IAV_Figures: An R project for generating main results in "Global agricultural responses to interannual climate and biophysical variability"

IAV_Figures

The goal of this R project (IAV_Figures) is to document the process of generating figures provided in the paper: "Global agricultural responses to interannual climate and biophysical variability" by Zhao*, Calvin, Wise, Patel, Snyder, Waldhoff, Hejazi, and Edmonds. The main figures in the paper can be reproduced using this R project.

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Paper abstract

Most studies assessing climate impacts on agriculture have focused on average changes in market-mediated responses (e.g., changes in land use, production, and consumption). However, the response of global agricultural markets to interannual variability in climate and biophysical shocks is poorly understood and not well represented in global economic models. Here we show a strong transmission of interannual variations in climate-induced biophysical yield shocks to agriculture markets, which is further magnified by endogenous market fluctuations generated due to producers' imperfect expectations of market and weather conditions. We demonstrate that the volatility of crop prices and consumption could be significantly underestimated (i.e., on average by 55% and 41%, respectively) by assuming perfect foresight, a standard assumption in the economic equilibrium modeling, compared with the relatively more realistic adaptive expectations. We also find heterogeneity in interannual variability across crops and regions, which is considerably mediated by international trade. Studying interannual variability provides fundamentally new insights on measuring and understanding climate impacts on global agriculture, and our framework lays the foundation for further investigating the full range of climate impacts on biophysical and human systems.

Data

In the data folder, `Fig1_2.RData` is included. This is the data processed based on raw GCAM outputs. These results are used for studying future climate impacts on agriculture with a focus the interannual variation transmission from climate and biophysical shocks to economic responses.

Uses

All the scripts can be sourced in order in `Run.R` to generate figures. Note that for ANOVA results, the code `ANOVA.R` was not sourced in`Run.R` is commented out as it takes hours (e.g., ~8 hour depending on many factors) to run.

R package version for replication

The version of R packages used is provided in the following table. Note that an older version of dplyr (0.8.5) was used initially, but we update it to dplyr (1.0.4) to use the nest_by function to accommodate broom updates.

R packages required				
scales_1.1.1	broom_0.7.0	egg_0.4.5	ggplot2_3.3.2	dplyr_1.0.4
gridExtra_2.3	extrafont_0.17	tidyr_1.1.2	cowplot_1.1.0	sf_0.9-6

Mappings to data and figures in paper

Figure number in paper	Location
Fig. 2	output/plot/Fig1
Fig. 3; Figs. S3-S5	output/plot/Fig2
Fig. 4; Figs. S8-S10	output/plot/Fig3
Fig. 5; Figs. S11-13; Fig S15	output/plot/Fig4
Figs. S17-S18	output/plot/OtherSIFigs
Table1 & Table S4	output/plot/ANOVA

Examples of key results (figures in paper)

Fig. 2 Climate impacts on global agriculture to mid-century. Cumulative (top panels) and interannual bottom panels) climate impacts on agricultural crop harvested area (a), production (b), consumption (c), price (d), export (e), import (f), realized yield (g) and biophysical yield (h) relative to the GCAM reference scenario, estimated under adaptive expectations.Note that realized yield are results from the model after considering endogenous yield responses. Curves and shadows denote average and 10 – 90 percentile ranges of GCAM results across all crop-region combinations (biomass and fodder crops not included), respectively. Climate scenarios (two climate models by two crop models under RCP8.5 and with carbon fertilization), distinguished by color, include HadGEM2-ES & EPIC (**HE**), GFDL-ESM2M& EPIC (**GE**), HadGEM2-ES & LPJ-GUESS (**HL**), and GFDL-ESM2M ES & LPJ-GUESS (**GL**). The density bars next to plots of cumulative change show heterogeneity across crop-region values in 2050 for the four climate scenarios (with corresponding shadow colors), with the crop-region average in each scenario (solid black lines) and scenario-average (dotted black line) highlighted. Interannual impact (bottom panels) is calculated as logarithmic changes of cumulative impact (top panels). The boxplot next to plots of interannual impact presents the mean values (points), the median values (line), the first and third quartiles (boxes), and the 10 – 90 percentile ranges (whiskers) of the standard deviations of interannual impact (i.e., interannual variability) across GCAM crop-region combinations.

Fig. 4 Interannual economic responses and correlations to biophysical yield shocks. The beta coefficient and correlation coefficient between economic variables (distinguished by color) and biophysical yield are presented. Each point denotes a crop in a region and a climate scenario, and only crop-regions in 10 – 90 percentile ranges of interannual variability in a climate scenario are presented. Beta coefficients are truncated to [-1, 1] (see **SI Fig. S8** for the figure with full ranges of Beta). Note that the relative interannual variability between economic variables and biophysical yield (ratio of standard deviations) is equal to the ratio of beta coefficient to the correlation coefficient. The slope of the lines represents the average relative interannual variability between economic variables and biophysical yield. The black dotted line has a slope of one. The boxplot attached above presents the mean values (points), the median values (line), the first and third quartiles (boxes), and the 10 – 90 percentile ranges (whiskers) of the squares of correlation coefficient, namely coefficient of determination (R-squared). Data source: GCAM simulation results

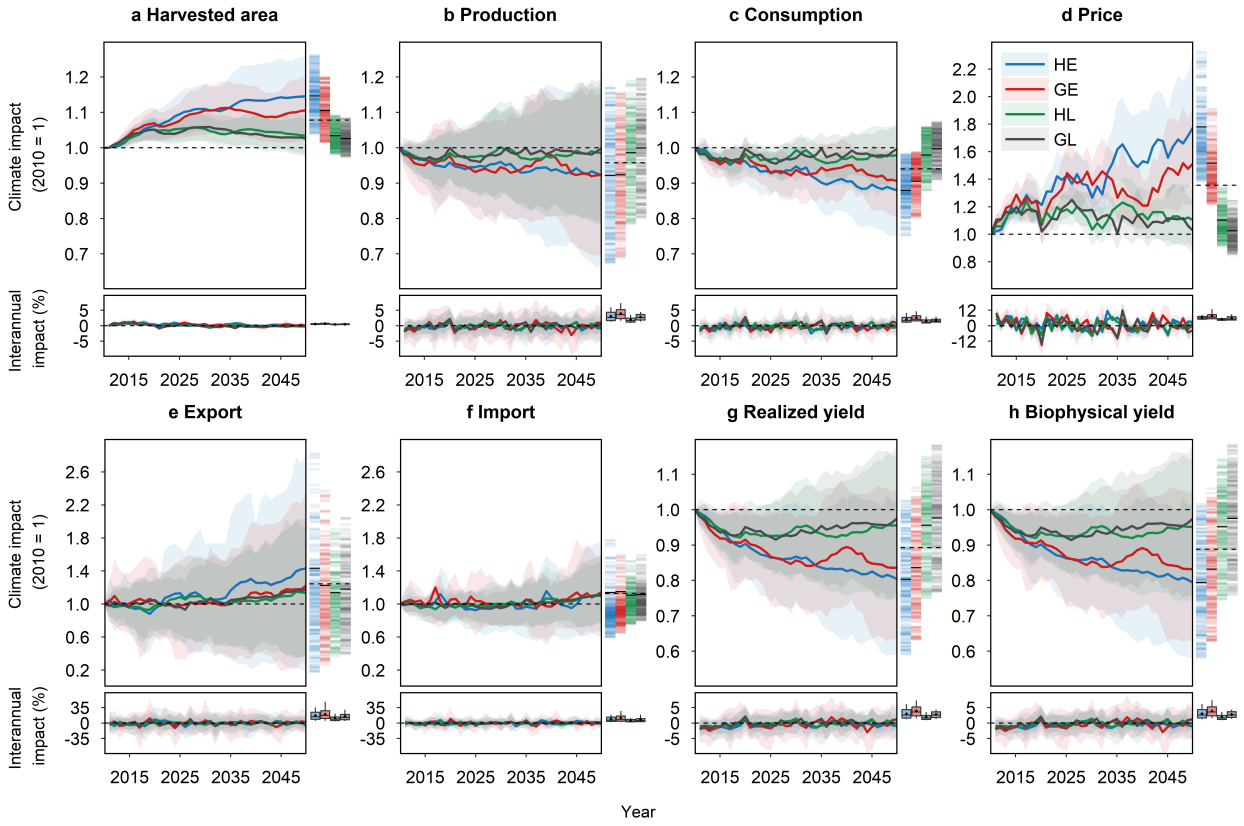

Figure 1: Cumulative (top panels) and interannual (bottom panels) climate impacts on agricultural crop harvested area (a), production (b), consumption (c), price (d), export (e), import (f), realized yield (g) and biophysical yield (h) relative to the GCAM reference scenario, estimated under adaptive expectations. Note that realized yield are results from the model after considering endogenous yield responses. Curves and shadows denote average and 10 – 90 percentile ranges of GCAM results across all crop-region combinations (biomass and fodder crops not included), respectively. Climate scenarios (two climate models by two crop models under RCP8.5 and with carbon fertilization), distinguished by color, include HadGEM2-ES & EPIC (HE), GFDL-ESM2M& EPIC (GE), HadGEM2-ES & LPJ-GUESS (HL), and GFDL-ESM2M ES & LPJ-GUESS (GL). The density bars next to plots of cumulative change show heterogeneity across crop-region values in 2050 for the four climate scenarios (with corresponding shadow colors), with the crop-region average in each scenario (solid black lines) and scenario-average (dotted black line) highlighted. Interannual impact (bottom panels) is calculated as logarithmic changes of cumulative impact (top panels). The boxplot next to plots of interannual impact presents the mean values (points), the median values (line), the first and third quartiles (boxes), and the 10 – 90 percentile ranges (whiskers) of the standard deviations of interannual impact (i.e., interannual variability) across GCAM crop-region combinations. See SI Table S3 for summary statistics and SI Fig. S7 for sensitivity of interannual variability to the coefficient of expectation. Data source: GCAM simulation results

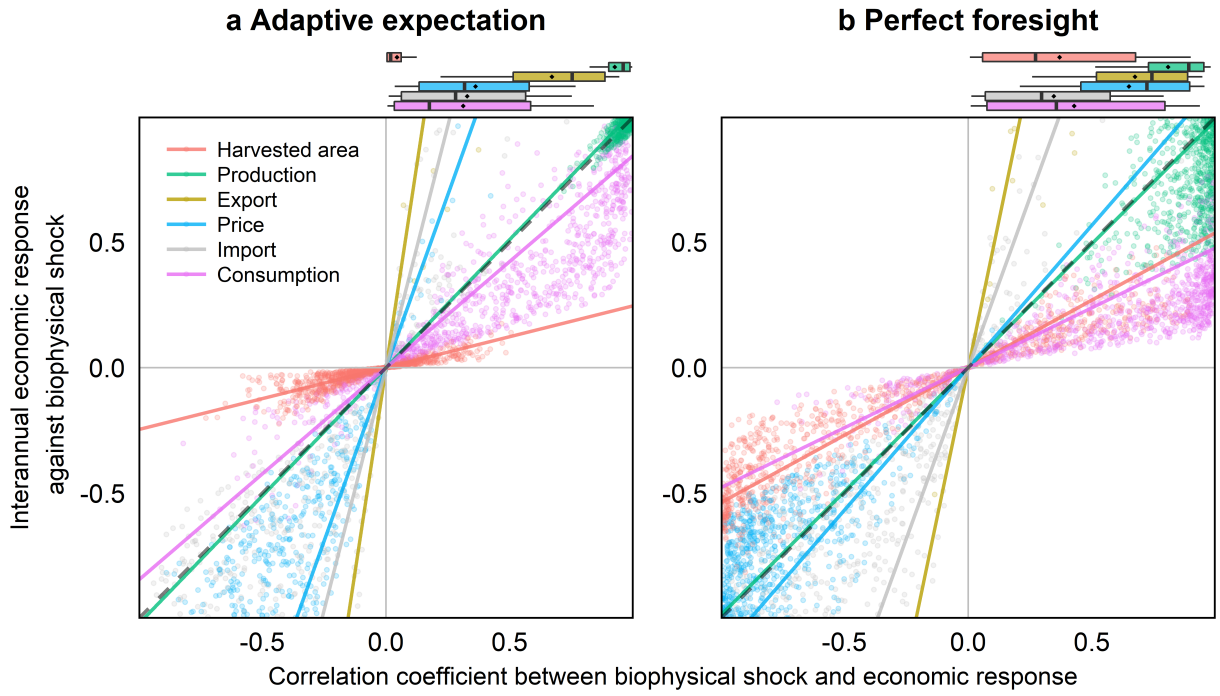

Figure 2: The beta coefficient and correlation coefficient between economic variables (distinguished by color) and biophysical yield are presented. Each point denotes a crop in a region and a climate scenario, and only crop-regions in 10 – 90 percentile ranges of interannual variability in a climate scenario are presented. Beta coefficients are truncated to [-1, 1] (see SI Fig. S8 for the figure with full ranges of Beta). Note that the relative interannual variability between economic variables and biophysical yield (ratio of standard deviations) is equal to the ratio of beta coefficient to the correlation coefficient. The slope of the lines represents the average relative interannual variability between economic variables and biophysical yield. The black dotted line has a slope of one. The boxplot attached above presents the mean values (points), the median values (line), the first and third quartiles (boxes), and the 10 – 90 percentile ranges (whiskers) of the squares of correlation coefficient, namely coefficient of determination (R-squared). Data source: GCAM simulation results