The Impacts of Drought on Land use and Agricultural Production in the Mississippi River Basin

Dominic White, Angelo Gurgel, Jennifer Morris, Sergey Paltsev and Adam Schlosser

Abstract

The incidence and severity of droughts has been intensifying in the past decades, offering serious risks for agricultural production. One of the largest agricultural producing regions in the U.S. is the Mississippi River Basin, representing a significant amount of global grain and soybean production. We enhance an economy-wide model, the U.S. Regional Energy Policy (USREP) model, by including disaggregated irrigated and rainfed crop production and land use change, to assess the potential economic and land use impacts from drought on the Mississippi River Basin. Drought yield impacts on crops imposed in the model from 2030 to 2050 are calculated based on data from historical droughts in the U.S. Overall, we find that drought has a negative impact on agricultural production and that the wider the scope of the drought either through greater coverage of crops or regions, the greater the damages to agricultural production. We observe that both impacted and unimpacted farmers and regions adopt a combination of adaptation strategies, including irrigated crop production, land use change and trade. While irrigation is used to mitigate some of the impacts, many of the impacted regions instead choose to change land use from crops to animal products. Among the adaptation strategies available to farmers, domestic and international trade offers the most effective way to dampen the economic impact from drought, with regions unimpacted by drought exporting agricultural products to impacted regions. This suggests to policymakers that reducing barriers to trade could limit the economic impacts of extreme weather events in the future.

1. Introduction

There are several forms of extreme weather events that could impact agriculture around the world. One of these extreme weather events is drought, which is defined by the National Drought Mitigation Center (NDMC) (2025) as “a deficiency in precipitation over an extended period of time (usually a season or more), resulting in a water shortage”. While it may not be as visibly destructive as a fire or storm, drought is ranked third among billion-dollar environmental events since 1980 by National Oceanic and Atmospheric Administration (NOAA) (2025), behind tropical cyclones and severe storms. The impacts of drought on agriculture, as described by National Integrated Drought Information System (NIDIS) (2025), include reduced crop yields, reduction in water supplies, heat stress from higher temperatures, and reduction in livestock production. In 2012, a severe drought impacted 80 percent of the agricultural land in the U.S. and resulted in 14.5 billion USD worth of loss payments by the federal crop insurance program due to lost production in the Great Plains and the Midwest. Therefore, drought represents a serious risk for agriculture and food security in the U.S.

The impacts of drought on society have been widely explored in the literature. This includes the global impacts and susceptibility to drought (Freedman et al. 2025), potential crop yield impacts (Kuwayama et al. 2018), the economic effects on the agricultural sector (Campbell, Crowley & Demura, 1983; Horridge, Madden & Wittwer, 2005; Lu & Hedley, 2004; Edwards, Gray & Hunter, 2009; Fleming-Muñoz, Whitten & Bonnett, 2023) and broader social and economic impacts (Edwards, Gray & Hunter, 2018). The results from this literature suggests that droughts have wide reaching economic implications on the regions affected including reductions in productivity, GDP, trade and employment. This is particularly concerning given the documented increase in the severity and frequency of droughts around the world (Chiang, Mazdiyasni & AghaKouchak, 2021; Mukherjee, Mishra & Trenberth, 2018). The global importance of agricultural production from the U.S. and the negative impacts from drought on the agricultural sector rationalize a deeper exploration of the land use and economic impacts from potential future droughts in the U.S.

The Mississippi River Basin (MRB) produces 92 percent of the U.S.’s agricultural exports and 78 percent of the world’s feed grains and soybean exports (National Parks Service, 2025). Agriculture dominates the land use in this region, with the main crops being grains and soybeans. The Mississippi River is also used as a significant trade highway with 60 percent of all grain exported from the U.S. shipped through the Port of South Louisiana and the Port of New Orleans. Given this significant contribution to the U.S.’s and the world’s agriculture, if the MRB experiences a persistent drought in future years, the impacts on food security, production and exports could be substantial.

The MRB has suffered droughts in the past, including a multi-year drought which started in 2020. The economic literature related to this and other droughts in the MRB are focused on trade implications (Kang & Lee, 2025; Steinbach & Zhuang, 2025; Arita et al. 2022). This research has found that trade is negatively impacted by the presence of a drought both from a reduction in agricultural production and from the reduction in mobility of barges down the water ways. We expand upon this literature by investigating the country-wide land use and economic implications of a persistent future drought in the MRB using a multi-sector economy-wide model. The novelty of our approach includes enhancing a US specific model to represent land use change, disaggregation of agriculture and irrigated and rainfed crop production. Furthermore, we use information on historical U.S. droughts to define plausible scenarios of future drought effects on crop yields.

The model we use to explore the impact of drought is the U.S. Regional Energy Policy (USREP) model. It has been enhanced for this research to include land use change and a disaggregated agricultural sector with six crop types, forestry, animal products, natural grassland and natural forestry. Within the six crop types, we represent both irrigated and rainfed crop production. This distinction is made because irrigation offers a viable adaptation strategy for farmers when hit by a drought (Wang & Ren, 2025).

To represent irrigated crop production in the U.S., we use the data and methodology provided in Ledvina et al. (2018) and Winchester et al. (2018). This approach accounts for the higher yields per hectare of land produced by irrigated crops as well as the additional water, capital, labor and intermediate input expenses associated with increasing irrigated crop land. We have expanded on the analysis undertaken by Winchester et al. (2018) by disaggregating the river basins represented to have a U.S. rather than global focus.

In the model, we include 17 U.S. regions, with six representing the MRB, these are the Missouri River Basin, the Ohio River Basin, the Upper Mississippi River Basin, the Lower Mississippi River Basin, the Tennessee River Basin and the Arkansas-White-Red River basin. The drought shock is modelled as a yield impact on rainfed and irrigated crops based on yield and drought severity estimates from Kuwayama et al. (2018) and Tinker (2026) respectively. The drought persists from 2030 to 2050 and is implemented over different scenarios which vary based on the crops and regions impacted. The model is able to capture the main adaptation strategies to drought economic agents may adopt including: (1) land use change between agricultural products as well as natural forests and natural grasslands; (2) a choice between rainfed and irrigated crop production; and (3) changing domestic and international trade flows. This approach signifies an advance in the literature by having an explicit representation of irrigated and rainfed crops across six different crop sectors as well as an estimation of the changes in trade flows both between regions in the US and from the US to the rest of the world.

Overall, our results indicate that there is a negative impact on the crop production in regions affected by drought which is an expected outcome. Also, that the wider the scope of the drought, the greater the damages to agricultural production. However, the major adaptation mechanisms available for drought shift among scenarios and are intensified when the shock hits more crops and a larger geographical area.

The most significant adaptation responses come from land use change as well as changes in domestic and international trade. When hit by a drought, farmers decide to shift land use towards crops or agriculture such as animal products not affected by drought. While irrigation offers an adaptation strategy, it is not enough to mitigate the impacts of a persistent drought. Furthermore, in response to drought, regions outside the MRB increase land use for rainfed crops more than irrigated crops. This is partly due to the additional expenses related to expanding irrigated land. A major concern is that it could increase their vulnerability to drought in the future.

This paper has four further sections. The next section includes an overview of the economy-wide model used and how it has been improved for this analysis. Section 3 outlines and discusses the key results from a drought scenario analysis. Section 4 provides some concluding remarks.

2. **Methodology**

2.1 The USREP model

The USREP model is an economy-wide model of the U.S. (Yuan et al., 2019), originally designed to analyze energy and environmental policies (Picciano et al., 2023; Yuan et al., 2022; Yuan et al., 2021; Dimanchev et al., 2019). It is a recursive-dynamic computable general equilibrium model and follows the same structure of similar classical Arrow-Debreu general equilibrium models, combining the analysis of equilibrium conditions with rational economic agents. This includes market interactions which are price-dependent and the generation and spending of income based on microeconomic theory. Households in the model are utility-maximizing and receive income from government transfers and the supply of factors of production to firms including capital, labor, land and resources. This income is spent on goods and services or is saved. The government represented collects tax revenue which is also spent on goods and services as well as household transfers. Firms are profit-maximizing and produce goods and services using primary factors of production and intermediate inputs from other firms. The model is calibrated using version 3.1 of the Wisconsin National Data Consortium (WiNDC) (Rutherford & Schreiber, 2019) and runs from 2017 (the base year) to 2050 with five-year time steps from 2020 to 2050. It is written using the Mathematical Programming System for General Equilibrium (MPSGE) (Rutherford, 1999), which operates as a subsystem within the General Algebraic Modeling System (GAMS). Further information on the data, methodology and assumptions related to the USREP model are described in Yuan et al. (2019).

To appropriately explore the impacts of drought in the MRB, the version of the USREP model used for this research has been improved from the base version described in Yuan et al. (2019). The model has been adjusted to represent (1) a disaggregated agricultural sector composed of irrigated crops, rainfed crops, animal products, forestry, natural forests and natural grasslands; (2) land use; (3) land use change and (4) water use and availability for irrigated crops.

Table 1: Regions represented in the USREP model.

Model Sector Name	**Region Name**	**U.S. States**
CA	California	California
FL	Florida	Florida
NY	New York	New York
TX	Texas	Texas
MI	Michigan	Michigan
VA	Virginia	Virginia
NENGL	New England	Massachusetts, Maine, New Hampshire, Vermont, Connecticut and Rhode Island
AZ-UT-NV	Arizona, Utah and Nevada	Arizona, Utah and Nevada
OR-WA-ID-AK-HI	Oregon, Washington, Idaho, Alaska and Hawaii	Oregon, Washington, Idaho, Alaska and Hawaii
GA-NC-SC	Georgia, North Carolina and South Carolina	Georgia, North Carolina and South Carolina
MD-DE-DC-NJ	Maryland, Delaware, District of Columbia and New Jersey	Maryland, Delaware, District of Columbia and New Jersey
MissRB	Missouri River Basin	Montana, Wyoming, Nebraska, North Dakota, South Dakota and Missouri

A-W-R-RB	Arkansas-White-Red River Basin	Colorado, Kansas, Oklahoma and New Mexico
TenRB	Tennessee River Basin	Tennessee and Alabama
LoMissRB	Lower Mississippi River Basin	Louisiana, Mississippi and Arkansas
OhRB	Ohio River Basin	Kentucky, Indiana, Ohio, West Virginia and Pennsylvania
UpMissRB	Upper Mississippi River Basin	Illinois, Iowa, Minnesota and Wisconsin

There are 17 regions in the model, described in Table 1, including a representation of the six major river basins in the MRB: the Missouri River Basin, the Arkansas-White-Red River Basin, the Ohio River Basin, the Tennessee River Basin, the Upper Mississippi River Basin and the Lower Mississippi River Basin. Furthermore, there are 24 sectors in this version of the USREP model (Table 2), with 10 of the sectors related to agriculture and land use as well as the sectors related to construction and services; manufacturing; energy extraction, production and distribution; and commercial transport represented in the base version of the model.

Table 2: Sectors represented in the USREP model.

Sectors			
Agriculture, forestry and fishing		**Manufacturing**	
wht	Wheat	che	Chemical products
gro	Other grains	nmp	Non-metallic mineral products
v_f	Vegetables and fruit	eis	Energy/emissions intensive sectors (embodied carbon > 0.5 kg per $)
osd	Oilseeds	pmt	Primary metals
pfb	Plant-based fibers	fbp	Food, beverage and tobacco products
ocr	Other crops	oth	Other sectors
oap	Animal products	**Energy Extraction, Production and Distribution**	
fof	Forestry, fishing and related activities	oil	Petroleum refineries
ngrs	Natural Grassland	ele	Electric power generation, transmission and distribution
nfrs	Natural Forestry	col	Coal mining
Construction and Services		gas	Natural gas extraction
srv	Services	cru	Crude oil and extraction
bld	Buildings – housing and other real estate	**Commercial Transport**	
		trn	Transportation

The remainder of the methodology section describes: (1) how agriculture, land use and land use change is represented in the USREP model (section 2.2); (2) how crops are further disaggregated into irrigated and rainfed crops (section 2.3); and (3) the inclusion of drought shocks in the model (section 2.4).

2.2 Agriculture in the USREP model

In the base version of the USREP model, land use was not represented and agriculture was aggregated into farms and forestry. The Global Trade Analysis Project (GTAP) WiNDC build stream (Rutherford & Schreiber, 2019) is used to split the production of aggregate agriculture sectors in the benchmark dataset into the agricultural sectors described in Table 2. This process allows for a representation of the benchmark inputs and outputs of these different sectors across the 17 regions in the model.[1] The base version of the USREP model does not include land as a factor input and we use the GTAP WiNDC build stream to inform the proportion of capital in each region which should be attributed to land for each sector.

Along with six types of agriculture, the updated model represents two types of natural land including natural forests and natural grasslands. Both of these natural land use options do not produce agricultural products but they do provide ecosystem services which enters consumers' utility function in the model, based on the approach used by Melilo et al. (2009); Gurgel et al. (2011) and Gurgel et al. (2016).

To estimate the hectares of land use for cropland, animal products, natural forests and natural grasslands in each region in 2017, we use data on Major Land Uses from USDA (2026). To split the hectares of cropland into different crop types within each region, we use Crop Acreage Data from USDA (2025).

Land use change in the model is represented using the Observed Land Supply Response (OLSR) approach (Melilo et al., 2009; Gurgel et al., 2016). This is where the conversion of land between uses is limited by associated capital and labor expenses as well as an elasticity of substitution between land uses based on the observed willingness to convert land. The theory behind this approach is that when converting from one type of land use to another, machinery (capital) and labor are required to make that change. One hectare of one type of land is converted to one hectare of another type of land through a land transformation function which represents these real inputs. This approach overcomes the challenge of preserving physical consistency in total land area from the commonly adopted Constant Elasticity of Transformation (CET) land-use functions (Schmitz et al., 2014). The inputs and elasticities used in this function are based on the approaches detailed in Melilo et al. (2009) and Gurgel et al. (2016).

2.3 Irrigated and rainfed crops in the USREP model

Crop production in the USREP model is split into rainfed and irrigated crops. This includes a representation of the higher yields per hectare of land produced by irrigated crops as well as the additional water, capital, labor and intermediate input expenses associated with expanding irrigated crop land. To achieve this, the data and methodology described in Winchester et al. (2018) and Ledvina et al. (2018) is adapted for the regional aggregation of the USREP model.

To split baseline agricultural crop land into irrigated and rainfed crops, we use the hectares of land use from the monthly irrigated and rainfed crop areas (MIRCA 2000) in the Global Crop Water Model (GCWM) dataset (Hoff et al. 2014), aggregated based on the agricultural and regional representation in the USREP model. To estimate the value of production for each crop type, we use price data from the Food and Agricultural Organization (FAO, 2025) and yield data from the MIRCA 2000 dataset (Hoff et al. 2014). Given this data contains more crops than are represented in the USREP model, we estimate

---

[1] To simplify model closure, we did not include vintaging for capital in the agricultural sector in this version of the USREP model.

production weighted average prices for each crop type represented in the model. The rainfed and irrigated yields and hectares are proportioned and used to split the output and the value of land as an input for each crop type respectively. The value of remaining inputs or residual costs are estimated as the difference between the value of output and land inputs for each crop type. The proportion of total residual costs which are used by irrigated crops is used to split the appropriate factor and intermediate inputs for rainfed and irrigated crops. For example, the residual costs for wheat in 2017 in the Upper Mississippi River Basin are 0.285 billion USD for irrigated crops and 0.239 billion USD for rainfed crops. This means that of the capital, labor and other intermediate inputs going to the original aggregate wheat sector, 54 percent are attributed to irrigated wheat and 46 percent are attributed to rainfed wheat.[2]

Rainfed crops have a production structure which is the same as other agriculture represented in the USREP model[3]. Irrigated crops have a similar structure but, as described in Winchester et al. (2018), to ensure that the amount of irrigated land for each crop type and region is equal to the amount of irrigated land available, we use an irrigation permit system. For each hectare of land used for irrigated crops in the model, one irrigation permit is required. In the benchmark, within each region, every crop type is endowed with the quantity of irrigation permits equal to the quantity of land used by irrigated crops in the base year (2017). These permits are treated as a factor of production in the model and are supplied by the household. Rainfed crops do not have irrigation permits included in their production structure.

To expand irrigated crop land in the model, irrigated permits need to be generated based on additional costs and subject to water resource constraints.[4] This approach ensures that any additional hectares of irrigated crop land results in a reduction in the same area of rainfed land. To increase irrigation permits beyond the endowment in the base year, water resources, capital, labor and intermediate inputs (from services and other sectors) are required. Water resources are represented through irrigation certificates. These certificates describe the amount of additional land which can be irrigated, estimated from the availability of water in the basins for each region and described in Ledvina et al. (2018). The land used for irrigated crop production can be expanded by improving conveyance efficiency, increasing water storage, and improving irrigation efficiency. This can be represented by region-specific irrigable land supply curves which describe the cost per hectare of expanding irrigated land, and have been calculated by Ledvina et al. (2018). Inputs of capital, labor and intermediate inputs are represented in a composite which can be substituted with an irrigation-specific resource. The elasticity in this substitution is based on the irrigable land supply curves from Ledvina et al. (2018) and the calibration routine outlined by Rutherford (2002). It implies that irrigating additional hectares requires installing irrigation infrastructure on new land and an upgrade to the existing farm infrastructure to gain access to more water. To allow for farmers to substitute between rainfed and irrigated land, each crop type has a production block with rainfed and irrigated inputs.[5]

---

[2] This approach is used to maintain balance in the benchmark model data.
[3] The figure representing this is shown in Appendix Figure A1.
[4] The figure representing this is shown in Appendix Figure A3.
[5] The figure representing this decision making is shown in Appendix Figure A4.

The data provided by Ledvina et al. (2018) has information on 12 U.S. water basins. These are mapped to the 17 regions in the USREP model, with the related elasticities and irrigation expansion potential the same in regions which are situated in the same water basin[6].

2.4 Representing Drought in the USREP model

Drought is represented in the model through persistent negative yield impacts on rainfed and irrigated crops in impacted regions. The size of these yield impacts is based on data from the Gridded Standardized Precipitation Index which captures the historical months of drought in the MRB (Tinker, 2026) as well as the estimated yield impacts on crops from additional weeks of drought as estimated by Kuwayama et al. (2018).

The information on historical droughts from Tinker (2026) is provided by NOAA's National Centers for Environmental Information (NCEI). It has information on the months of drought across a five-point drought monitor scale experienced by the major MRB river basins (the same six represented in the USREP model) between 1895 and 2025. The scale includes D0 which represents abnormally dry conditions, D1 which represents moderate drought conditions, D2 indicating severe drought conditions, D3 which are extreme drought conditions, and D4 which is exceptional drought conditions.

Kuwayama et al. (2018) used data from 2001 to 2013 to estimate the yield impacts from an additional week of drought on irrigated and rainfed corn and soybean crops (which are part of the grains and oilseeds crop sectors respectively in the USREP model) in the U.S. across the same five-point drought monitor scale (D0-D4) used by Tinker (2026).[7]

We combine information from these two sources to estimate the worst potential annual crop yield impacts from drought in different regions in the MRB. The yield impacts on corn and soybean crops at each drought level as calculated by Kuwayama et al. (2018) are multiplied by the average weeks in a month (4.345) and then by the number of months at each drought level, as described by Tinker (2026) from 1895 to 2025. The years with the worst yield impacts for rainfed corn and rainfed soybeans in each region are used to inform the negative yield impacts on all crops from drought in the USREP model. Table 3 shows the annual negative yield impacts included in the model. The impacts on grains and oilseeds are taken directly from the numbers calculated for corn and soybeans. For other crop types, the negative yield impact from drought is an average of grains and oilseeds. As the information from Kuwayama et al. (2018) is specific to grains and oilseeds and given how important these crops are to agriculture in the MRB, we include scenarios where drought only impacts grains and oilseeds as well as scenarios where drought impacts all crops[8].

This approach intends to assess how a potential persistent drought in the future could affect the U.S. as well as the adaptation mechanisms related to drought. As a basis for defining the size of the shock, we use information from drought events in the past. Alternatively, we could define our shocks by relying on running future climate change scenarios through climate models which pass information onto crop models to estimate yield impacts. However, there would be compounding uncertainty behind (1) the choice of climate scenario, (2) the choice of the climate model and its outputs and (3) the choice of the

[6] The mapping of these water basins to regions in the model are detailed in Appendix Table A1.
[7] The impacts estimated by Kuwayama et al. (2018) is shown in Appendix Table A2.
[8] While we are limited by only having access to data on drought impacts for grains and oilseeds, we do not believe it is likely droughts will only impact these crops.

crop model and its outputs. With all of this uncertainty it is unlikely this approach would be a better definition of shocks than the approach we have chosen here. The aim of this research is not to predict the future, but to understand the potential consequences of plausible extreme events in the future.

Table 3: The estimated annual yield impacts on grains, oilseeds and other types of crops as calculated from Kuwayama et al. (2018) and Tinker (2026).

Region	Rainfed Yield Impact			Irrigated Yield Impact		
	Grains	Oilseeds	Other	Grains	Oilseeds	Other
Upper Mississippi River Basin	-0.38	-0.34	-0.36	-0.07	-0.14	-0.10
Tennessee River Basin	-0.47	-0.39	-0.43	-0.10	-0.16	-0.13
Ohio River Basin	-0.37	-0.34	-0.36	-0.10	-0.14	-0.12
Missouri River Basin	-0.28	-0.30	-0.29	-0.06	-0.14	-0.10
Lower Mississippi River Basin	-0.45	-0.34	-0.39	-0.11	-0.15	-0.13
Arkansas-White-Red River Basin	-0.39	-0.35	-0.37	-0.06	-0.16	-0.11

3 Results

We project the economic and land use impacts of a persistent drought occurring from 2030 to 2050 across four different scenarios. These scenarios include: (1) the Upper Mississippi River Basin, the largest oilseed and grain producer in the U.S. (in the value terms), experiences a drought that impacts the production of grains and oilseeds; (2) the Upper Mississippi River Basin experiences a drought impacting all crops; (3) the entire MRB region is affected by a drought that impacts grains and oilseeds; and (4) all crops in the MRB region are impacted by drought. The aim of these scenarios is to explore the potential economic implications from a drought in the MRB, considering possible alternative levels of geographical coverage and crop damage severity.

The model represents major economic adaptation strategies to drought, which come from several management and production changes in the agricultural sector and changes in regional and international trade flows. Farmers can make choices over agricultural production and land use in response to the yield impacts from drought. Production decisions include whether to favor irrigated or rainfed crop production as well as the choice of switching land use between crops, animal products and natural land (forests or grassland). They also have the choice over whether to intensify production of drought affected crops by spending more on intermediate inputs, capital and labor to alleviate the yield losses. This would make production of those crops more expensive and less competitive than regions unaffected by drought. The representation of trade in the USREP model allows for regions impacted by drought to compensate reduced agricultural output with domestic or international imports.

As expected, our results indicate that damages to agricultural production increase as the scenarios get more extreme and the scope of the drought is amplified either through crop coverage or geographically. With regards to adaptation options, irrigation does not completely mitigate damage from drought in impacted regions but it does allow other regions to increase production as a compliment to rainfed crop production. Part of the reason irrigation does not offer a particularly affective adaptation mechanism is that irrigated crop yields decrease under drought, albeit at a lower magnitude than rainfed crops, as seen in Table 3. Land use change offers a mechanism for impacted farmers to shift from impacted crops such as grains and oilseeds towards unimpacted agricultural products such as wheat and animal products. The most significant adaptation instrument is trade between regions and internationally. This allows for agricultural products to flow from unimpacted to impacted regions and to significantly mitigate the risks associated with drought.

In regions affected by drought, the crops experiencing reduced yields will have a lower level of production compared to the baseline in 2050 and only some forms of agriculture increase production in response (Figures 1-4). As an example, when only grains and oilseeds are impacted by a drought in the Upper Mississippi River Basin (Figure 1), production of those crops in that region decrease by 79 and 67 percent respectively. In response, wheat (200 percent), other crops (9 percent) and animal products (22 percent) increase output. When all crops in the Upper Mississippi River Basin (Figure 2) are impacted by drought all crops in the region reduce output compared to the baseline (Figure 2) with other crops (83 percent) and vegetables and fruit (89 percent) decreasing by the highest proportion[9] and only animal products (47 percent) increasing output[10]. In the scenarios where the entire MRB experiences a drought, the production trends seen in the Upper Mississippi River Basin can be observed across all impacted regions (Figures 3 and 4). When only grains and oilseeds are affected by drought in the entire MRB (Figure 3), the negative impact (compared to the baseline) on the production of oilseeds in the MRB ranges from 47 to 77 percent and for grains it ranges from 6 to 86 percent. Crops unaffected by drought in the MRB in this scenario increase production in some sub-basin regions and decrease in others. For example, wheat increases in regions such as the Upper Mississippi River Basin (234 percent) and the Ohio River Basin (54 percent) and decreases in others including the Missouri River Basin (6 percent) and the Arkansas-White-Red River Basin (9 percent). The reason for the heterogeneous production response to drought is due to changes in regional agricultural comparative advantage, with farmers in some regions prioritizing production of unimpacted crops and others shifting land use to other forms of agriculture. For example, in both of the drought scenarios impacting the entire MRB, the production of animal products increases in most of the impacted regions.

Regions unimpacted by drought improve their comparative advantage of crops relative to the baseline, with some regions benefitting more than others. An example of a region which gains an advantage from every drought scenario is GA-NC-SC where output for oilseeds increases between 105 and 190 percent relative to the baseline and output for grains increases between 29 and 83 percent (Figures 1-4). The unimpacted regions which benefit the most from the drought scenarios are those which produce a relatively large amount of agriculture in the baseline. This includes regions within the MRB when only the Upper Mississippi River Basin is affected by drought and regions outside the MRB when the entire

[9] Plant-based fibers are not produced in either the baseline or drought scenarios in the Upper Mississippi River Basin so there is no change in production found.

[10] Forestry decreases output in all scenarios but this is linked to the multi-output nature of the WiNDC database and not forestry sector changes.

MRB is affected. For instance, in the scenario where all crops in the Upper Mississippi River Basin are impacted by drought, grain output in the Missouri River Basin (23 percent), the Arkansas-White-Red River Basin (39 percent), the Ohio River Basin (35 percent) and the Tennessee River Basin (213 percent) increase relative to the baseline. Conversely when all crops in the MRB are impacted by a drought, grain output decreases in the MRB regions and increases in regions outside the MRB such as Texas (134 percent), GA-NC-SC (59 percent), Virginia (156 percent) and New York (132 percent). To adjust for changes in crop production, the production of animal products in regions outside the MRB decrease in all drought scenarios.[11]

[11] The proportional changes in irrigated compared to rainfed production is not significantly different, the results from which can be seen in Appendix Figures B1-B4.

Figure 1: The proportional change of agricultural product output in the U.S. regions compared to the 2050 baseline under a drought impacting grains and oilseeds in the Upper Mississippi River Basin.

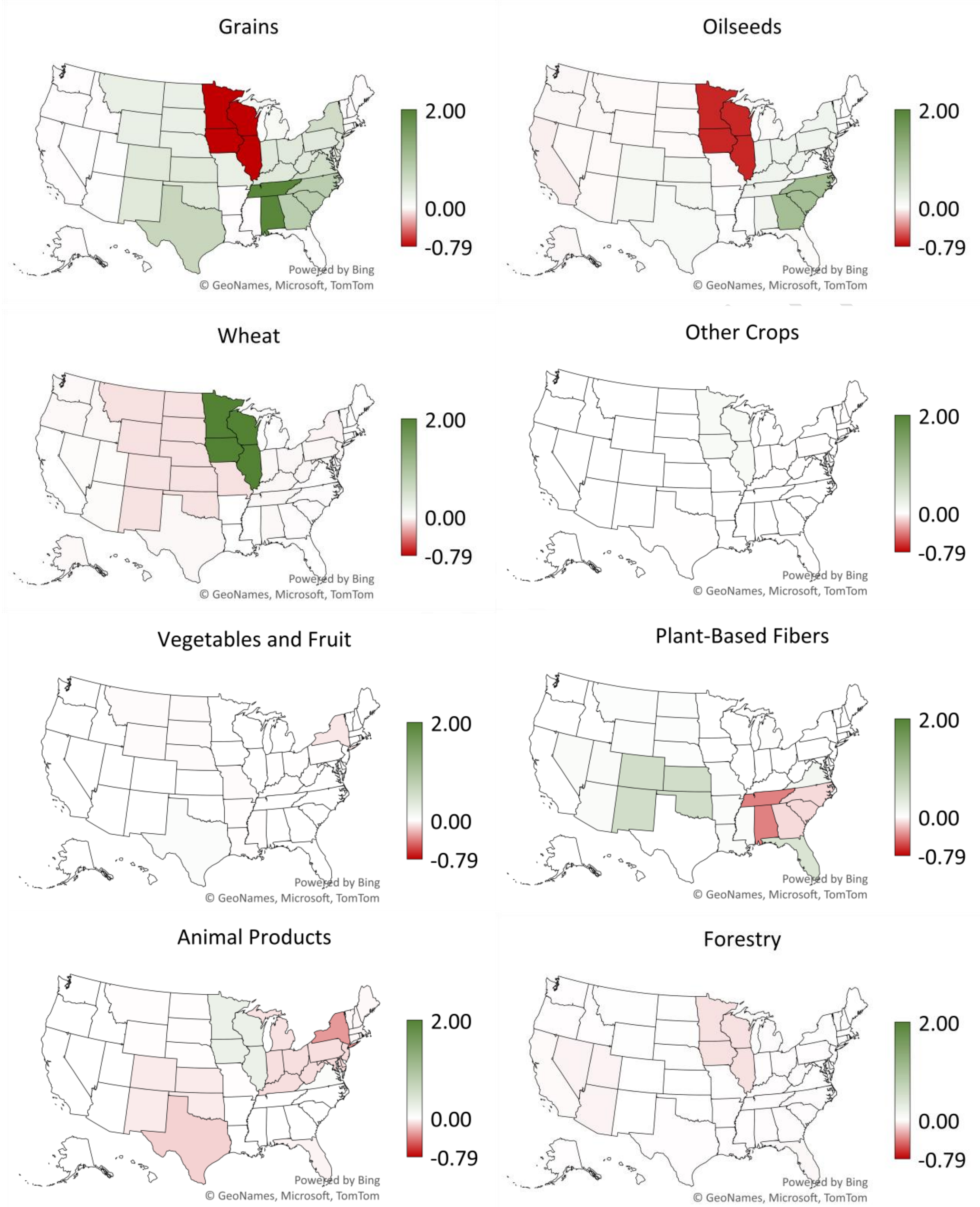


Figure 2: The proportional change of agricultural product output in the U.S. regions compared to the 2050 baseline under a drought impacting all crops in the Upper Mississippi River Basin.

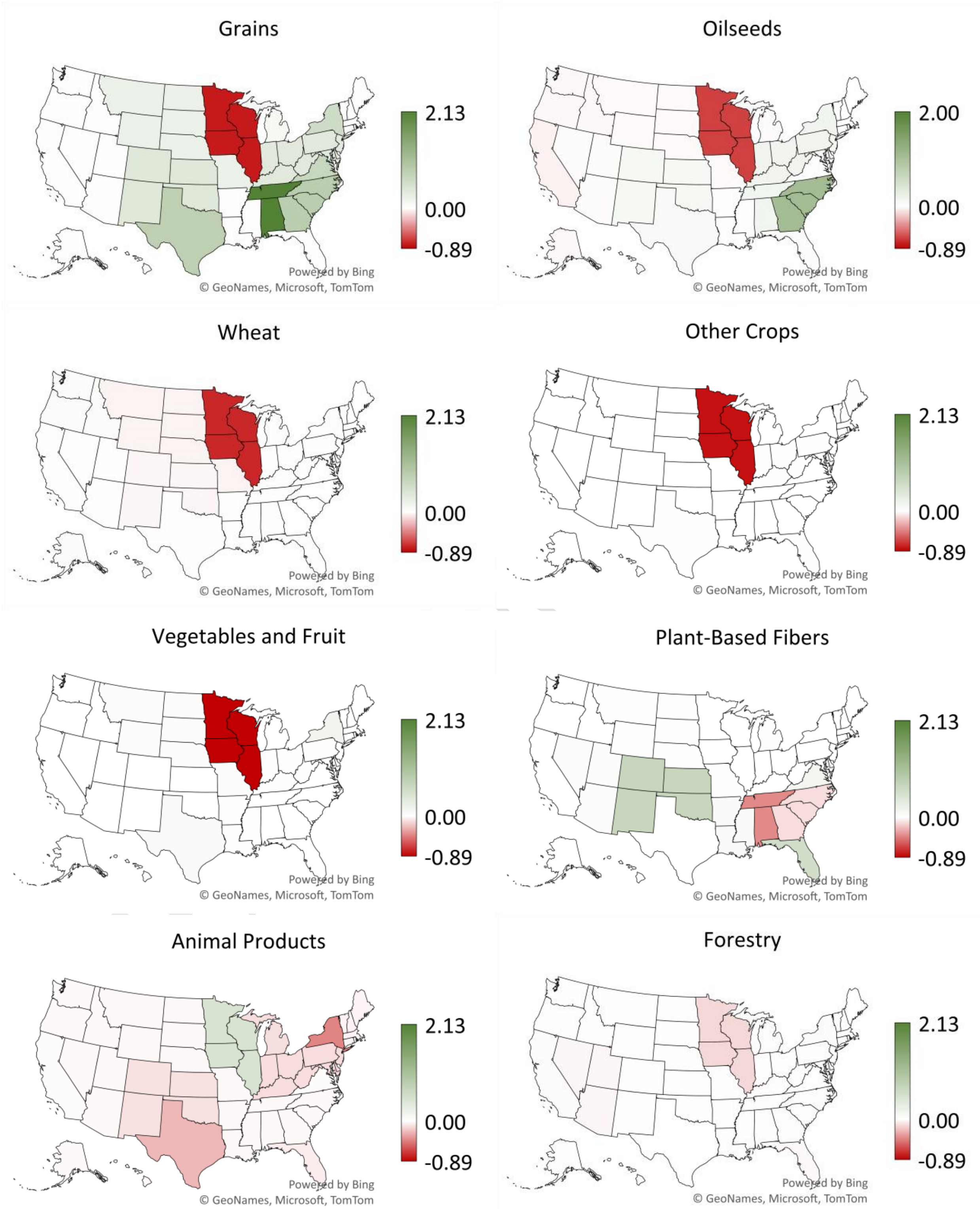


Figure 3: The proportional change of agricultural product output in the U.S. regions compared to the 2050 baseline under a drought impacting grains and oilseeds in the MRB.

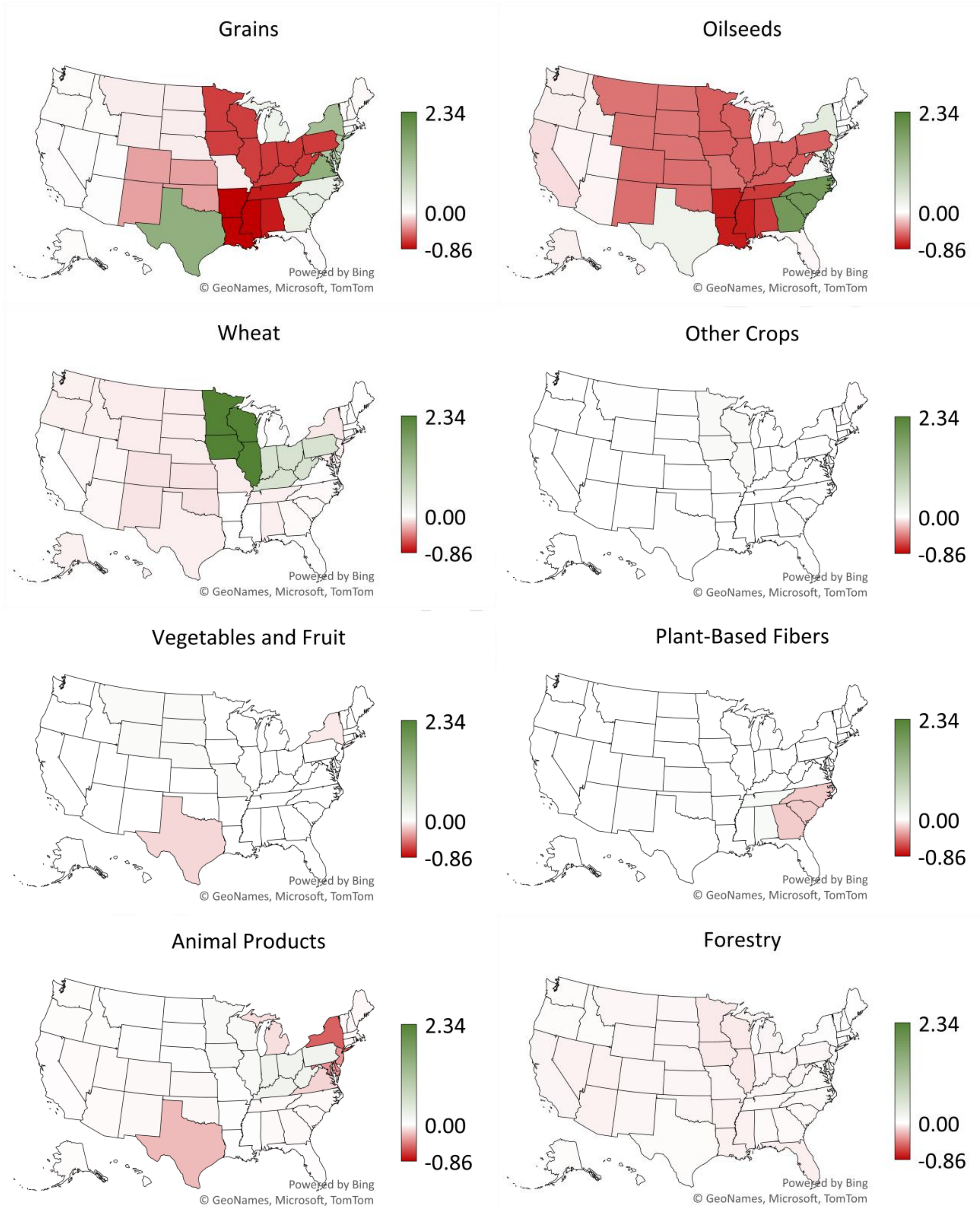
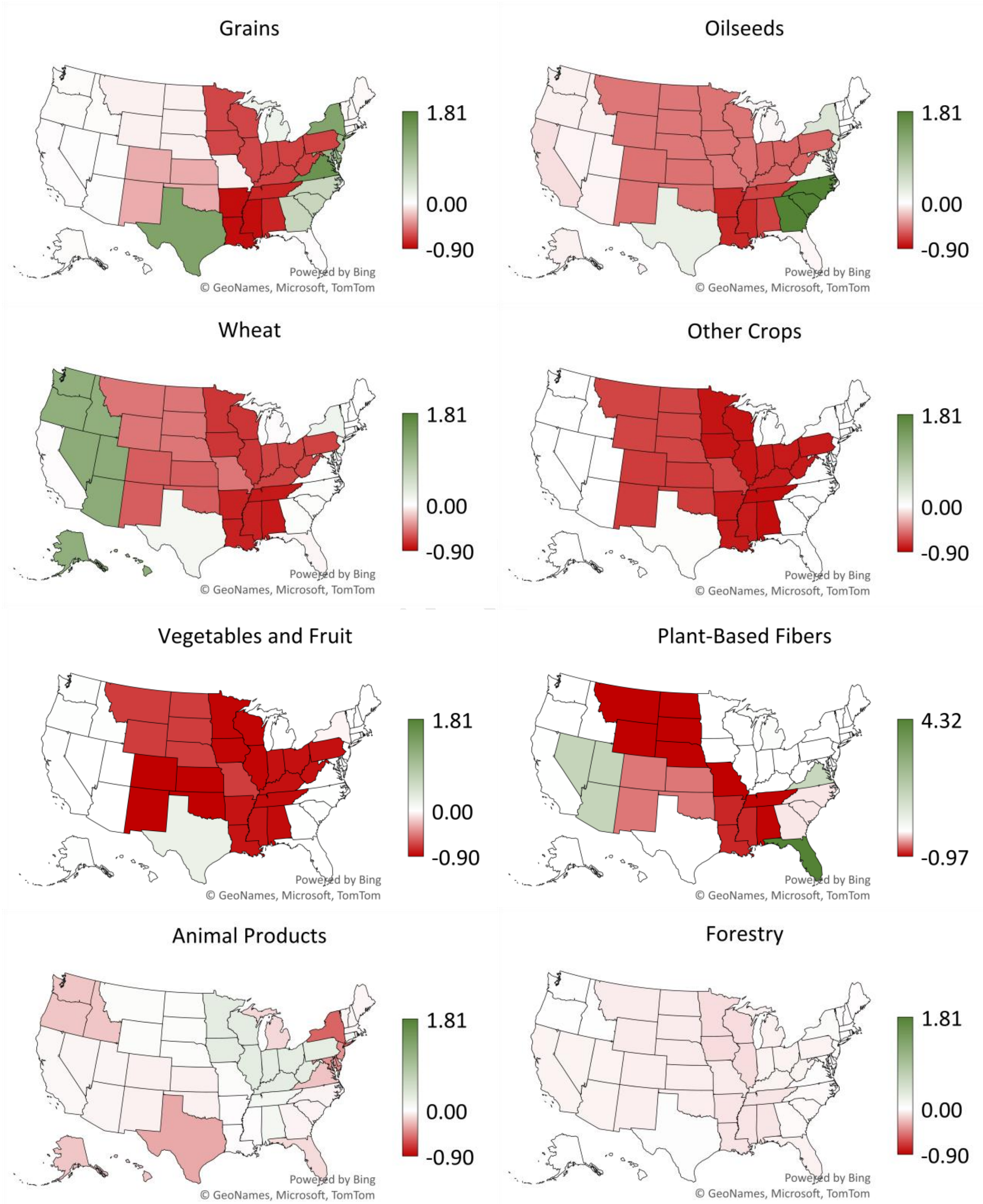


Figure 4: The proportional change of agricultural product output in the U.S. regions compared to the 2050 baseline under a drought impacting all crops in the MRB.[12]



[12] Plant-based fibers appear on their own scale to allow for visibility of other crop proportional changes.

The proportional changes in land use as a result of drought are not as extreme as the changes in agricultural production as farmers can still use land to produce drought impacted crops but at a lower yield than they did in the baseline. This is the adaptation strategy of intensification which partially mitigates yield losses and keeps land dedicated to producing drought impacted crops at a higher cost per unit of output compared to the baseline. The changes in land use compared to the 2050 baseline in the MRB differ depending on the drought scenario (Figure 5a and 5b). Land use in the entire MRB for grains increases (9 and 10 percent) in both scenarios impacting only the Upper Mississippi River Basin, reflecting regional shifts in grain cultivation from the Upper Mississippi towards other parts of the MRB, and decreases when the entire MRB is affected by drought. Likewise, land use for wheat increases (5 and 16 percent) in both scenarios where only grains and oilseeds are impacted and decreases in others. Land use decreases for oilseeds and increases for animal products across all scenarios (Figure 5a). When only the Upper Mississippi River Basin is affected by drought, irrigated land use for grains in the entire MRB increases by proportionally more than rainfed land use for grains (Figure 5b). However, when only grains and oilseeds are impacted by drought, land use for rainfed wheat increases and land use for irrigated wheat decreases. This is because while wheat offers the next best crop alternative to grains and oilseeds in the Upper Mississippi River Basin this is not the case for all regions in the MRB, with land use changing from wheat to other forms of agriculture in these drought scenarios. When all crops in the MRB are impacted, land use for all crops decrease on aggregate and only land use for rainfed other crops (8 percent) and rainfed vegetables and fruit (37 percent) increase compared to the baseline.

Natural grasslands and natural forests in the MRB increase in regions impacted by drought and decrease in regions unimpacted by drought, reflecting an overall shift in farmer's choices toward livestock and forestry activities under declining crop yields, and the opposite trend under relatively higher crop yields (Figure 5a). This is why both natural grasslands and natural forests decrease compared to the baseline when only the Upper Mississippi River Basin is impacted by drought and increase when the entire MRB is impacted. When only the Upper Mississippi River Basin is impacted by drought, natural grassland and natural forests decrease in the entire MRB due to a shift towards crop production in the unaffected MRB regions. However, natural areas increase in the Upper Mississippi River Basin. When the entire MRB is impacted by drought, both natural grassland and natural forests increase in the MRB. This land use response is due to the reduction in profitability of cropland in drought impacted regions, making some farmers reduce land use for agricultural production. As such, conversion of natural areas into agricultural production is not a common adaptation strategy inside the drought impacted region, but indirect changes in land use outside the region lead to some deforestation of natural areas.

In all drought scenarios, in 2050, land use for oilseeds (between 27 and 37 percent) and grains (between 20 and 29 percent) increase outside the MRB compared to the baseline, growing in magnitude as the scope of scenarios become broader (Figure 6a). Typically, land use for rainfed oilseeds and grains increase by a greater proportion than land use for irrigated oilseeds and grains (Figure 6b). This is driven by the higher expenses related to irrigated crop land expansion which outweighs the yield benefits from these crop types. In most scenarios, land use for other crop types, animal products and natural forests decrease outside the MRB compared to the baseline. However, in the scenario where all crops in the MRB are affected by drought, land use for all crops increase, with wheat (50 percent) increasing by the highest proportion. These results indicate that the second-best region to produce crops, outside the Upper Mississippi River Basin, is the MRB. The third best place is outside the MRB, which is why crop production outside the MRB becomes more prominent only when the entire MRB is impacted by drought. The changes in land use outside the MRB illustrate the relative increase in profitability of crops, especially grains and oilseeds, in regions unimpacted by drought. Furthermore, land use change outside the MRB favors rainfed crops over irrigated crops. A potential consequence of a higher proportional shift towards rainfed crop land over irrigated crop land could be a greater exposure to drought in the future as illustrated by the yield impacts in Table 3.

Figure 5: Land use change in the MRB as a proportional change compared to the 2050 for (a) all agriculture and natural land and (b) irrigated and rainfed crops.

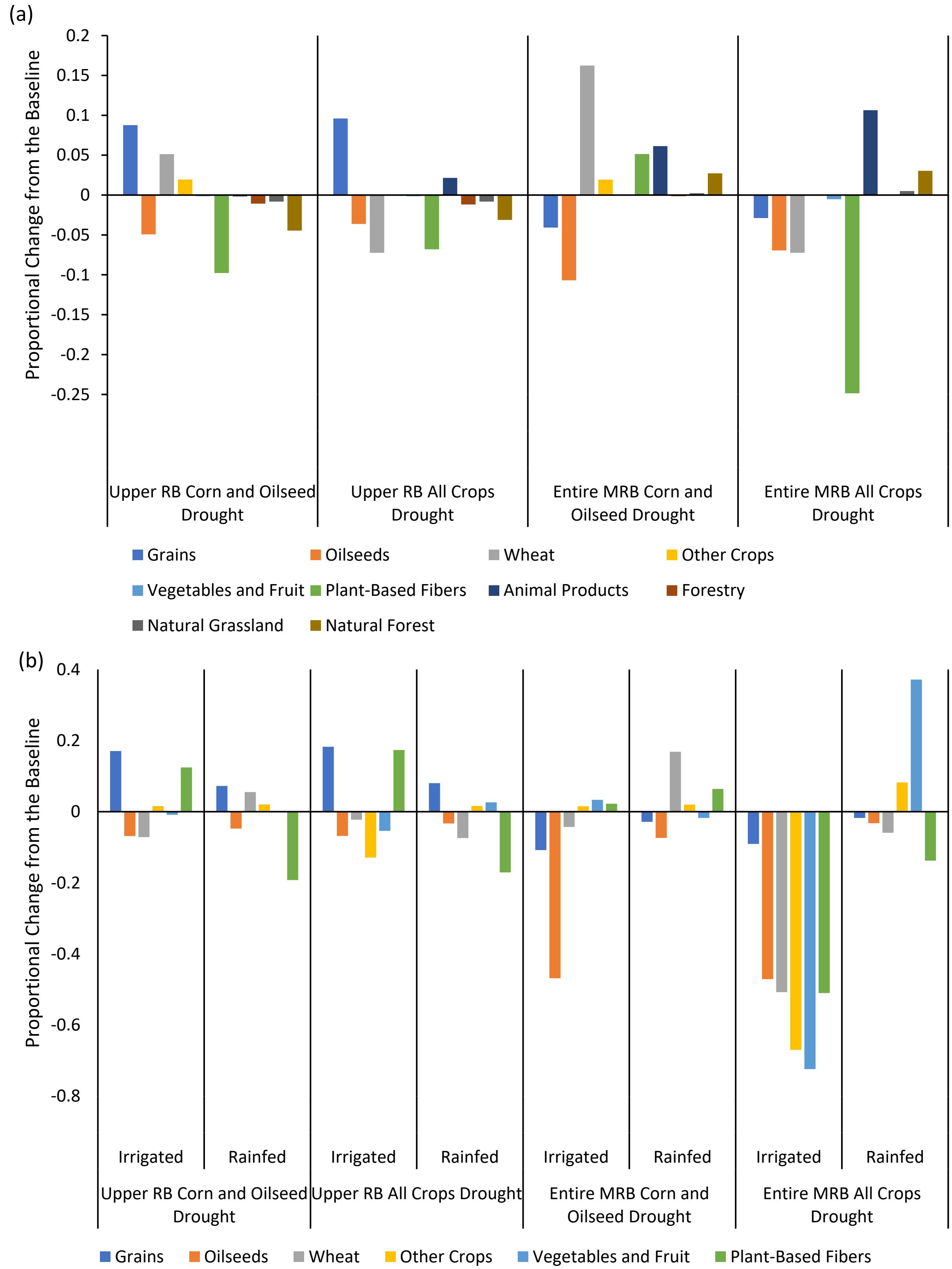
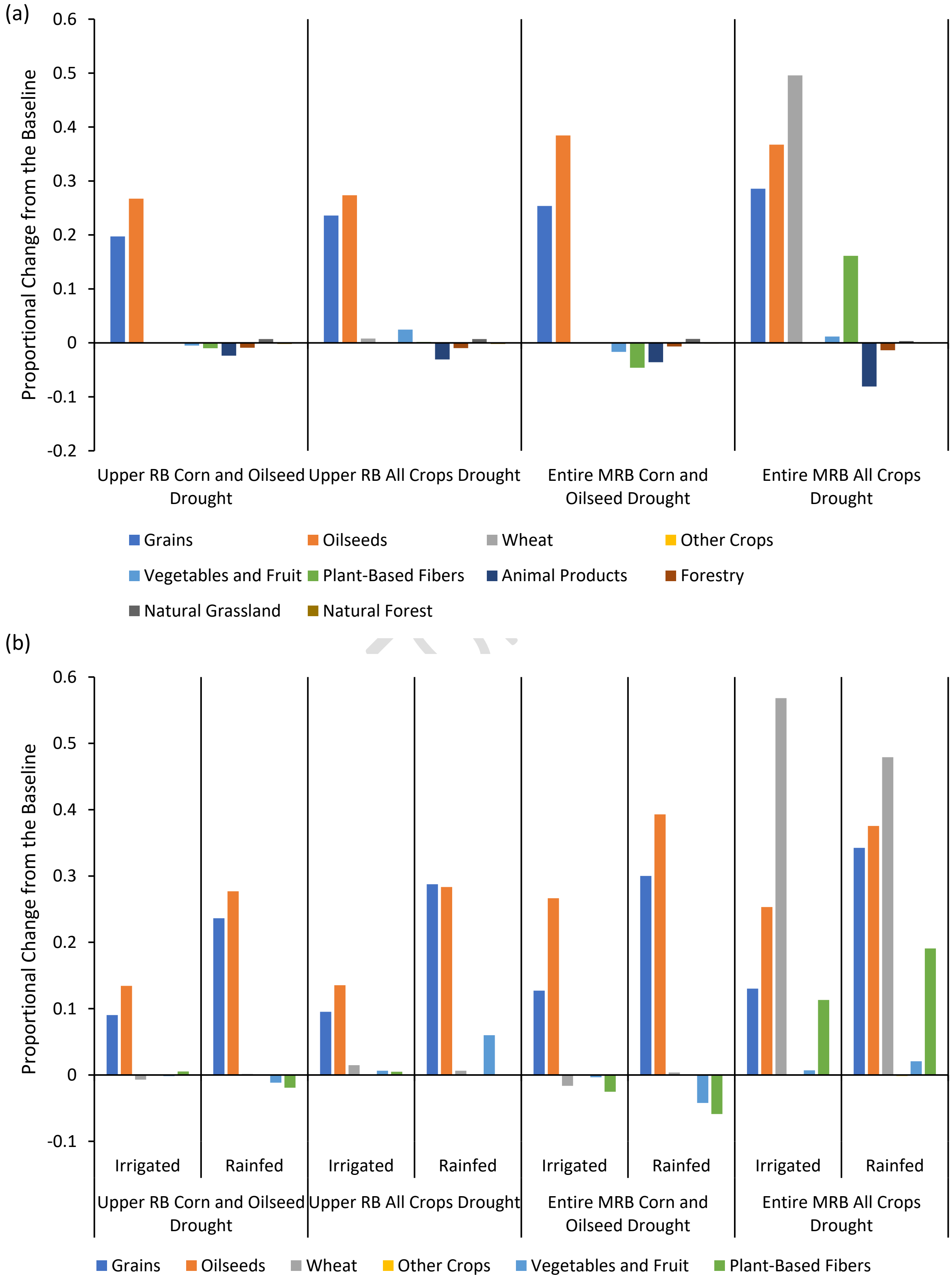


Figure 6: Land use change outside the MRB as a proportional change compared to the 2050 for (a) all agriculture and natural land and (b) irrigated and rainfed crops.



Regional adaptation to drought includes changes to domestic and international trade flows. As seen in Figures 7a and 7b, the changes in agricultural production from the different drought scenarios results in export changes from the MRB in 2050. Domestic exports of crops from the MRB decrease compared to the baseline in every drought scenario. The majority of this reduction comes from grains and oilseeds. In both the scenarios where only grains and oilseeds are impacted by drought, domestic exports of wheat from the MRB are higher than the baseline. The domestic exports of animal products from the MRB also increase compared to the baseline. There are similar trends when looking at international exports from the MRB.

Agricultural trade flows from regions outside the MRB in 2050 follow changes in agricultural output (Figure 8a and 8b). Domestic exports of crops increase compared to the baseline in all drought scenarios, especially for grains and oilseeds, with all crop exports increasing in the scenario where all crops in the MRB are impacted by drought. The domestic exports of animal products and forestry both decrease in all scenarios. Similar changes are seen in foreign exports of agricultural products, but to a lesser extent. This indicates that regions outside the MRB send a substantial amount of their increased agricultural output domestically to compensate for output changes in drought affected regions.

Figure 7: Exports of U.S. agricultural products from the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.

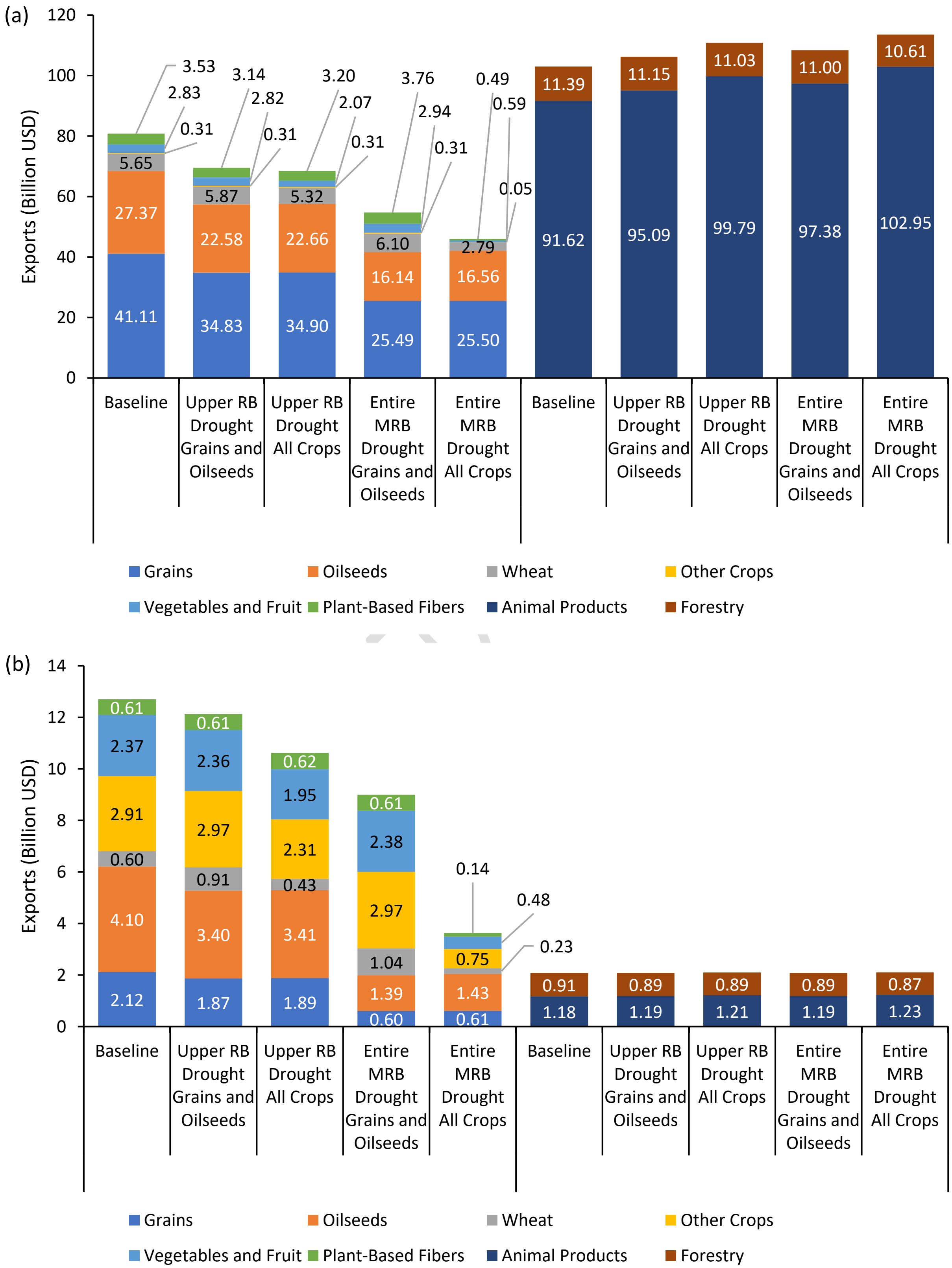
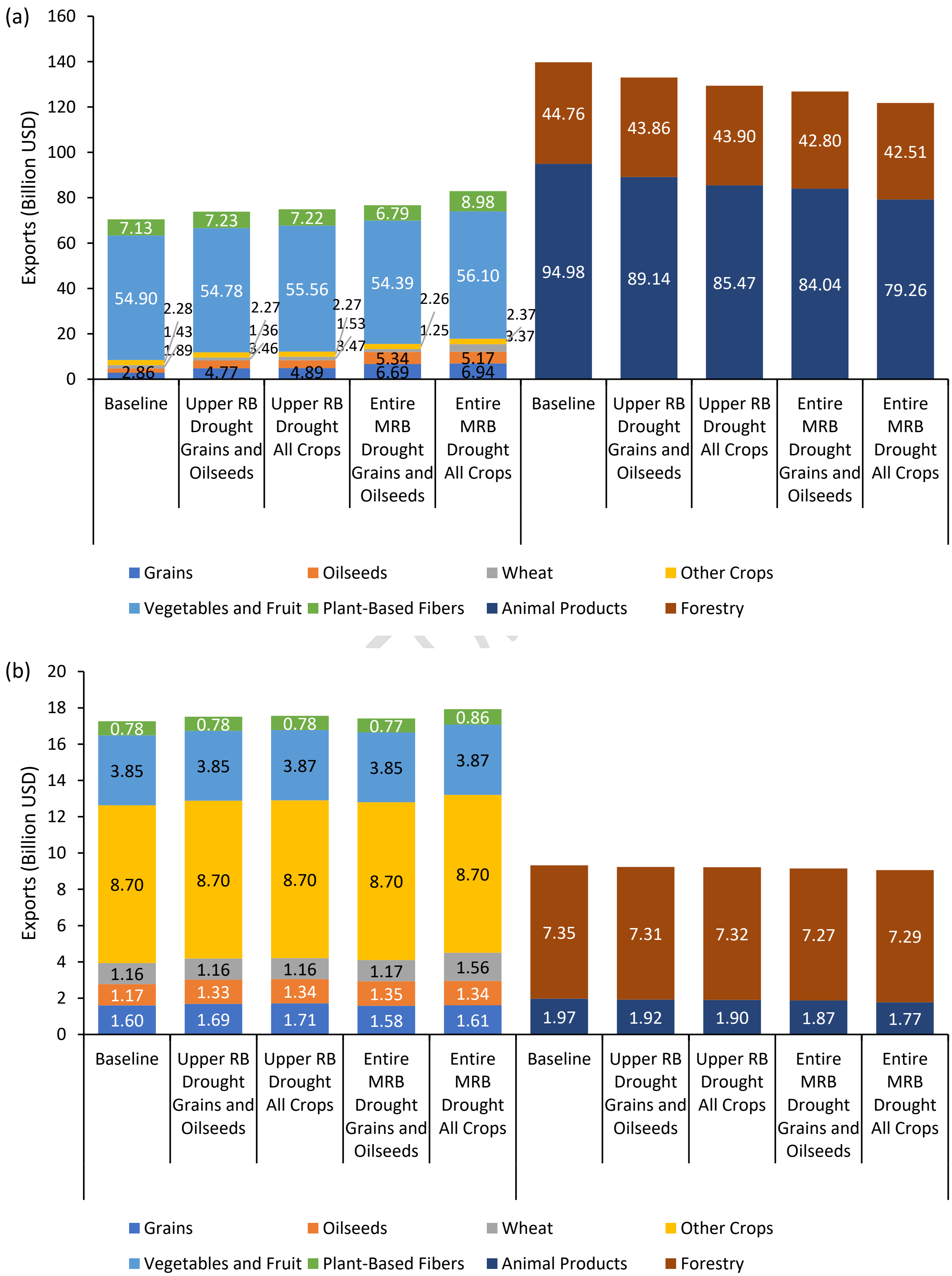
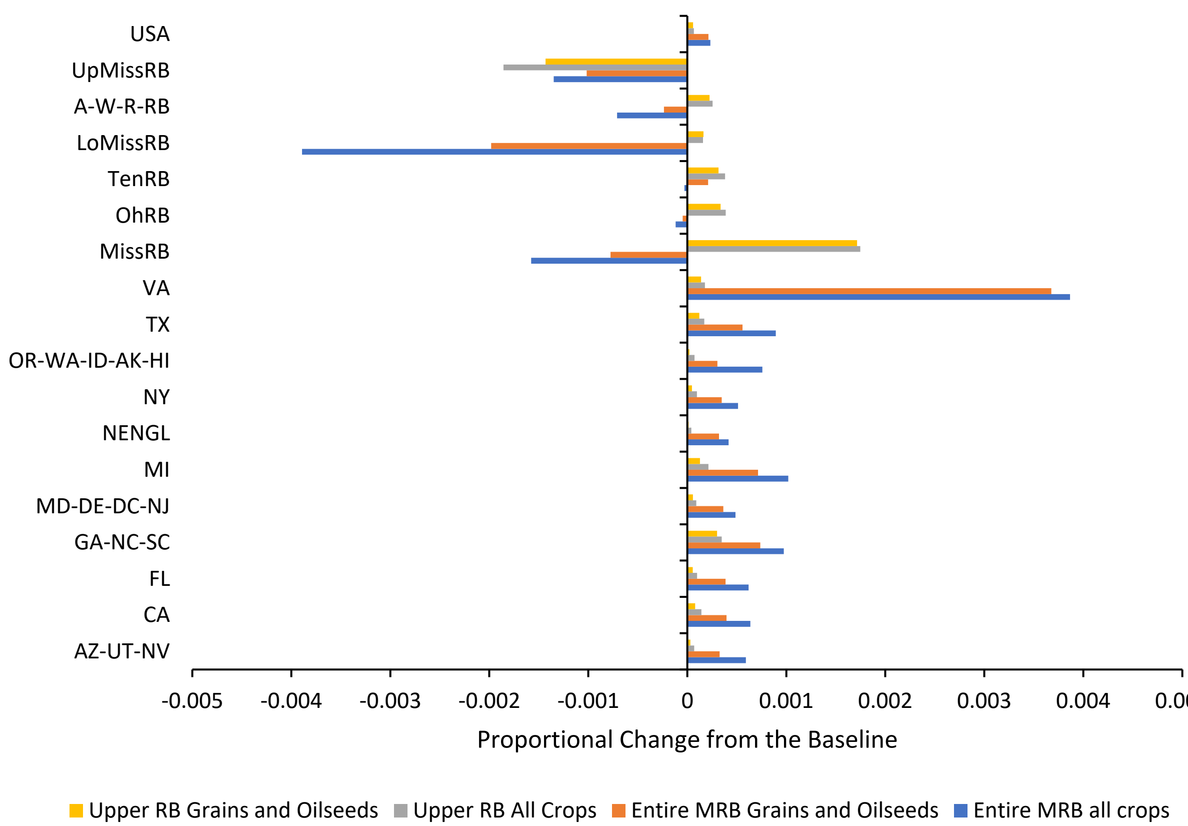


Figure 8: Exports of U.S. agricultural products from outside the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.



Impacts of the drought scenarios on the wider U.S. economy can be seen in Figure 9. As expected, the regions impacted by the drought experience a decrease in GDP relative to the baseline and regions unimpacted by the drought experience an increase. The largest decrease occurs in the Lower Mississippi River Basin (0.4 percent) and the largest increase occurs in Virginia (0.4 percent) when drought impacts all crops in the MRB. Looking at the impacts on the total U.S., across all scenarios, GDP marginally increases, with consumption and welfare following similar trends.[13] This result seems counter intuitive as it would be expected that a drought would negatively impact the wider economy. The reason for this outcome is due to the representation of the U.S. as a 'large economy' for trading purposes in the USREP model, meaning that changes in exports to the rest of the world have an impact on world prices. When a drought reduces the exports of crops from the U.S., world prices of those crops increase which benefits unimpacted regions exporting from the U.S. This positive impact on regions unimpacted by drought outweighs the negative impact on those regions impacted by drought. The positive impact on GDP, welfare and consumption for the total U.S. no longer exist when we run the model with the U.S. represented as a 'small economy', where it has limited or no impact on world prices from changes in exports[14].

Figure 9: Proportional change in GDP compared to the 2050 baseline across the four drought scenarios.



[13] The impacts on welfare, consumption and GDP are shown in Table B1.

[14] The GDP results where the U.S. is represented as a 'small economy' can be found in the Appendix Figure B5.

Overall, the results show a strong negative impact on production of crops and regions targeted by the shocks, as expected. Such declines in production may be as large as twice the yield shocks. This occurs because, when hit by a drought, farmers decide to shift land use toward those crops or agriculture products (such as animal products) not hit by the shock. The results also allow us to observe how the major adaptation mechanisms to drought shift among scenarios and are intensified when the shock hits more crops and a larger geographic scope. While irrigation offers an adaptation strategy for drought, it is not enough to mitigate the impacts of a persistent drought on crop production. This is because irrigated crops also suffer some yield impact under the drought shock (as shown in Table 3) and irrigation expansion is limited and costly, as dictated by the availability of water for irrigation in different regions and the costs associated with expanding irrigable land. Across the scenarios, the output response for grain production in regions unimpacted by drought is greater than the response to oilseeds and other impacted crops. This could be due to the harsher yield impacts from drought on grains rather than oilseeds, as seen in Table 3, combined with a relatively higher U.S. competitiveness in grains compared to other crops. When drought only impacts grains and oilseeds in a single MRB sub-basin, regional negative impacts on these crops are easily mitigated by shifting production to other crops and to animal products and increasing irrigation inside the impacted region, while grains and oilseed production expand outside the region. If all crops are impacted, conversions from crops to animal products are intensified to mitigate damages. When the geographic scope of the drought becomes larger, affecting the entire MRB and all crops, the major adaptation strategy inside the affected region is to replace crop production by animal products, while irrigation is not capable to avoid crop abandonment. Furthermore, there are strong shifts in intraregional trade of crops to compensate for reduced production in drought impacted regions.

The importance of trade for adaptation to drought is highlighted when the ability to import is restricted in drought affected regions. To explore this further, for the MRB drought scenario where all crops are impacted, we increased the cost of imports for MRB regions. The additional costs for imports are represented using increased transportation costs to impacted regions[15]. In this scenario the exports, imports and GDP of the MRB regions decrease by more than the original drought scenario impacting all crops in the MRB[16]. This demonstrates how trade can help buffer the impacts on agriculture and the wider economy from extreme weather events such as drought.

4 Conclusions

Drought is ranked third among billion-dollar environmental events since 1980 and represents a significant risk to the U.S. economy (NOAA, 2025). Farmers in the MRB supply a non-trivial quantity of the world's agricultural products (National Parks Service, 2025) and if a persistent drought occurs in the MRB, it is likely to cause costly disruptions to crops and trade. To understand the potential economic and land use impacts of persistent drought in the MRB, we improved and deployed the USREP model to explore a range of scenarios where drought impacts different regions and crops in the MRB from 2030 to 2050. Drought is represented through yield impacts on crops. The model allows to fully and consistently represent the major mechanisms for farmers to adapt to drought in both impacted and unimpacted regions, accounting for changes in supply and demand in all commodities and primary factors markets simultaneously, including changes in consumer's income and investments. These

[15] This is described in Appendix Figure C1.
[16] The results from this can be seen in Appendix Figures C2-C6.

adaption mechanisms include the ability for farmers to produce rainfed or irrigated crops; land use change between six crop types, animal products, forestry, natural grassland and natural forestry; and domestic and international trade flows.

A novelty of this approach is the differentiation of irrigated as well as rainfed crops. This involved representing the higher yields from irrigated crops as well as the water, capital, labor and intermediate input requirements to expand irrigated crop land. The methodology used here was an adaptation of the data and methodology described in Ledvina et al. (2018) and Winchester et al. (2018). Future research could expand on this approach by increasing the number of crops and regions represented in the USREP model which would allow for a finer spatial resolution to explore drought impacts.

The results show that while irrigated crops offer some adaptation from drought, they will not completely mitigate the effects of persistent drought, given they will also suffer negative yield impacts (Kuwayama et al., 2018). A much bigger adaptation to drought is the conversion of cropland towards pastures, shifting production from crops toward animal products in some of the impacted regions across all drought scenarios, with the main increase coming from the Upper Mississippi River Basin. Silburn, Robinson & Freebairn (2007) suggest that pastureland offers a healthier alternative for soil when cropping becomes unsustainable. This means, in certain regions, it could offer greater resilience in the presence of a drought. Animal products and grazing areas are unaffected by drought in the model, which partially explains the increased production of these products in impacted regions. However, it is likely that animal products will be negatively impacted by drought (NIDIS, 2025). We did not include these impacts here due to a lack of consistency in the literature on the yield impacts on this sector in the U.S. In the future, it would be interesting to explore the land use and economic implications of drought in the MRB with more of the agricultural sector impacted.

Similar to past literature exploring drought in the MRB, such as Kang & Lee (2025), Steinbach & Zhuang (2025) and Arita et al. (2022)**,** we find that total agriculture production in the U.S. suffers when part or all of the MRB is impacted by drought. This change in production is reflected by a reduction in domestic and international trade from the MRB. These reductions in trade occur without a representation of the decrease in river transport mobility from drought highlighted by Kang & Lee (2025), Steinbach & Zhuang (2025) and Arita et al. (2022). Nonetheless, we expand on this research by estimating the impacts of persistent future drought rather than historical drought as well as the potential adaptation mechanisms to drought including agricultural intensification, trade, the choice between irrigated or rainfed crop production and land use change. Future research could incorporate changes in transport mobility within the USREP model to explore how this could further exacerbate the negative impacts from drought.

The most important adaptation mechanism in the model is domestic and international trade. Flexibility of trade allows unimpacted regions to increase international exports and supply impacted regions with agricultural products. These changes in trade flows partially mitigate the impacts from drought in the MRB and dampen the wider economic impacts on the U.S. Of course, the trade possibilities influence all other changes in output and land use allocation observed in our results. This suggests that it is important for policymakers in the U.S. to limit obstacles to free domestic and international trade and allow for easier adaptation to persistent extreme weather events.

References

Arita, S., V. Breneman, S. Meyer and B. Rippey. (2022). *Low Mississippi River Barge Disruptions: Effects on Grain Barge Movement, Basis, and Fertilizer Prices*. farmdoc daily (12):164. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign. Retrieved December 15, 2025. https://farmdocdaily.illinois.edu/2022/11/low-mississippi-river-barge-disruptions-effects-on-grain-barge-movement-basis-and-fertilizer-prices.html

Campbell, R., Crowley, P. & Demura, P. (1983) Impact of drought on national income and employment. *Quarterly Review of the Rural Economy, 5*(3), 254–263.

Chiang, F., Mazdiyasni, O. & AghaKouchak, A. (2021). Evidence of anthropogenic impacts on global drought frequency, duration, and intensity. *Nature communications 12*(1), 2754. https://doi.org/10.1038/s41467-021-22314-w

Dimanchev, E. G., Paltsev, S., Yuan, M., Rothenberg, D., Tessum, C. W., Marshall, J. D., & Selin, N. E. (2019). Health co-benefits of sub-national renewable energy policy in the US. *Environmental Research Letters, 14*(8), 085012. https://doi.org/10.1088/1748-9326/ab31d9

Edwards, B., Gray, M. & Hunter, B. (2009). A Sunburnt Country: The Economic and Financial Impact of Drought on Rural and Regional Families in Australia in an Era of Climate Change. *Australian Journal of Labour Economics, 12*(1), 109-131.

Edwards, B., Gray, M. & Hunter, B. (2018). The social and economic impacts of drought. *Australian Journal of Social Issues, 54*(1), 22-31. https://doi.org/10.1002/ajs4.52

FAO (2025). *Producer Prices*. Food and Agriculture Organization of the United Nations. Retrieved June 14, 2025, from https://www.fao.org/faostat/en/#data/PP

Fleming-Muñoz, D.A., Whitten, S. & Bonnett, G.D. (2023). The economics of drought: A review of impacts and costs. *The Australian Journal of Agricultural and Resource Economics 67*(4), 501-523. https://doi.org/10.1111/1467-8489.12527

Freedman, H., AghaKouchak, A., Rigden, A.J., van der Hoek, A. & Tomlinson, B. (2025). Disparities in the impact of drought on agriculture across countries. *Scientific Reports, 15*, 13465. https://doi.org/10.1038/s41598-025-94166-z

Gurgel, A., Cronin, T., Reilly, J., Paltsev, S., Kicklighter, D. & Melillo, J. (2011). Food, Fuel, Forests, and the Pricing of Ecosystem Services. *American Journal of Agricultural Economics*, *93*(2), 342-348. https://doi.org/10.1093/ajae/aaq087

Gurgel, A., Chen, Y.-H. H., Paltsev, S. & Reilly, J. (2016). CGE models: linking natural resources to the CGE framework. In: A. Dinar and T. Briant (ed.), *The WSPC Reference On Natural Resources and Environmental Policy in the Era of Global Change: v. 3 – Computable General Equilibrium Models of Society*, World Scientific Publishing, New Jersey, p. 57-98.

Hoff, H., Döll, P., Fader, M., Gerten, D., Hauser, S. & Siebert, S. (2014). *Output of the Global Crop Water Model GCWM* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7422380

Horridge, M., Madden, J. & Wittwer, G. (2005) The impact of the 2002–2003 drought on Australia. *Journal of Policy Modeling, 27*(3), 285–308. https://doi.org/10.1016/j.jpolmod.2005.01.008

Kang, M., & Lee, S. (2025). Economic Impact of Mississippi River Drought on U.S. Agriculture: Insights from the Gravity Model. *Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis*, *Forecasting, and Market Risk Management*, Chicago, Illinois, April 14-15, 2025. https://doi.org/10.22004/AG.ECON.378995

Kuwayama, Y., Thompson, A., Bernknopf, R., Zaitchik, B. & Vail, P. (2018). Estimating the Impact of Drought on Agriculture Using the U.S. Drought Monitor. *American Journal of Agricultural Economics, 101*(1), 193-210. https://doi.org/10.1093/ajae/aay037

Ledvina, K., Winchester, N., Strezepek, K. & Reilly, J.M. (2018). New Data for Representing Irrigated Agriculture in Economy-Wide Models. Journal of Global Economic Analysis, 3(1), 122-155. https://doi.org/10.21642/JGEA.030103AF

Lu, L. & Hedley, D. (2004). The impact of the 2002-03 drought on the economy and agricultural employment. *Economic Round-Up, 3*, 25–43.

Melillo, J. M., Reilly, J. M., Kicklighter, D. W., Gurgel, A., Cronin, T. W., Paltsev, S., Felzer, B. S., Wang, X., Sokolov, A. P. & Schlosser, C. A., 2009. Indirect Emissions from Biofuels: How Important? *Science, 326*, 1397-1399. https://doi.org/10.1126/science.1180251

Mukherjee, S., Mishra, A. & Trenberth, K. E. (2018). Climate change and drought: a perspective on drought indices. *Current climate change reports, 4*, 145–163. https://doi.org/10.1007/s40641-018-0098-x

NDMC (2025). *Drought Basics*. National Drought Mitigation Center, University of Nebraska. Retirieved December 15, 2025, from https://drought.unl.edu/Education/DroughtBasics.aspx

NIDIS (2025). *Drought Impacts on Agriculture*. National Integrated Drought Information System (NIDIS), National Oceanic and Atmospheric Administration (NOAA). Retrieved December 14, 2025, from https://www.drought.gov/sectors/agriculture

NOAA (2025). *U.S Billion-Dollar Weather and Climate Disasters*. National Centers for Environmental Information (NCEI), National Oceanic and Atmospheric Administration (NOAA). DOI: 10.25921/stkw-7w73. Available from: https://www.ncei.noaa.gov/access/billions/

National Parks Service (2025). *Mississippi River Facts*. National Park Service. Retrieved December 14, 2025, from https://www.nps.gov/miss/riverfacts.htm

Picciano, P., Qiu, M., Eastham, S. D., Yuan, M., Reilly, J., & Selin, N. E. (2023). Air quality related equity implications of U.S. decarbonization policy. *Nature Communications, 14*(1), 5543. https://doi.org/10.1038/s41467-023-41131-x

Rutherford, T.F. (1999) Applied general equilibrium modeling with MPSGE as a GAMS subsystem: an overview of the modeling framework and syntax. *Computational Economics, 14*, 1–46. https://doi.org/10.1023/A:1008655831209

Rutherford, T.F. and A. Schreiber (2019). Tools for Open Source, Subnational CGE Modeling with an Illustrative Analysis of Carbon Leakage. *Journal of Global Economic Analysis, 4*(2), 1-66. http://dx.doi.org/10.21642/JGEA.040201AF

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., d'Croz, D.M., Popp, A., Sands, R., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A. & Valin, H. (2014). Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. *Agricultural Economics, 45*(1), 69-84. https://doi.org/10.1111/agec.12090

Silburn, D.M., Robinson, J.B. & Freebairn, D.M. (2007). Why restore marginal cropland to permanent pasture? Land resource and environmental issues. *Tropical Grasslands, 41*(3), 139-153.

Steinbach, S. & Zhuang, X. (2023). US agricultural exports and the 2022 Mississippi River drought. *Agribusiness An International Journal, 41*(1), 289-303. https://doi.org/10.1002/agr.21880

Tinker, R. (2026). *U.S. Drought Monitor*. NOAA, USDA, National Drought Mitigation Center. https://droughtmonitor.unl.edu/ (accessed February 19 2026)

USDA (2025). *Crop Acreage Data*. U.S. Department of Agriculture, USDA. https://www.fsa.usda.gov/tools/informational/freedom-information-act-foia/electronic-reading-room/frequently-requested/crop-acreage-data (accessed 2 March 2026)

USDA (2026). *Major Land Uses*. U.S. Department of Agriculture, USDA. https://www.ers.usda.gov/data-products/major-land-uses (accessed 15 February 2026)

Wang, L. & Ren, W. (2025). Drought in agriculture and climate-smart mitigation strategies. *Cell Reports Sustainability, 2*(6). https://doi.org/10.1016/j.crsus.2025.100386

Winchester, N., Ledvina, K., Strezepek, K. & Reilly, J.M. (2018). The Impact of Water Scarcity on Food, Bioenergy and Deforestation. The Australian Journal of Agricultural and Resource Economics, 62(3), 327-351. https://doi.org/10.1111/1467-8489.12257

Yuan, M., Barron, A. R., Selin, N. E., Picciano, P. D., Metz, L. E., Reilly, J. M., & Jacoby, H. D. (2022). Meeting U.S. greenhouse gas emissions goals with the international air pollution provision of the clean air act. *Environmental Research Letters, 17*(5), 054019. https://doi.org/10.1088/1748-9326/ac6227

Yuan, M., Tapia-Ahumada, K., & Reilly, J. (2021). The role of cross-border electricity trade in transition to a low-carbon economy in the Northeastern U.S. *Energy Policy, 154*, 112261. https://doi.org/10.1016/j.enpol.2021.112261

Yuan, M., Rausch, S., Caron, J., Paltsev, S. & Reilly, J. (2019). The MIT U.S. Regional Energy Policy (USREP) Model: The Base Model and Revisions. *Joint Program Technical Note*. https://cs3.mit.edu/publication/17331

Appendix A

Figure A1: Rainfed crop production in the USREP model.

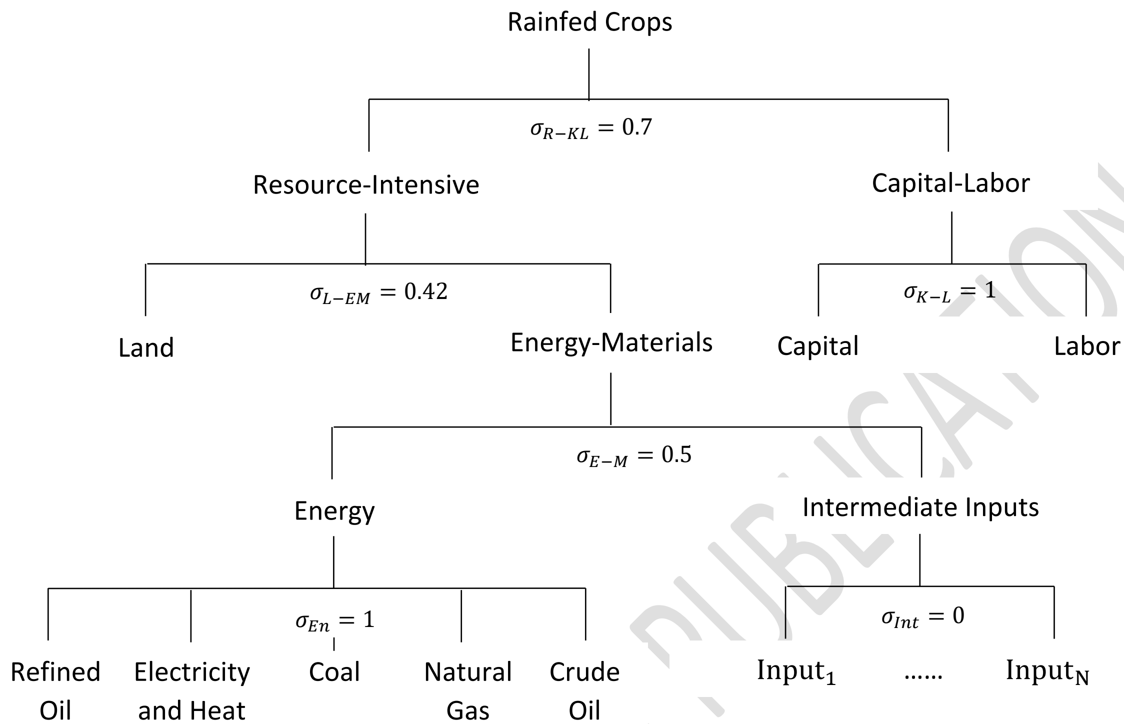


Figure A2: Irrigated crop production in the USREP model as described in Winchester et al. (2018).

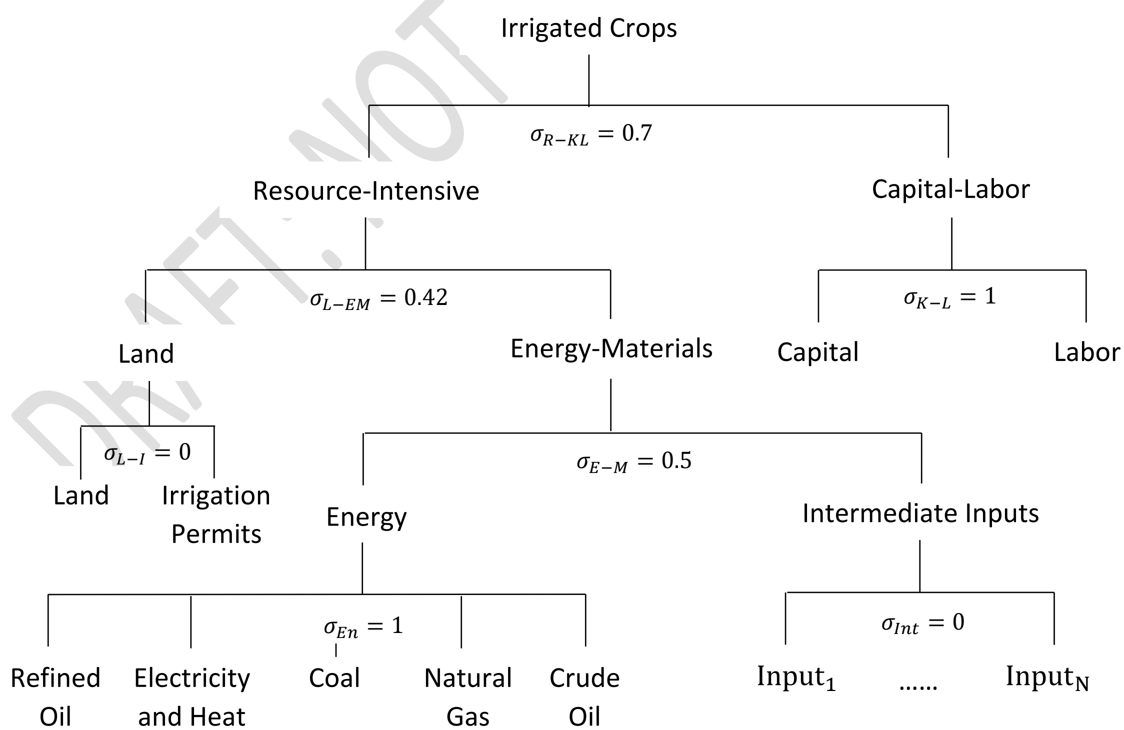


Figure A3: Production of irrigated land permits in each region in the USREP model as described in Winchester et al. (2018).

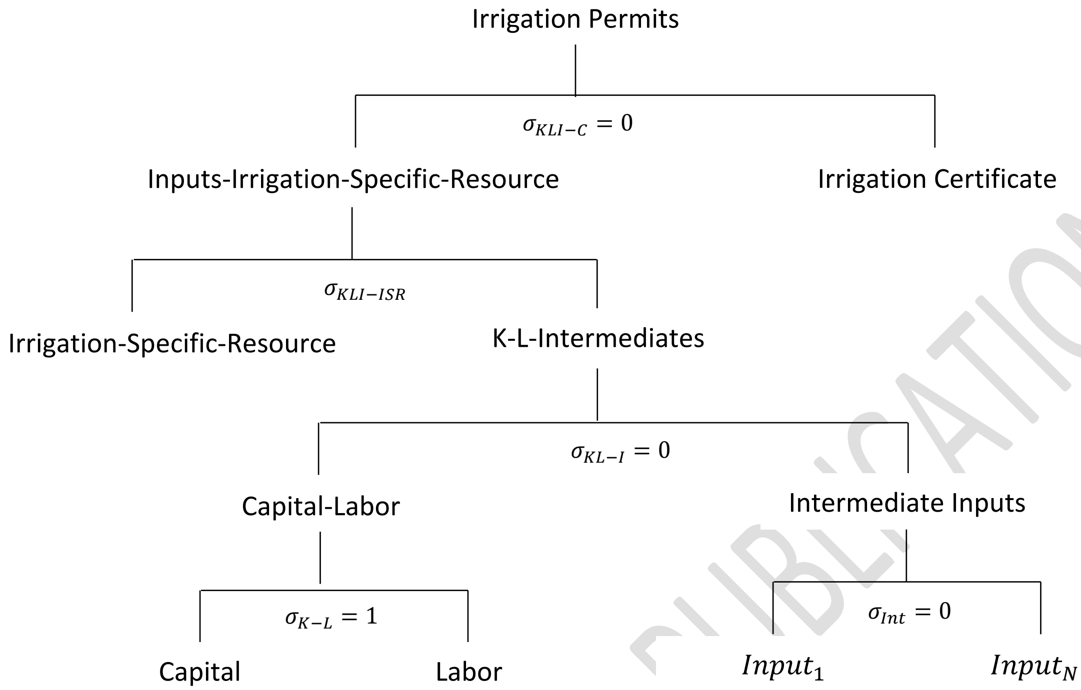


Figure A4: Substitution between rainfed and irrigated crops, based on the approach used in Winchester at al. (2018).

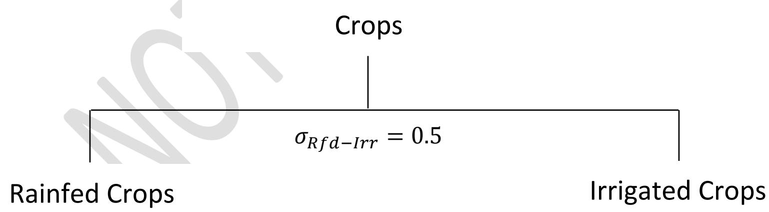


Table A1: The mapping of U.S. water basins described in Ledvina et al. (2018) to regions in the USREP model.

U.S. Water Basin Region	**Model Regions**
Arkansas	Arkansas-White-Red River Basin
California	California
Colorado	AZ-UT-NV
Columbia	OR-WA-ID-AK-HI
Great Basin	AZ-UT-NV
Great Lakes	Michigan[17]
Mississippi	Upper Mississippi River Basin and Lower Mississippi River Basin
Missouri	Missouri River Basin
Ohio	Ohio River Basin and Tennessee River Basin
Rio Grande	Arkansas-White-Red River Basin
South East United States	GA-NC-SC and Florida
North East United States	New England, MD-DE-DC-NJ, New York and Virginia
Western Gulf of Mexico	Texas

Table A2: The yield impacts from an additional week in drought for corn and soy, as estimated by Kuwayama et al. (2018).

Drought Level	Rainfed Yield Impact		Irrigated Yield Impact	
	Corn	Soy	Corn	Soy
D0	-0.00142	-0.00184	-0.0009390	-0.00013
D1	-0.00318	-0.00602	-0.000394	-0.00216
D2	-0.00622	-0.00591	-0.00135	-0.00292
D3	-0.0109	-0.00862	-0.00125	-0.0041
D4	-0.0119	-0.00657	-0.00485	-0.00077

[17] We use the information from Canada Great Lakes from the Ledvina et al. (2018) paper as it has been combined with the U.S. Great Lakes.

Appendix B

Table B1: Consumption, welfare and GDP in the U.S. in billions of USD in 2017, 2030 and 2050 across all four drought scenarios.

Year	Baseline	Upper RB Drought Grains and Oilseeds	Upper RB Drought All Crops	Entire MRB Drought Grains and Oilseeds	Entire MRB Drought All Crops
			Consumption		
2017	13308	13308	13308	13308	13308
2030	15393	15391	15391	15388	15388
2050	23505	23507	23507	23512	23513
			Welfare		
2017	20623	20623	20623	20623	20623
2030	23663	23658	23658	23652	23651
2050	36808	36811	36811	36816	36818
			GDP		
2017	19589	19589	19589	19589	19589
2030	22879	22874	22874	22867	22866
2050	36046	36048	36048	36053	36054

Figure B1: Rainfed, irrigated and total agricultural output as a proportional change from the baseline under a drought impacting grains and oilseeds in the Upper Mississippi River Basin.

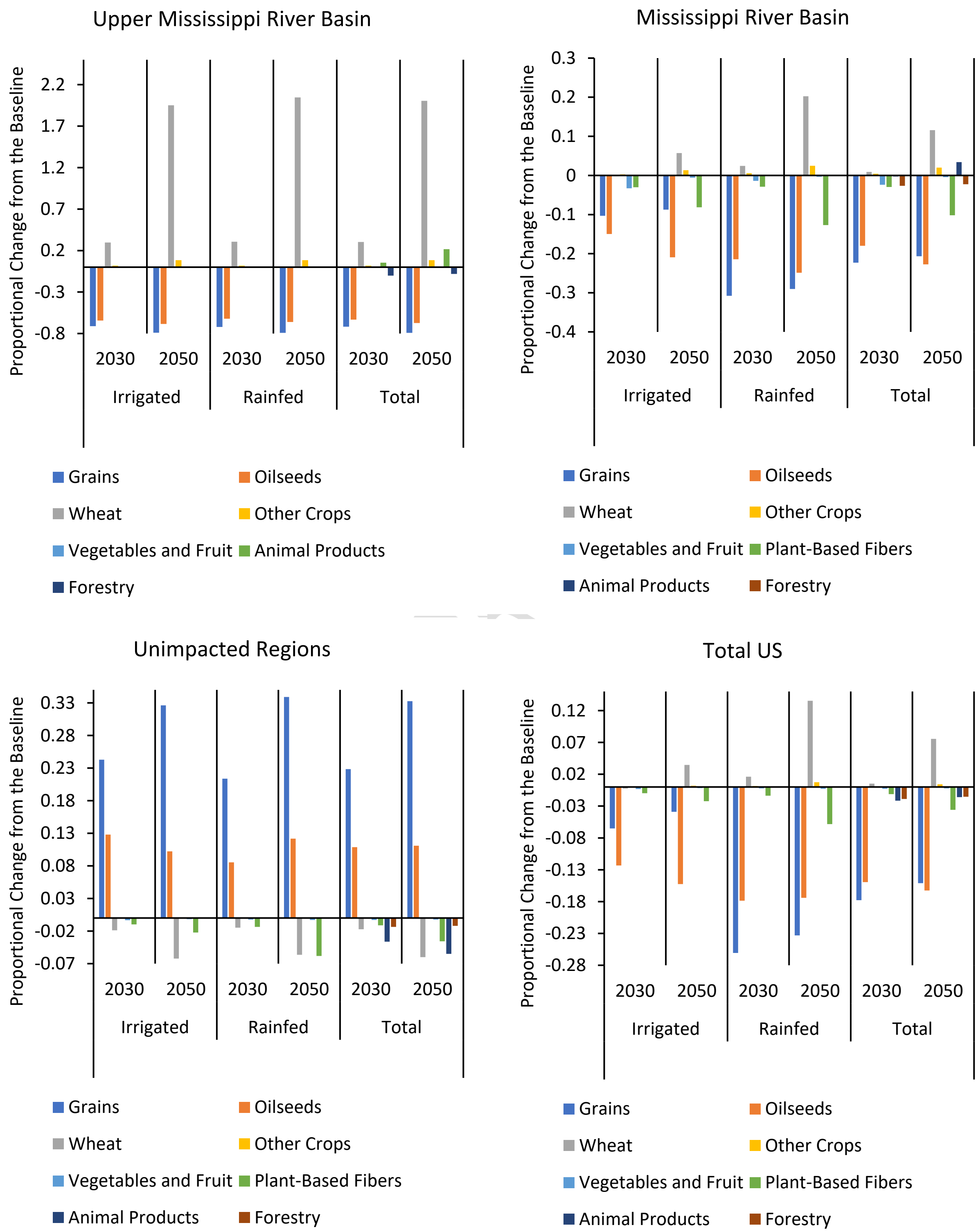


Figure B2: Rainfed, irrigated and total agricultural output as a proportional change from the baseline under a drought impacting all crops in the Upper Mississippi River Basin.

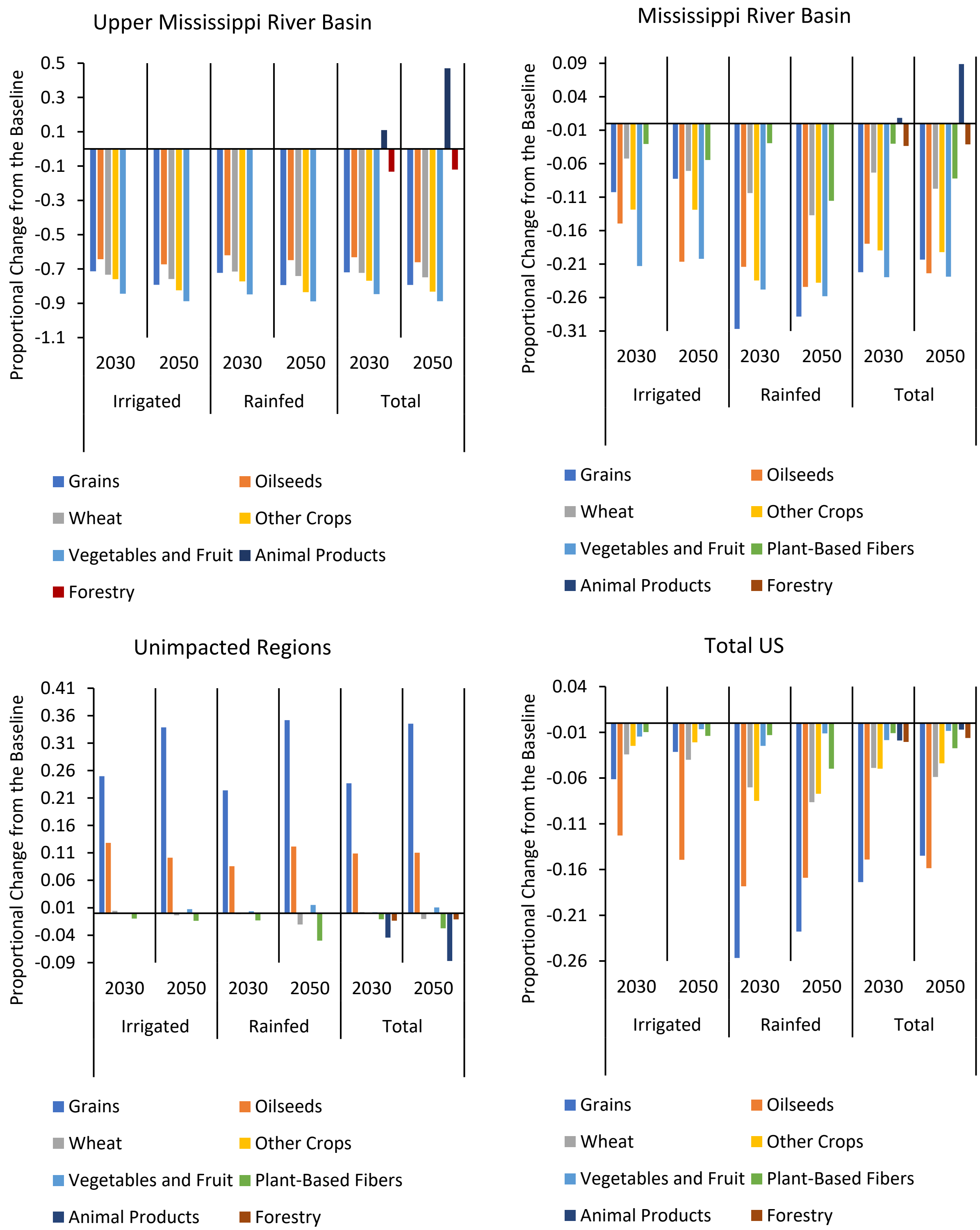


Figure B3: Rainfed, irrigated and total agricultural output as a proportional change from the baseline under a drought impacting grains and oilseeds in the MRB.

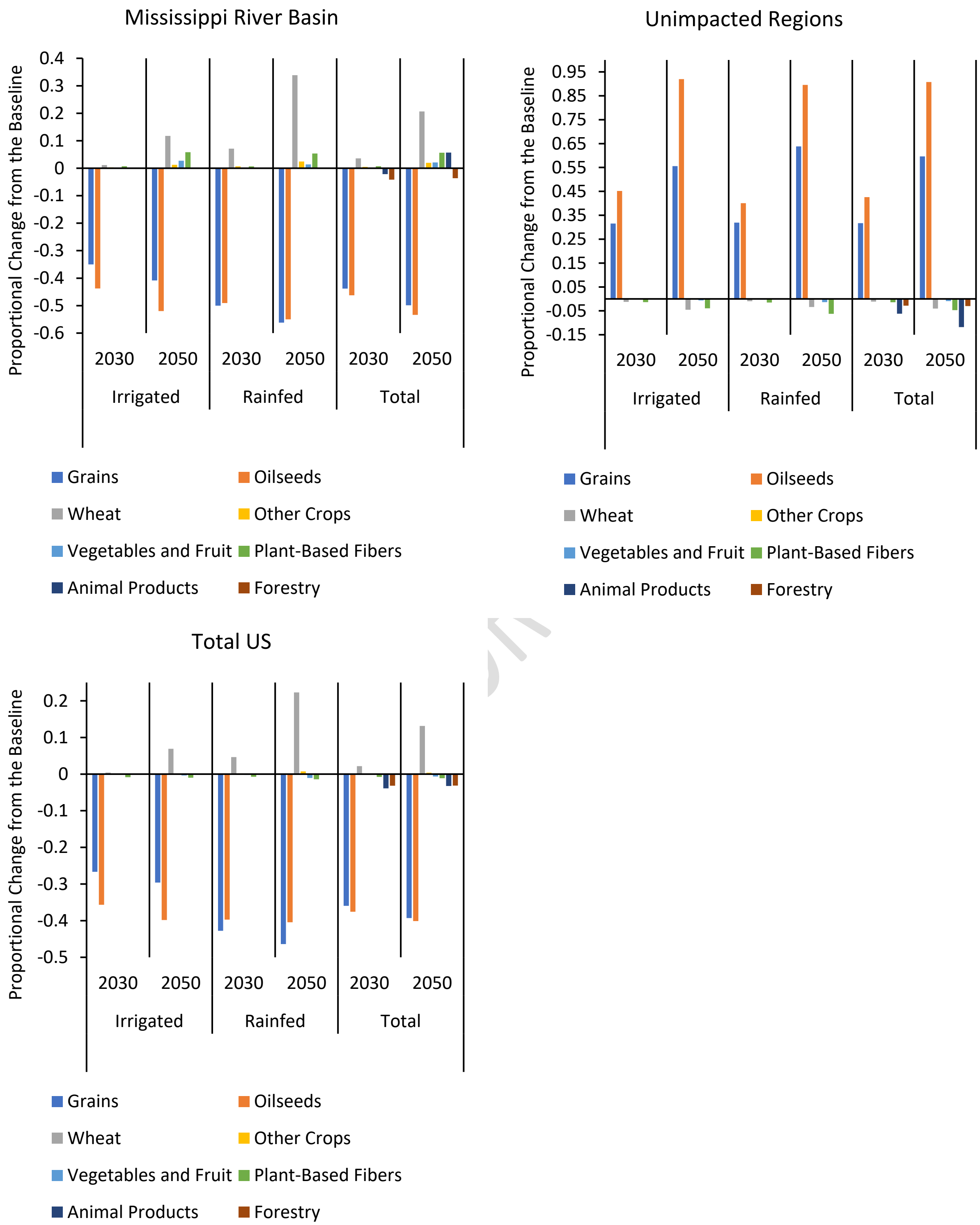


Figure B4: Rainfed, irrigated and total agricultural output as a proportional change from the baseline under a drought impacting all crops in the MRB.

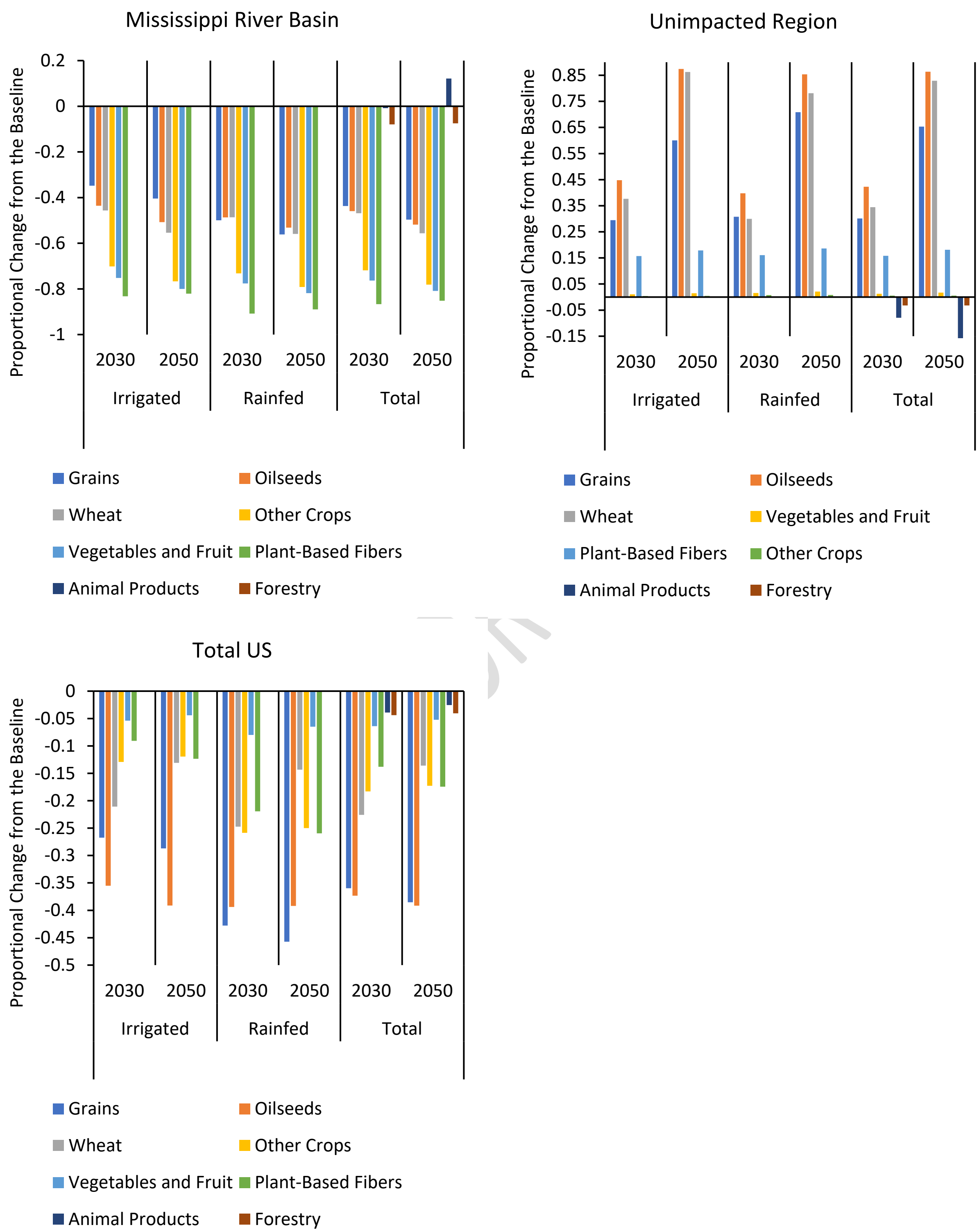
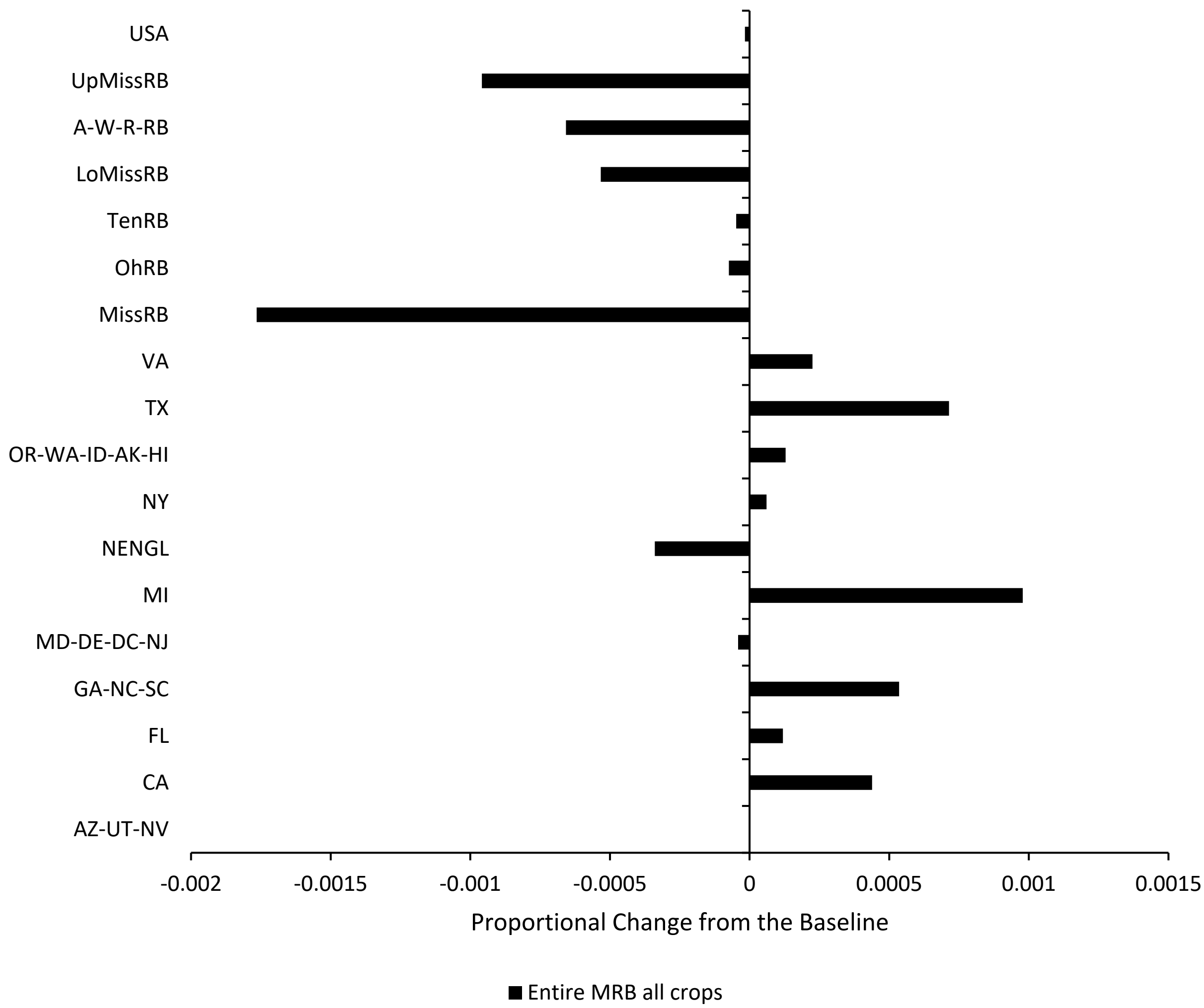


Figure B5: Proportional change in GDP compared to the 2050 baseline when all crops in the MRB are impacted by drought and if the U.S. is represented as a small economy.



Appendix C

Figure C1: The representation of imports to MRB in the model with additional transportation costs.

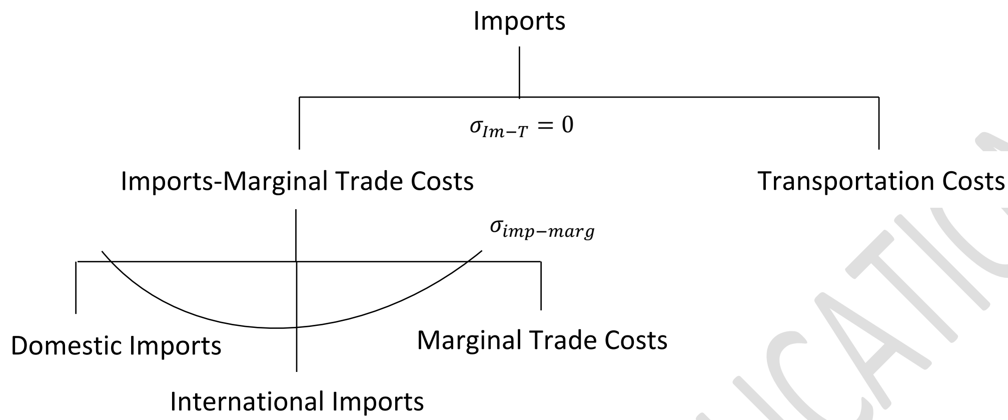
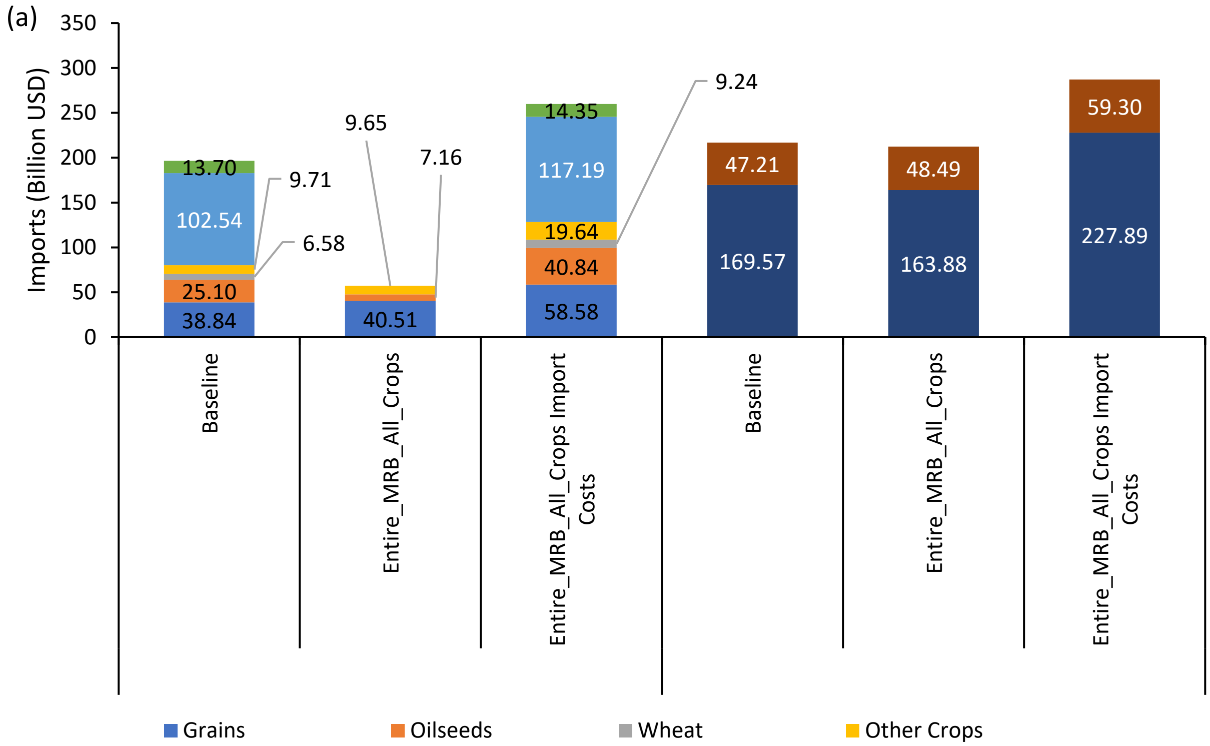


Figure C2: Imports of U.S. agricultural products to outside the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.



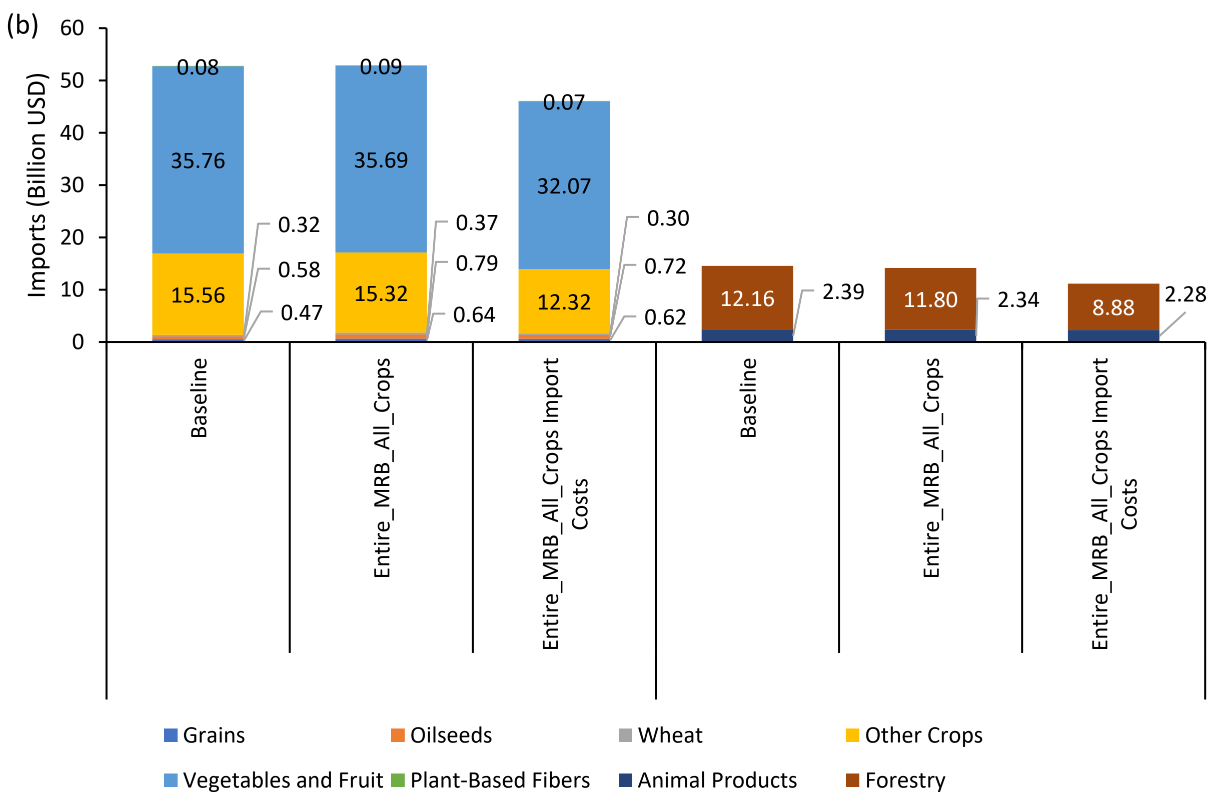
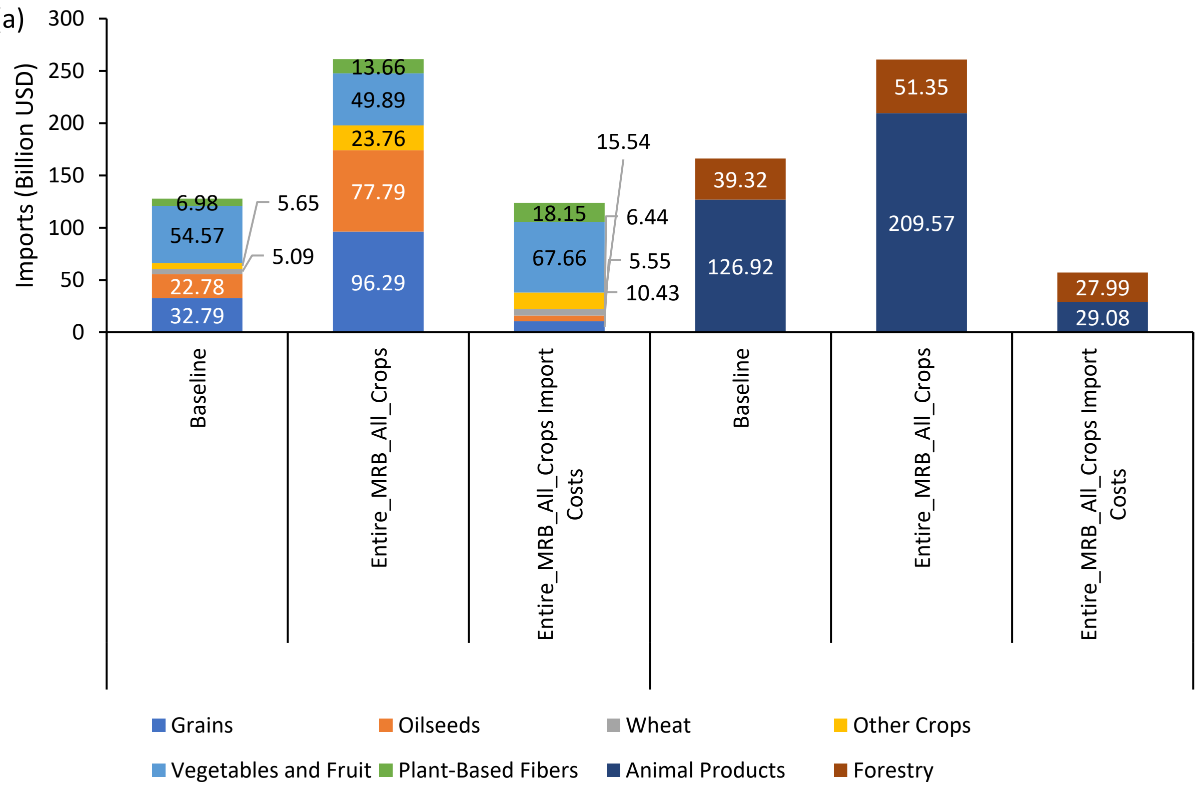


Figure C3: Imports of U.S. agricultural products to the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.

(a)



(b)

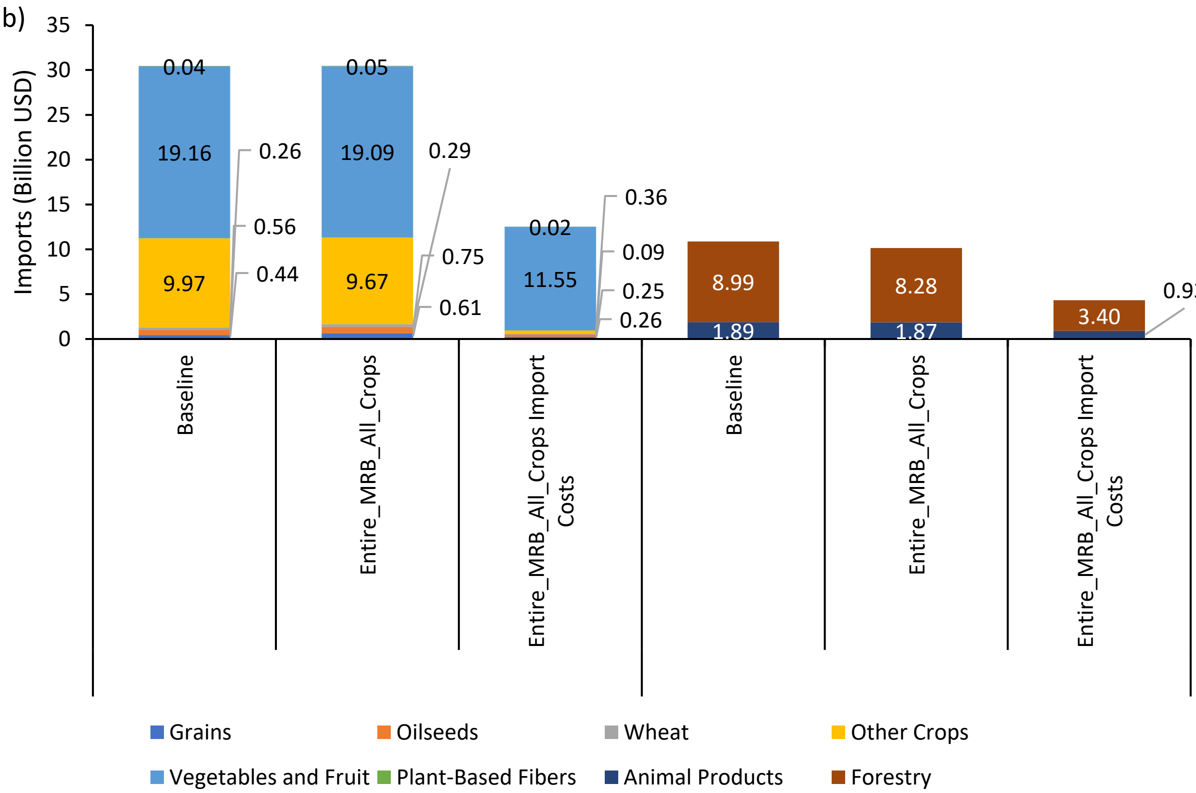


Figure C4: Exports of U.S. agricultural products from outside the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.

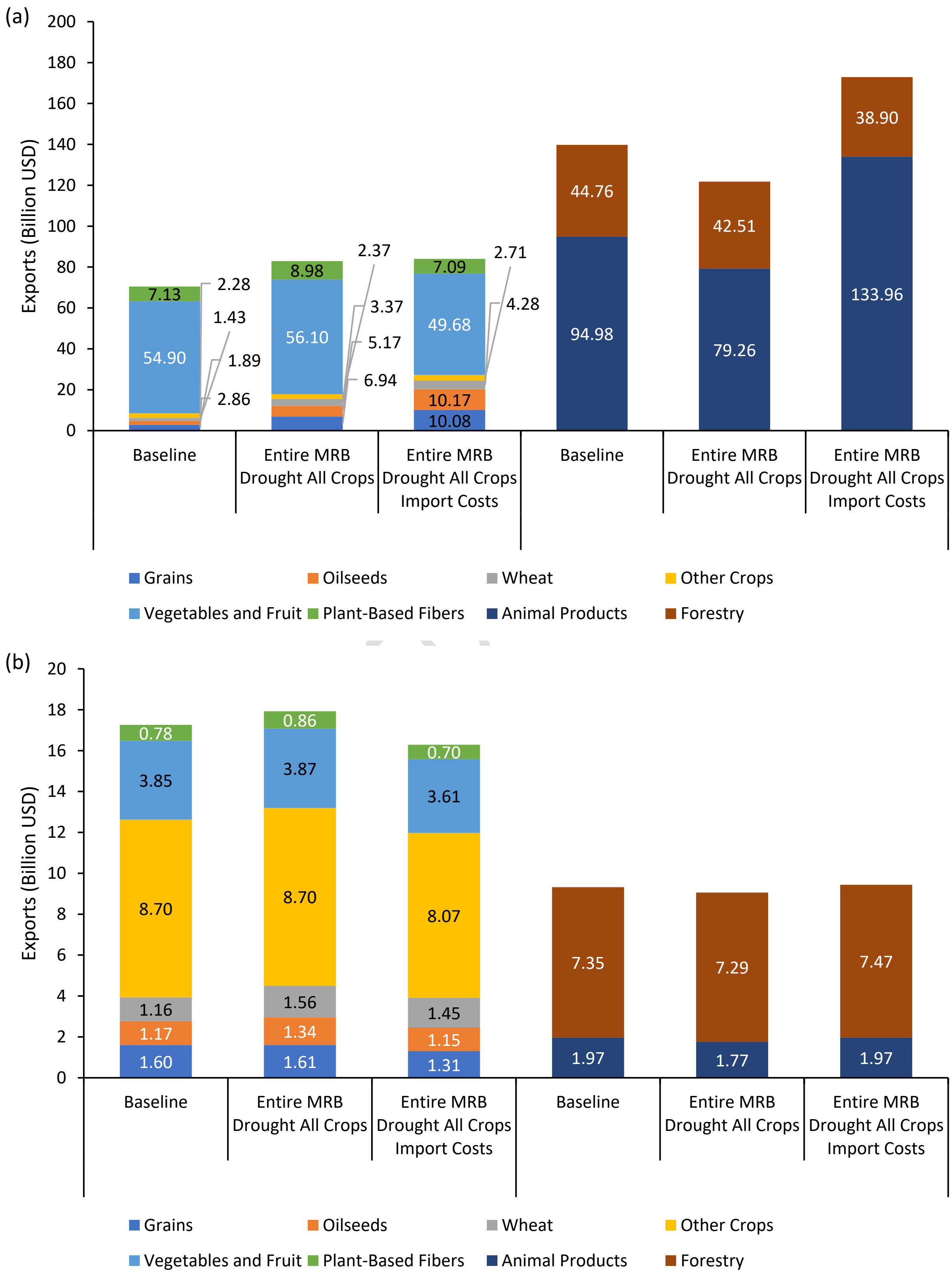
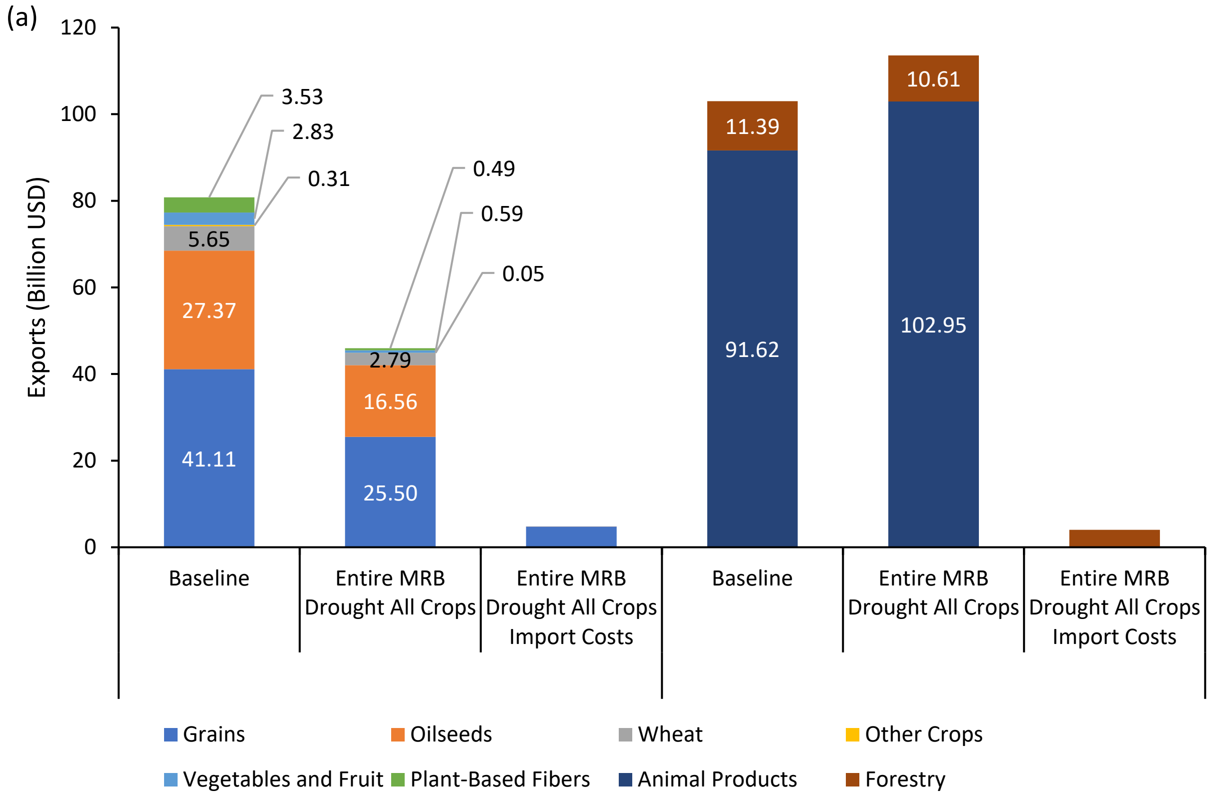


Figure C5: Exports of U.S. agricultural products from the MRB in 2050 (2017 Billion USD) (a) domestically and (b) internationally.



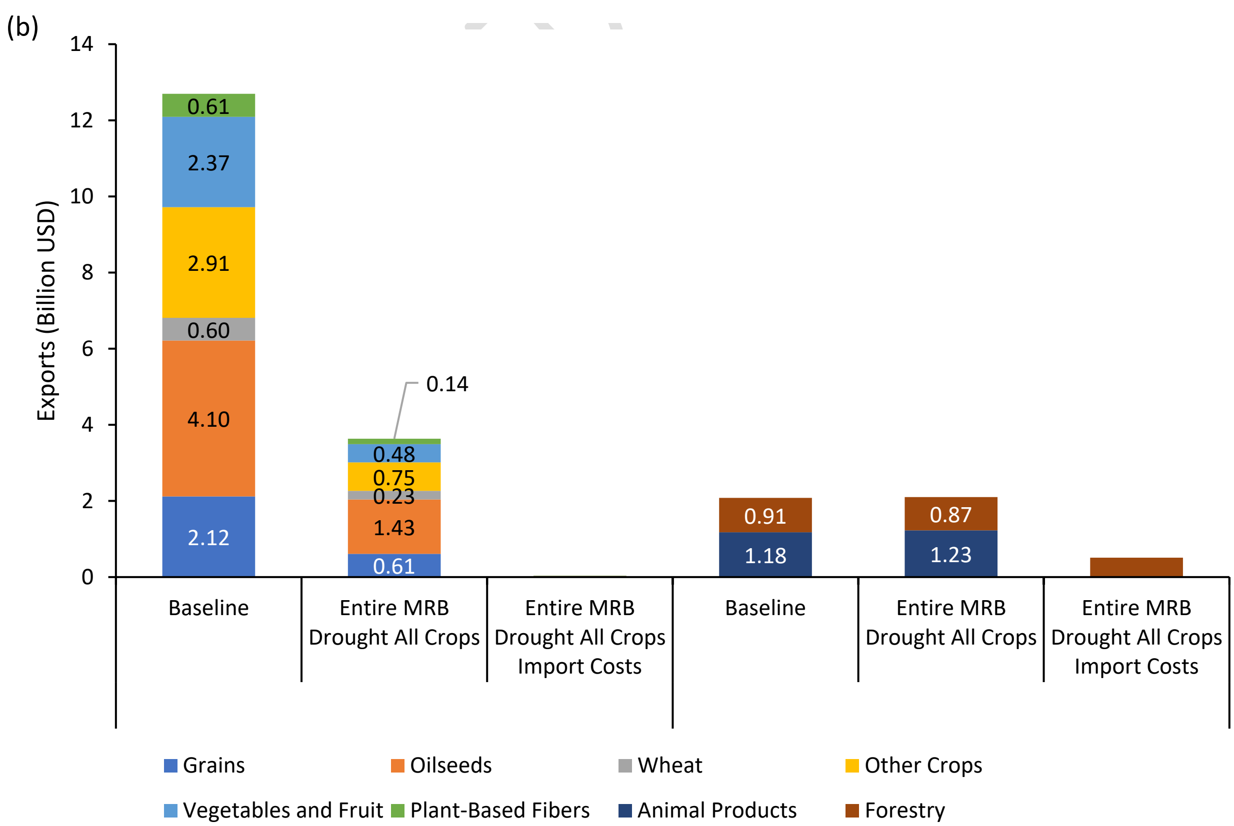


Figure C6: Proportional change in GDP compared to the 2050 baseline when all crops in the MRB are impacted by drought without additional import costs and with additional import costs.