^{ij}>0} \chi_v^{ij} \hat{X}_v^{ij} = \sum_j \chi_v^{ij} \hat{X}_v^{ij}$$

as well as

$$\sum_{i|X_v^{ij}>0} \gamma_v^{ij} \hat{X}_v^{ij} = \sum_i \gamma_v^{ij} \hat{X}_v^{ij}$$

Using the equations describing the equilibrium in relative changes, as well as Equation (23) (and remembering that $\delta_v^i = \pi_v^i$), we then have

$$\begin{aligned}
\frac{\sum_i \Delta \mathrm{LR}^i}{\sum_i P^i C^i} &= \phi \sum_i \delta^i \sum_v \delta_v^i \hat{q}_v^i \sum_j \chi_v^{ij} \hat{X}_v^{ij} - \phi \\
&= \sum_j \sum_v \hat{q}_v^j \sum_i \phi \delta^i \pi_v^i \chi_v^{ij} \hat{X}_v^{ij} - \phi \\
&= \sum_j \sum_v \hat{q}_v^j \sum_i \alpha^j b_v^j \phi_v^j \gamma_v^{ij} \hat{X}_v^{ij} - \phi \\
&= \sum_j \alpha^j \sum_v b_v^j \hat{q}_v^j \phi_v^j \hat{C}_v^j - \phi \\
&= \sum_j \alpha^j \sum_v b_v^j \left(\hat{p}_v^j + \phi_v^j - 1\right) \hat{C}_v^j - \phi \\
&= \sum_j \alpha^j \sum_v b_v^j \left(\hat{P}^j\right)^{\sigma^j - \epsilon^j} \left(\hat{p}_v^j\right)^{1-\sigma^j} - \sum_j \alpha^j \sum_v b_v^j \left(1 - \phi_v^j\right) \hat{C}_v^j - \phi \\
&= \sum_j \alpha^j \left(\hat{P}^j\right)^{1-\epsilon^j} - \sum_j \alpha^j \sum_v b_v^j \left(1 - \phi_v^j\right) \hat{C}_v^j - \phi \ .
\end{aligned}$$

Finally, note that by summing Equation (23) over the indices i, j, and v, we obtain

$$\phi = \sum_j \alpha^j \sum_v b_v^j \phi_v^j \ ,$$

which, using the facts that $\sum_i \alpha^i = 1$ and $\sum_v b_v^i = 1$, implies that

$$\frac{\sum_i \Delta \mathrm{LR}^i}{\sum_i P^i C^i} = \sum_i \alpha^i \left[\left(\hat{P}^i\right)^{1-\epsilon^i} - 1\right] - \sum_i \alpha^i \sum_v b_v^i \left(1 - \phi_v^i\right) \left(\hat{C}_v^i - 1\right) \ .$$

C Equality of crop variant production value shares and land shares

To ease notation, we omit the region superscript. By definition, the share of variant v in regional crop production is

$$\begin{aligned}
\delta_v &= \frac{q_v Y_v}{\sum_u q_u Y_u} \\
&= \frac{q_v L A_v \left(\pi_v\right)^{1-\frac{1-\rho}{\theta}}}{\sum_u q_u L A_u \left(\pi_u\right)^{1-\frac{1-\rho}{\theta}}} \\
&= \frac{\left(\pi_v\right)^{\frac{1-\rho}{\theta}} \left(\pi_v\right)^{1-\frac{1-\rho}{\theta}}}{\sum_u \left(\pi_u\right)^{\frac{1-\rho}{\theta}} \left(\pi_u\right)^{1-\frac{1-\rho}{\theta}}} \\
&= \frac{\pi_v}{\sum_u \pi_u} \\
&= \pi_v \ ,
\end{aligned}$$

where we have used (3) and (4).

D Relationship between the cross-price elasticity and the elasticity of substitution

This section derives the relationship between the elasticity of organic food demand with respect to the price of conventional food and the elasticity of substitution between conventional and organic food.

First note that due to quasilinearity, the uncompensated and compensated demands are one and the same. Starting from Equation (1), we get that the cross-price compensated elasticity is

$$\begin{aligned}
\frac{\partial C_2^i}{\partial p_1} \frac{p_1}{C_2^i} &= \left(\sigma^i - \epsilon^i\right) \left(P^i\right)^{-1} p_1 \frac{\partial P^i}{\partial p_1} \\
&= \left(\sigma^i - \epsilon^i\right) \left(P^i\right)^{-1} p_1 \left(P^i\right)^{\sigma^i} \beta_1^i \left(p_1\right)^{-\sigma^i} \\
&= \left(\sigma^i - \epsilon^i\right) \beta_1^i \left(P^i\right)^{\sigma^i - 1} \left(p_1\right)^{1-\sigma^i} \ .
\end{aligned}$$

The share of conventional in food expenditures is equal to

$$\begin{aligned}
b_1^i &= \frac{p_1 C_1^i}{p_1 C_1^i + p_2 C_2^i} \\
&= \frac{\beta^i \beta_1^i \left(P^i\right)^{\sigma^i - \epsilon^i} \left(p_1\right)^{1-\sigma^i}}{\beta^i \left(P^i\right)^{\sigma^i - \epsilon_i} \left(\beta_1^i \left(p_1\right)^{1-\sigma^i} + \beta_2^i \left(p_2\right)^{1-\sigma^i}\right)} \\
&= \beta_1^i \left(P^i\right)^{\sigma^i - 1} \left(p_1\right)^{1-\sigma^i} \quad .
\end{aligned}$$

Therefore, we have that $\frac{\partial C_2^i}{\partial p_1} \frac{p_1}{C_2^i} = b_1^i \left(\sigma^i - \epsilon^i\right)$, which establishes that $\sigma^i = \epsilon^i + \frac{1}{b_1^i} \frac{\partial C_2^i}{\partial p_1} \frac{p_1}{C_2^i}$.

E GAMS code for policy analysis

```
SETS  I "REGIONS"   /POOR,RICH/
      V "VARIANTS"  /CONV,ORG/ ;
ALIAS(I,J) ;

PARAMETERS  EPSILON(I)          "FOOD DEMAND ELASTICITY IN REGION I"
            SIGMA(I)            "SUBSTITUTION ELASTICITY IN CONSUMPTION
               BETWEEN VARIANTS IN REGION I"
            THETA(I)            "LAND HETEROGENEITY"
            LSHARE(I,V)         "SHARE OF LAND IN VARIANT V IN REGION I"
            ALPHA(I)            "CONSUMER EXPENDITURE SHARE FROM REGION I"
            B(I,V)              "CONSUMER EXPENDITURE SHARE ON VARIANT V IN
               REGION I"
            DDELTA(I,V)         "SHARE OF VARIANT V IN VALUE OF CROP
               PRODUCTION IN REGION I"
            DELTA(I)            "SHARE OF REGION I IN VALUE OF CROP
               PRODUCTION"
            CHI(I,J,V)          "SHARE OF REGION I'S PRODUCTION OF VARIANT V
               SHIPPED TO REGION J"
            GGAMMA(I,J,V)       "SHARE OF REGION J'S AVAILABILITY OF VARIANT
               V ORIGINATING IN REGION I"
            PHI(I,V)            "CROP SHARE OF THE FOOD DOLLAR FOR VARIANT V
               IN REGION I"
            ;

SCALAR     CAPPHI               "OVERALL CROP SHARE OF THE FOOD DOLLAR"
           ;

**ELASTICITIES
EPSILON("POOR") = 0.6 ;
```

```
EPSILON("RICH") = 0.3 ;
SIGMA(I) = 1.5 ;
THETA(I) = 1.52 ;

**OBSERVED SHARES
ALPHA("POOR") = 0.67 ;
ALPHA("RICH") =1-ALPHA("POOR") ;

B("POOR","ORG") = 0.003 ;
B("RICH","ORG")= 0.040 ;
B(I,"CONV")=1-B(I,"ORG") ;

LSHARE("POOR","ORG") = 0.007 ;
LSHARE("RICH","ORG") = 0.030 ;
LSHARE(I,"CONV") = 1-LSHARE(I,"ORG") ;

DELTA("POOR") = 0.78 ;
DELTA("RICH") = 1-DELTA("POOR") ;

CAPPHI = 0.25 ;

**RECOVERY OF SHARES TRADED
PARAMETERS    GPPRODUCTION(I,V)    "CROP CALORIES OF VARIANT V PRODUCED IN REGION I"
              TRADE(I,J,V)         "CROP SHIPMENT OV VARIANT V FROM I TO J"   ;

TABLE  DATA
             ORG              TOTAL         NETEXPORTS
RICH     3.80e+13          2.11e+15         3.17e+14
POOR     2.98e+13          4.94e+15        -3.06e+14   ;

GPPRODUCTION(I,"ORG") = DATA(I,"ORG") ;
GPPRODUCTION(I,"CONV") = DATA(I,"TOTAL")-DATA(I,"ORG")  ;

SCALAR AALPHA        "SHARE OF RICH REGION IN VALUE OF CONSUMPTION OF ORGANIC VARIANT"
       PSI           "SHARE OF TOTAL ORGANIC CROP (IN CALORIES) USED BY RICH REGION" /0.80/

       AVGTAU        "AVERAGE ICEBERG TRADE COST"
       TAU           "ICEBERG TRADE COST FOR TRADE OF ORGANIC FROM POOR TO RICH" /1.05/
       ;
```

```
AALPHA=B("RICH","ORG")*ALPHA("RICH")/(B("POOR","ORG")*ALPHA("POOR")+B("RICH","ORG")*ALPHA("RICH")) ;
AVGTAU=-DATA("RICH","NETEXPORTS")/DATA("POOR","NETEXPORTS") ;

TRADE("POOR","RICH","ORG") = PSI*SUM(I,GPPRODUCTION(I,"ORG")) -GPPRODUCTION("RICH","ORG") ;
TRADE("RICH","POOR","CONV") = DATA("RICH","NETEXPORTS") + TRADE("POOR","RICH","ORG")/TAU ;

CHI("RICH","POOR","CONV") =  TRADE("RICH","POOR","CONV")/GPPRODUCTION("RICH","CONV") ;
CHI("POOR","RICH","CONV") = 0 ;
CHI("RICH","POOR","ORG") = 0 ;
CHI("POOR","RICH","ORG") =  TRADE("POOR","RICH","ORG")/GPPRODUCTION("POOR","ORG");

CHI("RICH","RICH","CONV") = 1-CHI("RICH","POOR","CONV") ;
CHI("RICH","RICH","ORG") = 1-CHI("RICH","POOR","ORG") ;
CHI("POOR","POOR","ORG") = 1-CHI("POOR","RICH","ORG") ;
CHI("POOR","POOR","CONV") = 1-CHI("POOR","RICH","CONV") ;

DISPLAY GPPRODUCTION,AALPHA,AVGTAU,TAU,PSI,TRADE,CHI ;

************************************

**DEDUCED PARAMETER VALUES
DDELTA(I,V) = LSHARE(I,V) ;
PHI(J,V)$B(J,V) = CAPPHI*SUM(I,DELTA(I)*LSHARE(I,V)*CHI(I,J,V))/ALPHA(J)/B(J,V) ;
GGAMMA(I,J,V)$B(J,V) = CAPPHI*DELTA(I)*LSHARE(I,V)*CHI(I,J,V)/ALPHA(J)/B(J,V)/PHI(J,V)  ;

DISPLAY DELTA,DDELTA,ALPHA,B,PHI,GGAMMA ;

*************************************

SCALAR PI2R "POLICY-INDUCED CHANGE IN ORGANIC ACREAGE SHARE" ;

POSITIVE VARIABLES  PINDEX(I)  "CHANGE IN PRICE INDEX IN REGION I"
                    P(I,V)     "CHANGE IN PRICE OF FOOD VARIANT V IN REGION I"
                    Y(I,V)     "CHANGE IN SUPPLY OF CROP VARIANT V IN REGION I"
```

```
                    L(I,V)      "CHANGE IN AREA OF CROP VARIANT V IN REGION I"
                    NEWACRES    "ACREAGE EXPANSION IN RICH TO OFFSET POLICY"
                    ;

VARIABLES X(I,J,V)  "CHANGE IN AVAILABILILTY OF VARIANT V FROM REGION I IN REGION J"
          Q(I,V)    "CHANGE IN PURCHASE PRICE OF CROP VARIANT V IN REGION I"
          OBJ       "FAKE OBJECTIVE"
          CS        "CHANGE IN CONSUMER SURPLUS"
          PS        "CHANGE IN PRODUCER SURPLUS"
          SW        "CHANGE IN SOCIAL WELFARE"
          ;

**POLICY SHOCK
PI2R = 5 ;

EQUATIONS PRICEINDEX(I)          "PRICE INDEX FOR REGION I"
          DEMAND(I,V)            "DEMAND FOR VARIANT V IN REGION I"
          SHIPMENTS(I,V)         "SHIPMENTS OF VARIANT V FROM REGION I"
          NONNEGTRADE(I,J,V)     "NONNEGATIVE TRADE FLOWS"
          ARBITRAGE(V)           "PROPORTIONAL CHANGE IN CROP PRICES BETWEEN REGIONS"
          ARBITRAGECONV          "PROPORTIONAL CHANGE IN CONV CROP PRICE BETWEEN REGIONS"
          NOORGTRADE             "ELIMINATION OF ORGANIC TRADE"
          CROPNETPRICE(I,V)      "RELATION BETWEEN FOOD PRICE AND FARM PRICE FOR VARIANT V"
          NONNEGCROPPRICE(V)     "NONNEGATIVE CROP PRICES IN POOR"
          ACRES(I)               "REGIONAL LAND CONSTRAINT"
          ACRESEXPAND            "LAND CONSTRAINT WITH LAND EXPANSION IN RICH"
          ACRESPOOR              "LAND CONSTRAINT IN POOR"
          ACRESALLOCATION        "ACREAGE ALLOCATION IN POOR REGION"
          PRODUCTION(I,V)        "OUTPUT AS FUNCTION OF ACREAGE SHARE"
          PRODUCTIONPOOR(V)      "OUTPUT AS FUNCTION OF ACREAGE SHARE IN POOR"
          PRODUCTIONEXPAND(V)    "OUTPUT AS FUNCTION OF ACREAGE WITH LAND EXPANSION IN RICH"
          PI2CHANGE              "CHANGE IN ORGANIC ACREAGE IN RICH REGION"
          PI2CHANGEEXPAND        "CHANGE IN ORGANIC ACREAGE WITH LAND EXPANSION IN RICH"
          PI2CHANGEALL(I)        "CHANGE IN ORGANIC ACREAGE IN BOTH REGIONS"
          OBJECTIVE              "FAKE OBJECTIVE FUNCTION"
          CONSSURP               "CONSUMER SURPLUS"
          LANDRENT               "RENT TO LAND OWNERSHIP"
```

```
          WELFARE                "SOCIAL WELFARE"
          PRICEOFFSET            "ZERO FOOD PRICE EFFECT IN POOR"
          ;

PRICEINDEX(I)..              PINDEX(I) =E= SUM(V$B(I,V),B(I,V)*P(I,V)**(1-SIGMA(I)))**(1/(1-SIGMA(I))) ;
PRICEOFFSET..                1 =E= PINDEX("POOR") ;
DEMAND(I,V)$B(I,V)..         SUM(J$GGAMMA(J,I,V), GGAMMA(J,I,V)*X(J,I,V)) =E= PINDEX(I)**(SIGMA(I)-EPSILON(I))*P(I,V)**(-SIGMA(I)) ;
SHIPMENTS(I,V)..             Y(I,V) =E= SUM(J$CHI(I,J,V),CHI(I,J,V)*X(I,J,V)) ;
NONNEGTRADE(I,J,V)..         0 =L= X(I,J,V) ;
ARBITRAGE(V)..               Q("POOR",V) =E= Q("RICH",V) ;
NOORGTRADE..                 0 =E= X("POOR","RICH","ORG") ;
ARBITRAGECONV..              Q("POOR","CONV") =E= Q("RICH","CONV") ;
CROPNETPRICE(I,V)$B(I,V)..   P(I,V) =E= PHI(I,V)*Q(I,V)+1-PHI(I,V) ;
NONNEGCROPPRICE(V)..         0 =L= Q("POOR",V) ;
ACRES(I)..                   1 =E= SUM(V,LSHARE(I,V)*L(I,V))  ;
ACRESEXPAND..                NEWACRES =E= SUM(V,LSHARE("RICH",V)*L("RICH",V)) ;
ACRESPOOR..                  1 =E= SUM(V,LSHARE("POOR",V)*L("POOR",V))  ;
PI2CHANGE..                  PI2R =E= L("RICH","ORG")  ;
PI2CHANGEEXPAND..            PI2R =E= L("RICH","ORG")/NEWACRES ;
ACRESALLOCATION..            L("POOR","CONV") =E= Q("POOR","CONV")**THETA("POOR")/SUM(V,LSHARE("POOR",V)*Q("POOR",V)**THETA("POOR")) ;
PI2CHANGEALL(I)..            PI2R =E= L(I,"ORG") ;
PRODUCTION(I,V)..            Y(I,V) =E= L(I,V)**(1-1/THETA(I)) ;
PRODUCTIONPOOR(V)..          Y("POOR",V) =E= L("POOR",V)**(1-1/THETA("POOR")) ;
PRODUCTIONEXPAND(V)..        Y("RICH",V) =E= NEWACRES**(1/THETA("POOR"))*L("RICH",V)**(1-1/THETA("POOR")) ;
OBJECTIVE..                  OBJ =L= 1 ;
CONSSURP..                   CS  =E= SUM(I,ALPHA(I)*(1-PINDEX(I)**(1-EPSILON(I)))/(1-EPSILON(I)))   ;
LANDRENT..                   PS =E= CAPPHI*(SUM(I,DELTA(I)*SUM(V,DDELTA(I,V)*Q(I,V)*Y(I,V)))-1) ;
WELFARE..                    SW =E= 10E6*(CS+PS) ;

**STARTING VALUES
P.L(I,V) = 1 ;
PINDEX.L(I) = 1 ;
Q.L(I,V) = 1 ;
X.L(I,J,V) = 1 ;
```

```
Y.L(I,V) = 1 ;
NEWACRES.L = 1 ;
OBJ.L = 0 ;

**ZERO TRADES
X.FX(I,J,V)$(CHI(I,J,V)=0) = 1 ;

**BOUNDS TO AID WITH ALGORITHM CONVERGENCE (CHECK THAT THEY ARE NOT BINDING)
P.LO(I,V) = 0.0001 ;
P.UP(I,V) = 1.9 ;
L.LO(I,V) = 0.0001 ;

MODEL TEST /PRICEINDEX,DEMAND,SHIPMENTS,NONNEGTRADE,ARBITRAGE,CROPNETPRICE,
    NONNEGCROPPRICE,ACRES,PRODUCTION,CONSSURP,LANDRENT,WELFARE/ ;
**THIS MODEL SHOULD REPLICATE THE UNDISTORTED EQUILIBRIUM
SOLVE TEST USING NLP MAXIMIZING SW

MODEL EQUILIBRIUM1 /PRICEINDEX,DEMAND,SHIPMENTS,NONNEGTRADE,ARBITRAGE,
    CROPNETPRICE,NONNEGCROPPRICE,ACRES,PI2CHANGE,ACRESALLOCATION,PRODUCTION,
    OBJECTIVE/ ;
MODEL OFFSET1 /PRICEINDEX,PRICEOFFSET,DEMAND,SHIPMENTS,NONNEGTRADE,ARBITRAGE,
    CROPNETPRICE,NONNEGCROPPRICE,ACRESEXPAND,ACRESPOOR,PI2CHANGEEXPAND,
    ACRESALLOCATION,PRODUCTIONPOOR,PRODUCTIONEXPAND,OBJECTIVE/ ;
**THESE MODELS PROVIDE COUNTERFACTUAL VALUES WHENEVER ORGANIC TRADE IS
    PRESERVED

MODEL EQUILIBRIUM2 /PRICEINDEX,DEMAND,SHIPMENTS,NONNEGTRADE,NOORGTRADE,
    ARBITRAGECONV,CROPNETPRICE,NONNEGCROPPRICE,ACRES,PI2CHANGE,ACRESALLOCATION
    ,PRODUCTION,OBJECTIVE/ ;
MODEL OFFSET2 /PRICEINDEX,PRICEOFFSET,DEMAND,SHIPMENTS,NONNEGTRADE,NOORGTRADE,
    ARBITRAGECONV,CROPNETPRICE,NONNEGCROPPRICE,ACRESEXPAND,ACRESPOOR,
    PI2CHANGEEXPAND,ACRESALLOCATION,PRODUCTIONPOOR,PRODUCTIONEXPAND,OBJECTIVE/
     ;
**THESE MODELS PROVIDE COUNTERFACTUAL VALUES WHENEVER ORGANIC TRADE IS
    SUPPRESSED

**MAIN PROGRAM
SOLVE EQUILIBRIUM1 USING NLP MAXIMIZING OBJ ;

PARAMETERS    DELTAU(I)     "CHANGE IN CONSUMER WELFARE IN REGION I"
              DELTACS       "CHANGE IN CONSUMER WELFARE"
              DELTARI(I)    "CHANGE IN LAND RENT IN REGION I"
              DELTAR        "CHANGE IN LAND RENT"
```

```
            C(I,V)       "REGIONAL CHANGE IN CONSUMPTION"
            DELTARW(I)   "CHANGE IN REGIONAL WELFARE"
            DELTAW       "CHANGE IN SOCIAL WELFARE"
            ;

DELTAU(I) = (1-PINDEX.L(I)**(1-EPSILON(I)))/(1-EPSILON(I)) ;
DELTACS = SUM(I,ALPHA(I)*DELTAU(I)) ;
DELTARI(I) = SUM(V,DDELTA(I,V)*Q.L(I,V)*Y.L(I,V))-1 ;
C(I,V)$B(I,V) = PINDEX.L(I)**(SIGMA(I)-EPSILON(I))*P.L(I,V)**(-SIGMA(I)) ;
DELTARW(I) = DELTAU(I) + (CAPPHI*DELTA(I)/ALPHA(I))*DELTARI(I) ;
DELTAR = SUM(I,CAPPHI*DELTA(I)*DELTARI(I)) ;
DELTAW = DELTACS+DELTAR ;

DISPLAY  DELTAU,DELTACS,DELTARI,DELTARW,DELTAR,DELTAW,P.L,PINDEX.L,C,Q.L,L.L,X
    .L;

**COUNTERFACTUAL POLICY WITH EXPANDED ACREAGE IN RICH
SOLVE OFFSET1 USING NLP MAXIMIZING OBJ ;

DISPLAY NEWACRES.L;
```

F Parameter distributions for sensitivity analysis

Figure F.1: Parameter distributions