

# **The Farm Economics and Solvency Projector (FarmESP)**

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# 1 Introduction

The Farm Economics and Solvency Projector (FarmESP) is a stochastic simulation model that projects future financial health for individual farms over a multi-year forecasting horizon. The primary uses of FarmESP are routine generation, as market conditions evolve, of probabilistic projections of farms' future financial conditions and simulating their financial outcomes under alternative policy and management scenarios.

A farm's revenues and costs are represented in great detail, with a typical instance of the model consisting of several hundred equations and values. The model currently can represent row crop farms, dairies, and ranches. Production and price variables are stochastic, and the model thereby characterizes the risk that is inherent to agricultural firms. A farm's financial condition is characterized using *pro forma* financial statements that reflect the combined effects of all relevant values, including stochastic production, stochastic output prices, stochastic costs, government program payments, crop insurance indemnities, debt service, and taxes.

FarmESP is directly descended from FLIPSIM ([Richardson and Nixon, 1981, 1986](#)), which was refined and used for analyses and congressional briefings over the course of decades. FarmESP therefore reflects this tremendous body of experience. FarmESP was developed, building on this solid foundation, to extend model capabilities and incorporate detailed representation of features of the farm financial landscape that have risen to prominence in the 21<sup>st</sup> century. In particular, crop insurance is represented in much greater detail in FarmESP than in the previous model.

This monograph provides a detailed description of FarmESP. The remainder of this introduction provides a high-level overview of the model and description of prior applications of FarmESP and its predecessor. The following chapter describes the many data sources used by the model. Subsequent chapters each describe an individual model component in detail.

## 1.1 Model Overview

This section provides an overview of the model structure, and is essentially a condensed presentation of the remaining chapters. This high-level overview facilitates an appreciation of the overall structure, before the detailed descriptions of individual model components are presented.

The primary data employed by the model are detailed information reflecting production and financial aspects of a farm. Each farm can consist of multiple entities, with each entity reflecting amounts of owned, cash rented, and share rented land, an arbitrary number of crop production Risk Management Agency (RMA) units, Farm Service Agency (FSA) base acres, zero or more bovine herds (used for either dairy or beef cattle production), an arbitrary list of equipment owned, a schedule of fixed costs including land debt service. For a typical commercial scale farm operation, this primary farm data consists of hundreds of individual values.

An important secondary source of data reflects projections for the U.S. agricultural sector. These consist of stochastic forecasts of prices for agricultural commodities, and price indexes corresponding to various categories of input costs. These values are required at an annual observation frequency. Additional data sources include USDA data governing FSA payments and data from RMA that are employed in calculating crop insurance premiums and indemnities. Data used by the model will be described in detail in chapter 2.

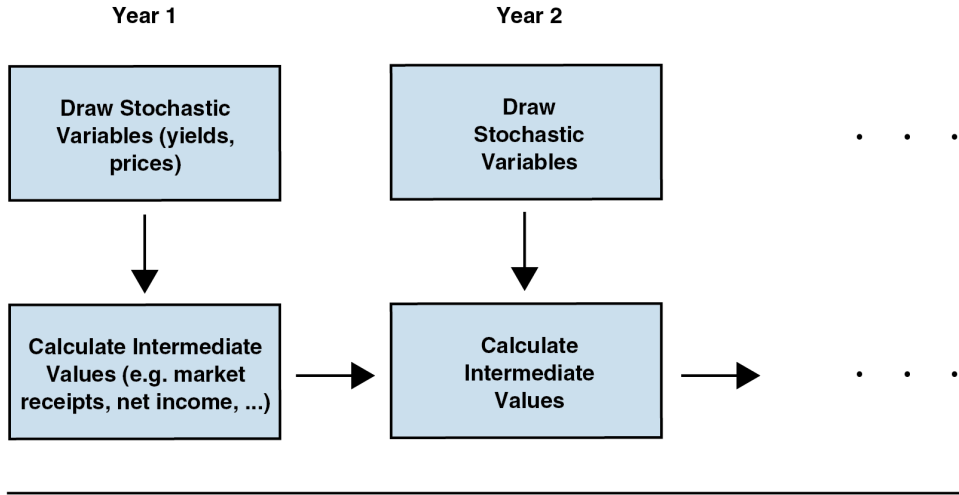
The model is stochastic and recursive dynamic. Being stochastic, model operation consists of a simulation exercise consisting of numerous individual trials. Each trial consists of a calculations over a sequence of years over the forecast horizon. For a single year within a single trial, joint random draws are generated or selected for all stochastic variables, such as farm crop yields, county crop yields, and prices. These stochastic values are then employed in the calculation of a very large number of intermediate variables, such as market receipts, government program payments, crop insurance indemnities, and tax payments. The next year within the same trial is then simulated analogously. The model is recursive dynamic in the sense that within each trial, the values calculated in one year are often employed in the calculations for following years.<sup>1</sup> For example, the farm's ending cash at the end of one year determines the starting cash and is used in calculating any carryover loan interest paid in the following year. This stochastic, recursive dynamic structure is illustrated in figure 1.1. Technical details of the simulation process are described chapter in 12.

A farm's entities can each reflect an arbitrary number of crop production RMA units. Within FarmESPan arbitrary number of *entities* may also be created on a

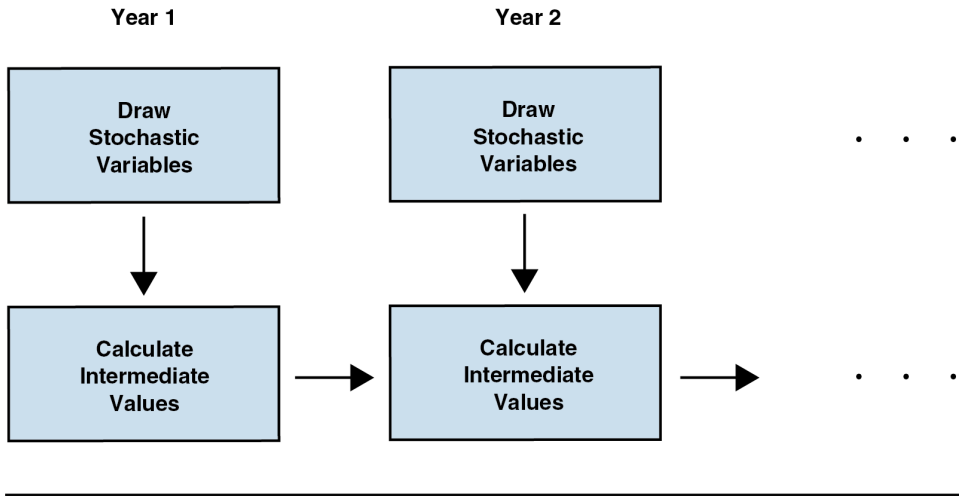
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<sup>1</sup>The model is not *fully* dynamic, in the sense that there is no forward-looking optimization.

**Trial 1:**



**Trial 2:**



**Trial 3:**

•  
•  
•

Figure 1.1: Recursive dynamic stochastic simulation

given operation. This allows for instances where multiple entities are utilized within one operation. In practice this could impact the amount of government payment limits an operation receives. With each RMA unit there will be associated a repeating pattern for planted acres, thereby accommodating crop rotation. Crop yields for each RMA unit are decomposed into a deterministic trend component and a stochastic deviation from that trend. These trend deviations are drawn from a probability distribution reflecting the RMA unit's production history.

Commodity production from each RMA unit is marketed at a local price that is an affine transformation of a stochastic national benchmark price. Variable production costs are represented for each individual production RMA unit, thereby accommodating multiple production practices across the operation. Some of these costs are calculated at a constant rate per planted acre, others are calculated per harvested RMA unit of the commodity. Twenty-two different variable cost categories are represented, including items such as seed, nitrogen fertilizer, irrigation fuel, and checkoff program contributions. Crop production, associated market receipts, and associated variable costs are described in full detail in chapter 3.

Crop insurance policies are represented in great detail in the model. Primary individual coverage policies are accommodated: yield protection (YP), revenue protection (RP) and revenue protection with harvest price exclusion (RP-HPE). The basic, optional and enterprise RMA unit structures are available. Production history and approved yield calculation options are available, including trend adjustment and yield exclusion. Premiums for these policies are calculated using the exact instructions in RMA's M13 Handbook ([USDA Risk Management Agency, 2020a](#)) using relevant input data in RMA's Actuarial Data Master ([USDA Risk Management Agency, 2020b](#)). The area-wide loss policies Supplemental Coverage Option (SCO) and Stacked Income Protection Program (STAX) are also available and represented in full detail. Crop insurance features of the model are described in full detail in chapter 4.

Farm entities can have an arbitrary number of bovine herds for producing milk or animals for beef production. The dynamics of bovine herds are carefully modeled, as the animals move through their life cycle over multiple years. Feedstuffs may be either purchased or grown on the farm, and the consumption rate is reflected separately for bovines at different ages and in different roles (e.g., nursing versus dry cows). Farm entities may operate their own feedlot operation for fattening steers for slaughter, and custom raising for dairy heifers are also available. Model features related to dairies and ranches are described in detail in chapter 5.

Model farms receive a wide array of government payments. Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) county programs are reflected in both their original configurations (for calculations reflecting years through 2018) and revised configurations under the 2018 Farm Bill (for years 2019 and beyond).

Additional ongoing program payments reflected in the model include Loan Deficiency Payments (LDPs), and Dairy Margin Coverage (DMC) indemnities. Various temporary program payments are added to the model as needed, such as those for the Market Facilitation Program (MFP) versions one and two, Coronavirus Food Assistance Program (CFAP), Emergency Commodity Assistance Program (ECAP), and Farmer Pridge Assistance Program (FBA). These model features are presented in chapter 6.

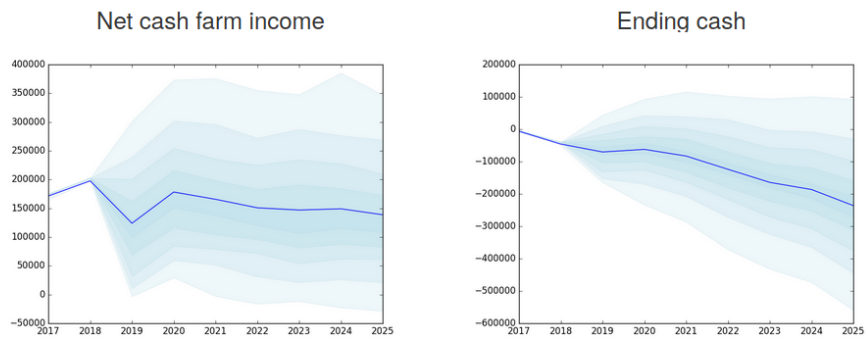
Farm entities in the model can own an arbitrary number of pieces of equipment. The life cycle of each item is tracked individually, including variables reflecting its routine replacement and accounting treatment. Values for each item reflect purchase date, replacement value, useful life, book value, and various values related to replacement strategy (buy new or used, financing details). This is all described in detail in chapter 8.

Numerous types of fixed costs are represented: debt service, salaries, land rents, maintenance, property taxes, depreciation, and many others. Amortization schedules for long-term loans are employed for tracking equity as time passes. Entities are subject to federal and state income taxes calculated as appropriate for the entity type (sole proprietorship, partnership, or corporation). *Pro forma* cash-flow statements, income statements, and balance sheets summarize all relevant revenues, expenditures and net worth for each farm. These can be calculated for an individual trial, or means for individual values within the financial statements can be calculated. Fixed costs, farm debt, and financial statements are detailed in chapters 9, 10, and 11, respectively.

The overall raw output of the recursive dynamic stochastic simulations is a three-dimensional array of values, with the dimensions reflecting model variables, years within the simulation horizon, and individual stochastic trials. For a single farm, this array typically consists of about 24 megabytes of numbers. To digest this raw output and present it in an easily usable form, it is typically browsed in a web-based output server. This output browser can summarize simulation results in various useful ways. As an example, the high-level results summary page for a single farm is presented in figure 1.2.

## 1.2 Applications

FarmESP has been used for routine briefings to the U.S. House and Senate Agriculture Committees since 2018. These routine briefings update U.S. policy makers on the evolution of market conditions, and generally correspond to published briefing papers (e.g. [Outlaw et al., 2019b,a](#), among others). In addition to these routine briefings, policy makers also rely on analysis from FarmESP as they consider changes to agricultural policy. For example, Congress requested analysis from



Entity: CORP

Vital signs

	2017	2018	2019	2020	2021	2022	2023	2024	2025
<b>Net cash farm income</b>	171,403	197,802	123,982	178,294	165,704	150,878	146,991	149,229	138,868
<b>Ending cash</b>	-6,251	-45,764	-70,223	-62,187	-82,862	-123,872	-164,303	-186,347	-236,080
<b>Change in cash</b>	-6,251	-39,513	-24,459	8,036	-20,675	-41,010	-40,431	-22,044	-49,733
<b>Real net worth (2017 dollars)</b>	1,516,611	1,608,631	1,631,053	1,646,258	1,697,747	1,676,046	1,660,834	1,670,847	1,691,818

Probabilities

	2017	2018	2019	2020	2021	2022	2023	2024	2025
<b>End cash negative</b>	1.00	1.00	0.81	0.72	0.75	0.80	0.86	0.86	0.87
<b>Change in cash negative</b>	1.00	1.00	0.61	0.46	0.60	0.66	0.66	0.59	0.71
<b>Real net worth greater than in 2017</b>	0.00	0.97	0.98	0.89	0.92	0.86	0.79	0.80	0.78

Figure 1.2: Example high-level summary of simulation output for a single farm

FarmESP during the preparation of the 2018 Farm Bill, as presented in [Outlaw et al. \(2018\)](#) and in confidential reports to Congress.

Outside of analysis for congress, FarmESP is perhaps most often used to evaluate the effects of new or revised government programs on farm financial health. For example, the effects of recent trade frictions and associated trade aid (MFP) programs were analyzed in [Fischer et al. \(2020\)](#), revealing that the programs had substantially reduced the probabilities of U.S. farms having negative ending cash several years hence. However, FarmESP is much more generally useful for evaluating the effects of any change in policy, market conditions, or management practices. In [Raulston et al. \(2020\)](#), for example, the effects of increasing debt levels and increasing interest rates were analyzed. In [Herbst et al. \(2020\)](#), the effects of producers' choices for Dairy Margin Coverage (DMC) on farm financial health were evaluated. In [Fischer et al. \(2021\)](#) and [Outlaw et al. \(2021\)](#), the potential impact to changes to the federal tax exemptions on agricultural operations were evaluated.

FarmESP is the direct successor to FLIPSIM ([Richardson and Nixon, 1981, 1986](#)). Due to the very long history of this ancestor, its uses and publications illustrate a wider array of potential applications for FarmESP. In addition to FLIPSIM being used for routine and special-purpose analyses for congress from 1981 through 2017, it was used for a large body of research applications. A small subset of such publications are briefly mentioned here. The effects of changing financial and market conditions have been a frequent topic of exploration using FarmESP's predecessor ([Brorsen et al., 1984](#); [Hughes et al., 1985](#); [Leatham et al., 1986](#)). Evaluation of the effects on farm profitability of various available management and marketing strategies is another strength of the models' approach and capabilities ([Richardson and Nixon, 1982](#); [Bailey and Richardson, 1985](#)). Crop insurance choices are an important variety of this latter application (e.g. [Lemieux et al., 1982](#)). Public policy choices have, of course, been a frequent application of FLIPSIM ([Richardson and Nixon, 1984](#); [Smith et al., 1985](#); [Nixon et al., 1990](#); [Knutson et al., 1997](#)). Again, this list of examples of published applications is far from comprehensive.

## 2 Data

Data used in FarmESP consists of three primary components. These are the data reflecting the farm operation being simulated, data reflecting the aggregate agricultural sector in the United States, and USDA data.

### 2.1 Farm Data

The primary data used in the simulations reflect the details of a farm operation. These data consist of many hundreds of individual values for a typical commercial scale farm. The data are arranged in the general structure shown in the nested list below. The data must consist of at least one entity, but any number of entities are accommodated. In this context, an entity represents a complete farming operation. Typically, all of the representative farms in the AFPC dataset are set up as 1 entity. That being said, the number of FSA "entities" used to determine the amount of government payments is established elsewhere within FarmESP. For all of the individual items within the entity (crop production tracts, FSNs, etc.), there may be an arbitrary number (including zero) of instances of the item. All data are collected for a specific year. For example, an individual variable cost reflects a specific year, and these are later adjusted for alternative years using price indices.

- General descriptive information
- Entities (one or more)
  - Entity-wide information such as fixed costs and interest rates
  - Crop production tracts
  - Farm service numbers (FSNs)
  - Land loans
  - Equipment
  - Simple activities
  - Bovine herds

– Lump-sum payments

The remainder of this subsection describes the data within each of the individual components of an entity. The crop production tract component of an entity's data reflects production of a row crop on a specific parcel of land, generally corresponding to a tract as recognized under individual coverage policies offered by the USDA Risk Management Agency (RMA). These tracts need not reflect exclusive use of a physical piece of land; multiple tracts may reflect cultivation of different crops on a single physical parcel of land (as with a crop rotation). Individual values employed for a crop tract include the state, county, sub-county (as defined by RMA), crop, crop type, and production practice for the tract. These values are all recorded using the corresponding official RMA numeric codes. Proportions of the land that are owned, cash leased, and crop shared are recorded, as is the landlord's share of production for crop shared tracts. Throughout this documentation, the terms *crop share* or *share lease* are used to describe a leasing arrangement where the tenant and landlord share a portion of the crop harvested on that land.

Local prices received for the crop are collected for an arbitrary number of historical years, as are parameters used to infer a local price from national crop prices in simulated future years. Values related to cottonseed production and prices are also collected for cotton tracts. An arbitrary number of years of production history (planted acres and realized production) are reflected in these data, as well as a current expected yield. These values are used to characterize the distribution of stochastic crop yields and to additionally serve as the tract's Actual Production History (APH) for calculating its crop insurance Approved Yield and Rate Yield. Numerous additional values related to crop insurance are collected: policy choice (YP, RP, or RP-HPE), unit structure (basic, optional, or enterprise), trend-adjustment option, coverage level, yield exclusion years, and parameters related to any area-wide loss coverage (STAX or SCO). Finally, variable costs paid by the farmer and the landlord (in the case of crop share leasing) are recorded for twenty-two categories listed below. Some of these costs are represented as cost per acre cultivated, others are cost per unit of the crop produced.

- Seed
- Seed technology fee
- Nitrogen fertilizer
- Potash and phosphorus fertilizer
- Herbicide
- Insecticide

- Fungicide
- Defoliant
- Growth regulator
- Chemical application costs
- Boll weevil eradication
- Scouting and consultants
- Irrigation fuel
- Fuel
- Water
- Drying
- Ginning
- Hauling
- Checkoff
- Harvesting fuel
- Custom harvesting
- Custom hauling

Data for each entity can reflect an arbitrary number of Farm Service Numbers (FSNs) as defined by the USDA Farm Service Agency (FSA) for the purpose of calculating and dispersing government program payments. Basic data for each FSN are the state and county in which the FSN is located. For each FSN, data for an arbitrary number of crops can be specified. For each, the crop and simple practice (irrigated or non-irrigated) are specified, as are the share of FSA payments that accrue to the landlord (if any), and the the proportion of base acres that are provided by the share lease (if any). The main data for each crop on an FSN, however, are the number of base acres, FSA program choice (Price Loss Coverage (PLC) or Agricultural Risk Coverage), and PLC payment rate (if PLC is selected). These latter values are collected separately for the entity's choices under the 2014 and 2018 Farm Bills.

Each entity can have an arbitrary number of long-term loans. For each, the following values governing loan payments are stored: year the loan was taken out, the loan term in years, the interest rate *per annum*, percentage of the current balance, acres of land, and the current market values of the land and any buildings purchased with the loan.

Each entity can own an arbitrary number of pieces of equipment. For each, loan data similar to that collected for land loans is stored. Additionally, values related to accounting treatment and replacement are stored: The current market value of the item, the replacement value, the useful life of the item, and the number of years over which the item is depreciated. Data for a typical commercial-scale farm will reflect many dozen such items.

Data can be stored for zero or more simple activities, which are defined as production activities in which the entity engages where there is no significant risk. For each, the input values collected are the number of productive units, and various values per productive unit: production yield, output price, and variable cost. Additionally, a variable cost per unit of output, fixed costs, and fixed revenues can be specified for each simple activity.

Each entity can operate zero or more bovine herds for dairy or beef cattle production. A large number of input values for the each bovine herd reflect the herd size, herd dynamics, and herd management strategy. These are discussed in detail in the section within chapter 5 that describes herd dynamics. For dairy herds, various data governing milk production and marketing are mean milk production per cow, average calving interval, average number of dry days for cows, average age at first calving, average number of dry cows, an arbitrary-length local milk price history, and parameters relating local milk prices to regional milk prices for simulated future years. Also for dairies, Dairy Margin Coverage (DMC) choices are stored by year: the coverage percent tier I coverage level, and tier II coverage level (when relevant). For bovines of different genders and at different life stages, typical marketing weights and values related to marketing prices are stored: price history, and parameters relating the marketing price to a relevant national or regional price in simulated future years. Data related to custom raising (if any) are stored: number of immature animals that are diverted, the length of time they are away, the cost per day per animal, fixed cost per animal, and typical number of animals that die while away. For each bovine herd, the entity may engage in its own feedlot/finishing operation for steers, and if so then relevant data are needed for this which are analogous to the data for custom raising. Additionally, data on local prices for fed steers are required, including a history of prices received and parameters for localizing simulated future regional or national prices for fed steers. An arbitrary number of purchased feedstuffs can be specified. For each, a local price history and parameters relating future simulated local prices to relevant regional or national prices are specified. Additionally, the average feeding quantities for each gender of bovine at each life stage must be specified for each feedstuff. For grown feedstuffs, analogous data are required, with the exception of those related to local prices. For grown feedstuffs, a crop and crop type, corresponding to one or more of the crop production units described earlier, must

additionally be specified. Several types of variable cost for the bovine herd are needed, as listed below. Some of these are specified per animal, while others are per hundredweight of milk.

- Veterinary and medicine
- Breeding
- Milk supplies and route truck
- DHIA and herd testing
- BST
- Bedding
- Hoof trimming
- Co-op retained revenue
- Milk promotion assessments
- Milk hauling
- Marketing
- *Ad valorem* rate for animal sale fees
- Checkoff fees
- Salt and minerals
- Animal hauling

Finally, for each entity one time payments may be specified for each calendar year. These may be positive or negative, and can be used for irregular payments or costs that do not fit naturally into one of the regular cost or revenue items.

The farm data can be edited in a user-friendly web browser-based editing program, a small section of which is shown in figure 2.1. The farm data are stored in JavaScript Object Notation (JSON), a human-readable plain text format, which facilitates automated manipulation of farm data using computer programs if desired.

### **2.1.1 AFPC Representative Farms**

The Agricultural and Food Policy Center (AFPC) at Texas A&M University has developed and maintains all of the data described above for more than ninety representative crop farms, dairies, and livestock operations in major production areas across the United States. Locations and types for these farms are shown in figure 2.2. The data for each farm are developed using panels of producers in each

**Crop & type**

**Practice**

Express as a proportion (e.g., '0.20'). Be sure that this number and the two numbers below sum to 1.0

**Proportion of land for this tract that is cash leased.**

Express as a proportion (e.g., '0.32')

**Proportion of land for this tract that is share leased.**

Express as a proportion (e.g., '0.48'). If this number is not zero, be sure to enter landlord's shares of production and costs.

**Landlord's share of production**

Landlord gets this proportion of the production from the portion of this tract that is share leased. Express as a proportion. For example, if the landlord gets half, enter '0.5'

**Expected yield**

Producer-expressed expected yield for the YEAR AFTER the data year. expressed as official

Figure 2.1: Farm data editor

local area and a consensus-building interview process. Sometimes two farms are developed in each region using separate panels of producers: one is representative of moderate size full-time farm operations, and the second panel represents farms that are generally two to three times larger. These are reflected in figure 2.2 as two sets of numbers for a single location. For example, there are medium and large representative feed grain farms in northern Iowa.

The data collected from the panel farms are analyzed using FarmESP. The producer panels are provided pro-forma financial statements for their representative farm and are asked to verify the accuracy of simulated results for the past year and the reasonableness of a five-year projection. Each panel must confirm that the output from the model reasonable reflects the economic activity on their representative farm prior to using the farm for policy analysis.

AFPC’s representative farms are generally updated once every two to three years. Intermediate and long-term debt financing is established based on farm category. The initial debt levels are generally assumed to be 20 percent for row crop operations, 1 percent for beef cattle ranches, and 30 percent for dairies. These debt levels are based on a stratified tabulation of the ERS-USDA Farm Cost and Returns Survey (using the survey data for moderate to large size farms in states where AFPC has representative farms) and panel member input.

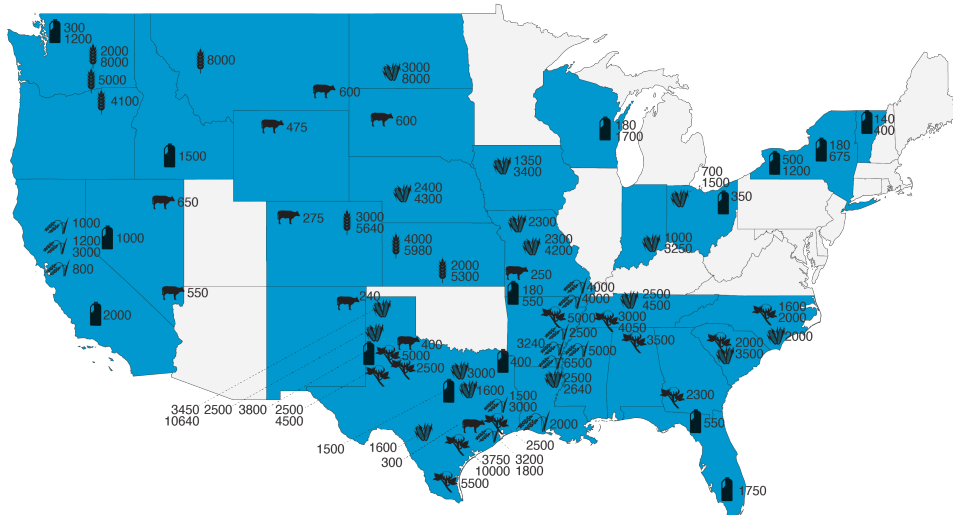


Figure 2.2: AFPC representative farm locations and types

## 2.2 Agricultural Sector Baseline

A second type of data required for FarmESP reflects future projected conditions in the overall U.S. agricultural economy at an annual observation frequency. These data consist of two categories. The first category is national and regional prices for agricultural commodities, including row crops, dairy and livestock. These data contain numerous possible future time paths for each variable, and implicitly represent the joint probability distributions over all relevant prices, thereby embodying not just expected future prices, but also the variability of each price and co-variability among prices for each year in the forecast horizon.

Second, the agricultural sector baseline required by FarmESP must include various price indices. Unlike the price projections, these are single projected future time paths for each index; they are not stochastic. Indices are required for agricultural land in various regions, and for several production input categories, roughly corresponding to the categories of variable costs described in the previous section: seed, herbicide, fuel, *et cetera*.

AFPC generally employs an agricultural sector baseline provided by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri. A recent example of their baseline is described in [Food and Agricultural Policy Research Institute \(2020\)](#), although the raw stochastic projections that underlie such reports are not generally made public by FAPRI.

### 2.2.1 Monthly Dairy Margin Variables

Stochastic future price paths, with an annual observation frequency, are the generally required agricultural sector baseline input for FarmESP. This baseline input contains many variables, including four needed for calculating Dairy Margin Coverage (DMC) program payments: the all-milk price, the alfalfa hay price, the soybean meal price, and the corn price.

However, *monthly* observations of the dairy margin are needed for calculating DMC payments, and we are therefore required to generate random monthly values for each of the four variables related to DMC from possible future realizations of the annual average values emanating from the agricultural sector baseline. This subsection describes the process used for generating these monthly stochastic draws, using as an input the annual stochastic draws from the agricultural sector baseline. The process we employ will result in random monthly prices that reflect, for each of the stochastic trials, the inter-year random price path from the baseline for that trial, but with a monthly observation frequency and with additional intra-year short-run randomness also imposed.

The process we employ requires several steps which are described below.

Each step is illustrated using the actual historical all-milk prices over the years 2000 through 2017, so that at the end we can compare the random monthly prices generated using the process to actual realized monthly prices, thereby demonstrating that the random prices we generate are a plausible reflection of reality.

### Step 1: Up-sampling average annual prices

Given a series of annual average prices (hereafter, series A), we employ a cubic smoothing spline to generate a corresponding series of arbitrarily high-frequency observations. The spline is fit using the mid-point of each year as grid points. The resulting series will obviously not reflect any intra-year variability pattern. Picking new observation points to reflect the middle of each month, we refer to this un-seasonalized, up-sampled series as series B. This is illustrated in figure 2.3.

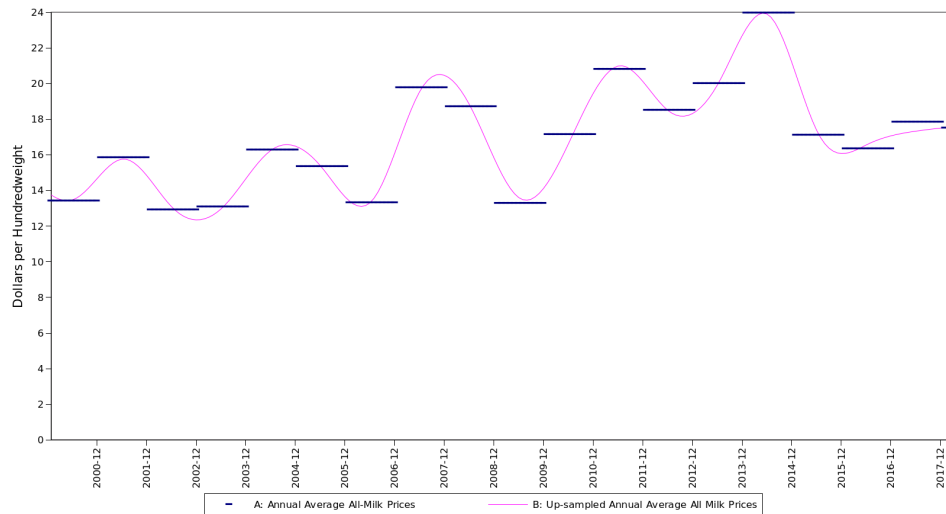


Figure 2.3: Fitting a cubic smoothing spline to annual average milk prices

### Step 2: Incorporating price seasonality

For the all-milk price (but not the other prices), we accommodate a seasonal price component. As will become obvious, the intra-year seasonal variability is overwhelmed by inter-year price variability, and seasonal adjustment factors would very difficult to reliably fit econometrically.

We instead infer seasonal adjustment factors from class III milk futures prices. Specifically, we observe the class III milk futures settlement prices for May 31,

2018 on the Chicago Mercantile Exchange for contracts delivering in calendar 2019. These prices reflect a small amount of expected future inter-year price change, however. We specify a linear (across time) adjustment to the 2019 delivery prices such that the January 2020 delivery price of \$16.10 per cwt would be equal to the January 2019 delivery price of \$16.29. Our adjusted January 2019 price is equal to our unadjusted January 2019 price. Our adjusted February price is the unadjusted February price plus  $(\$16.29 - \$16.10) \div 12$ . Our adjusted March price is the unadjusted March price plus  $2 \times (\$16.29 - \$16.10) \div 12$ , and so forth. Thus adjusted prices are illustrated in figure 2.4.

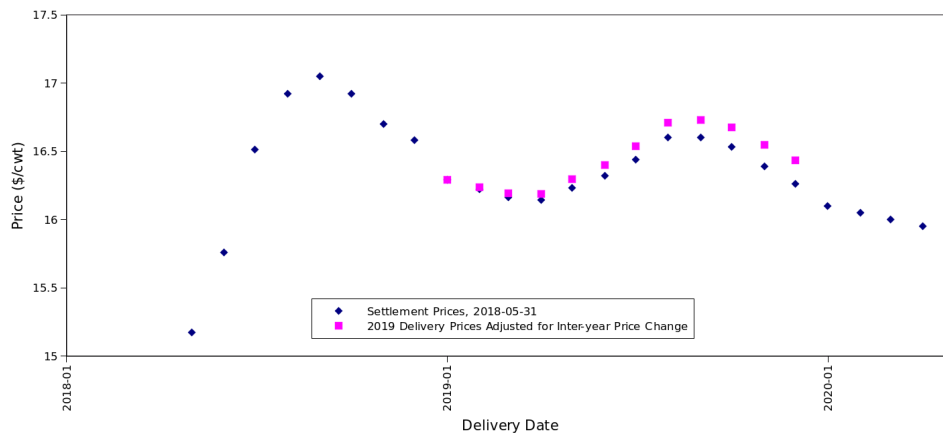


Figure 2.4: Class III milk forward curve

We then calculate monthly multiplicative adjustment factors by dividing each month's adjusted 2019 futures prices by the average 2019 adjusted futures price of \$16.4354. These range from a low for April of  $\$16.1875 \div \$16.4354 = 0.9849$  to a high for September of  $\$16.7267 \div \$16.4354 = 1.0177$ . We then use these multiplicative seasonal adjustment factors to adjust the un-seasonalized conditional expected prices for each month (series B) from the previous step. This results in a series of seasonalized, up-sampled annual average prices (series C), as illustrated in figure 2.5.

### Step 3: Random short-run variability

We specify an autocorrelated short-run random component as follows.

$$u_t = \rho u_{t-1} + \epsilon_t$$

$$\epsilon_t \text{ i.i.d. } N(0, \sigma)$$

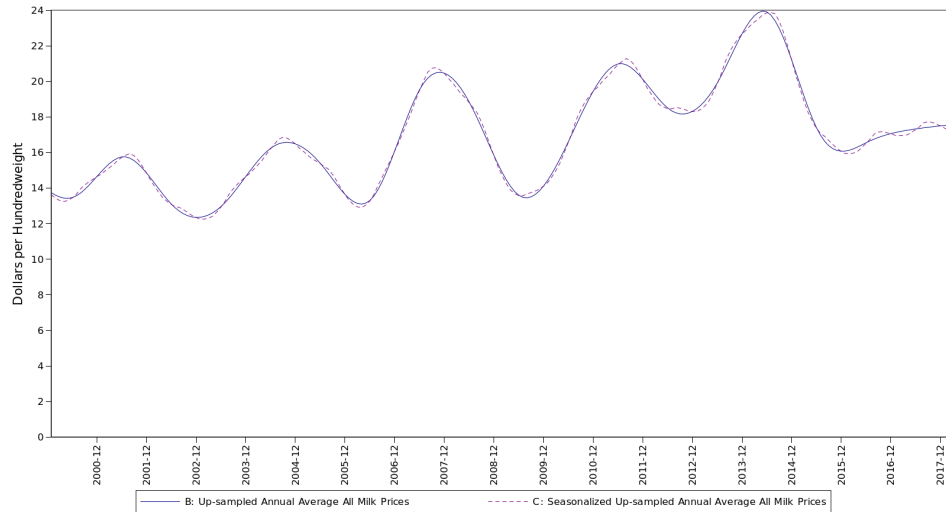


Figure 2.5: Adding seasonality to up-sampled milk prices

For each series, we recover a historical  $u_t$  series by subtracting actual observed monthly prices from the corresponding series C from the previous step (for the all-milk price) or series B (all other prices). A value  $\hat{\rho}$  is calibrated using a simple OLS regression of the recovered  $u_t$  series on its own lag. This estimated autocorrelation parameter is then used to recover a historical  $\epsilon$  series, and a value  $\hat{\sigma}$  is calibrated as the sample standard deviation of the recovered series. Fitted parameters for the four series are presented in table 2.1.

	All-milk Price (\$/cwt.)	Corn Price (\$/bu.)	Soybean Meal Price (\$/ton)	Alfalfa Price (\$/ton)
$\hat{\rho}$	0.82	0.94	0.89	0.87
$\hat{\sigma}$	0.71	0.21	25.52	5.49

Table 2.1: Calibrated parameters for short-run random deviation processes

This process is used to generate a random  $u_t$  series. This short-run random component observation for each month is then added to the seasonalized conditional mean for that month (series C). This results in a final random series for one trial (series D for a single example random trial), as shown in figure 2.6.

This completes the process of generating a single random monthly price series using annual observations like those projected using our structural model. Finally, we can compare a random series generated using the process above (series D), starting only with a set of annual average prices (series A), to actual observed

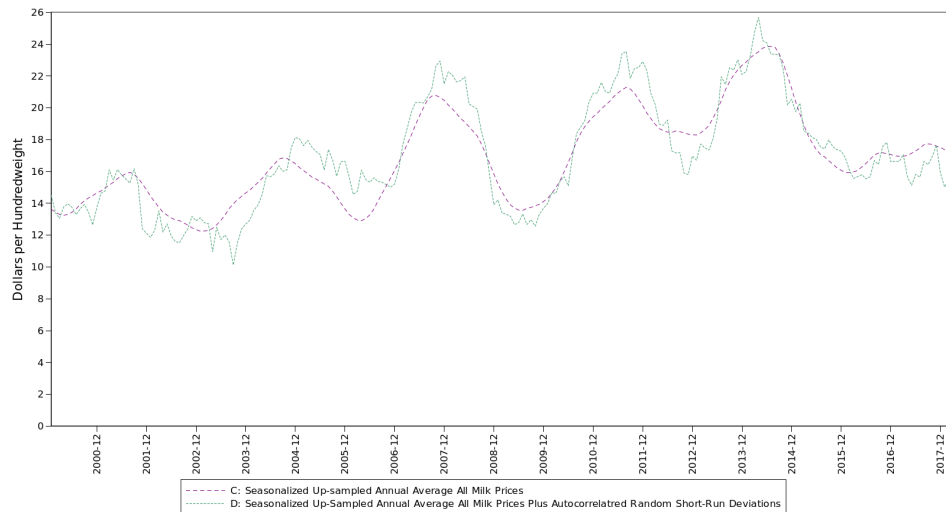


Figure 2.6: Adding short-run variability to seasonalized, up-sampled dairy prices

monthly all-milk prices (series E) over our sample period. This is shown in figure 2.7.

## 2.3 USDA Data

The third category of data required for FarmESP is those data emanating from the USDA. These come from two primary sources: the Risk Management Agency (RMA) and the Farm Service Agency (FSA).

### 2.3.1 Risk Management Agency Data

Crop insurance premiums and indemnities are calculated using official instructions and using relevant input data from RMA’s Actuarial Data Master (ADM [USDA Risk Management Agency, 2020b](#)). These are used for COMBO policies (YP, RP, and RP-HPE) as well as area-wide loss policies (SCO and STAX). These data consist of numerous tables of values. The tables are used for looking up values such as base rates, covarege level adjustment factors, and so forth, typically conditioned on numerous factors such as crop, crop type, county, state, production practice, policy type, coverage level, unit structure, and others. In the process of calculating a single premium or indemnity, values from numerous tables are required.

The data in the ADM are highly structured and well-organized. Important



Figure 2.7: A single realized random price series versus actual observed all-milk prices

values are coded consistently across tables. For example, a single consistent set of crop, crop type, and practice codes are used throughout all ADM tables (e.g., non-irrigated grain corn is crop 41, type 16, practice 3). Consequently, we query the tables directly as they are provided by RMA. The ADM tables are published for each crop year, and we query year-specific tables for historical years, and the latest table for future years.

### 2.3.2 Farm Service Agency Data

FSA data are not provided publicly with a consistent overall organization over years and across individual data types. FarmESP therefore employs a custom curated database of FSA data releases. This database coerces the FSA data, to the maximum extent possible, to use standardized RMA identifying codes. Largely, FSA recognizes less detail in identifying crops, their various types, and practices. For example, RMA recognizes several types of wheat: spring, winter, durum, and others. For FSA, wheat is simply *all wheat*. The custom database of FSA data reflects this limited detail.

Various items of data are reflected in the database, all of which relate to governing FSA program payments. These items include historical ARC county yields, PLC reference prices, ARC "floor" yields, and loan rates.

## 3 Crop Production

Crop production is a core component of the FarmESP model. In the following sections, we describe model components related to this: crop yields, production and marketing receipts, and finally variable costs.

### 3.1 Crop Yields

Crop yields are a critical determinant of farm financial outcomes and a key source of risk for those outcomes. They are therefore a critical component of the model. We first describe the overall representation of yields in the model, and then describe the random sampling approach.

#### 3.1.1 Yield Representation

Crop yields for individual production tracts are represented using an expected value and additive deviation from that expected value<sup>1</sup>. Using the historical production observations, historical yield deviates,  $v_t$ , are recovered as the residuals from an OLS regression of historical yield observations on their associated years:

$$YIELD_t = \beta_0 + \beta_1 YEAR_t + v_t$$

For simulated years, a conditional (on year) expected yield variable,  $EXPYLD_t$ , is calculated from the expected yield for the tract in the farm data for the data year. This is adjusted for other years assuming a constant rate of yield growth

$$EXPYLD_t = EXPYLD_{data} (1 + \eta)^{(YEAR_t - YEAR_{data})}$$

where  $EXPYLD_{data}$  is the expected yield in the farm data,  $YEAR_{data}$  is the year represented by the farm data, and  $\eta$  is the rate of yield growth.

---

<sup>1</sup>Equations in this section are for an individual production tract. We do not add an index for this to avoid cluttering the notation.

The yield in simulated years is then calculated as the conditional expected yield plus an additive deviation,  $YDEV_t$  that is directly stochastically drawn:

$$YLD_t = EXPYLD_t + YDEV_t \quad (3.1)$$

Actual yield observations are used preferentially in the simulations. For example, if actual observations for production data for 2018 are in the farm data, and the year 2018 is being simulated, the actual yield observation is used for all trials. This overlap is possible due to a burn-in period being simulated, where one or two years are “simulated” even though they are actually historical years. This burn-in period is used to verify farm data for recently updated farms, and validate model output against known recent market data.

### 3.1.2 Random Sampling for Yield Deviations

In most cases,  $YDEV_t$  is generated stochastically. The historical recovered  $v_t$  observations are used to constitute a kernel density estimate (KDE) probability distribution that is used for this purpose. As described in section 12.2, a copula is used to model dependence among the values that are directly randomly sampled in the simulations. It is therefore necessary to specify a percent point function (PPF; the pseudo-inverse of the cumulative distribution function) for calculating stochastic draws for  $YDEV_t$  using dependent standard uniform draws,  $u$ , emanating from the copula drawing algorithm.

Kernel density estimation (KDE) is a non-parametric approach to estimating a PDF using a data sample. The general form of the estimator is

$$\hat{f}(v|b, \check{v}) = \frac{1}{Mb} \sum_{m=1}^M \kappa\left(\frac{v - \check{v}_m}{b}\right)$$

where the  $\check{v}$  constitute a sample of  $M$  observations for a random variable,  $b$  is a scalar parameter called *bandwidth*, and  $\kappa(\cdot)$  is a kernel function with a non-negative range. Usually  $\kappa$  has the following properties:

$$\kappa(\tilde{v}) = \kappa(-\tilde{v})$$

$$\int_{-\infty}^{\infty} \kappa(\tilde{v}) d\tilde{v} = 1$$

Commonly, including in FarmESP, the standard normal PDF is used as  $\kappa$ . In FarmESP, the Scott rule is used for specifying  $b$  (Scott, 1979).

Given a fitted PDF  $\hat{f}$ , it is simple to use the relationship between the PDF and CDF to define a CDF:

$$\hat{F}(v) = \int_{-\infty}^v \hat{f}(\tilde{v}) d\tilde{v}$$

In FarmESP, numeric integration is used to evaluate  $\hat{F}(v)$ .

An analytic solution is not available for the PPF  $\hat{F}^{-1}(u)$  that is needed for generating a random draw given a value for  $u$ . This is therefore accomplished using numerical optimization. For a given  $u$ , denote the corresponding value of  $\hat{F}^{-1}(u)$  as  $v^*$ . One approach to finding  $v^*$  (that is, evaluating the PPF) is as the solution to a simple root finding problem. Specifically,  $v^*$  is the value of  $v$  such that

$$\hat{F}(v^*) - u = 0$$

The first derivative of the function whose root is sought is simply  $\hat{f}(v)$ , since  $u$  is a fixed value in the context of evaluating the PPF. This is a very well-behaved optimization problem because the CDF is non-decreasing, meaning there is no risk of local extrema. Moreover, the availability of a first derivative function means that highly-efficient optimization algorithms can be employed.

### 3.2 Production and Market Receipts

For each crop production tract, a repeating planted acres pattern is specified in the farm data. For example, a sequence  $PA = \{100, 100, 0\}$  would be specified to indicate that one hundred acres of the crop are planted two out of every three years, and the tract is fallow or the associated actual physical tract of land is planted to some other crop every third year (this would be represented in FarmESP as a separate virtual production tract, likely with a planted acres pattern  $PA = \{0, 0, 100\}$ ). For a given simulation year  $YEAR_t$ , we pluck from  $PA$  element number

$$(YEAR_t - YEAR_{start}) \text{ mod } \text{card}(PA)$$

where element indexing in  $PA$  begins with zero,  $YEAR_{start}$  is the first simulated year,  $\text{mod}$  is the modulo operator, and  $\text{card}(PA)$  is the cardinality of  $PA$ . The individual element of  $PA$  selected for a given year is the planted acres for that tract year:  $PLNTAC_t$ .

A binary indicator variable,  $FAIL_t$ , can be specified that takes a value of one in the event that a catastrophic event occurs (e.g., hail), and zero otherwise. Harvested acres are then

$$HARVAC_t = PLNTAC_t \times (1 - FAIL_t).$$

The quantity of the commodity produced and owned by the producer is calculated as

$$PROD_t = HARVAC_t \times YLD_t \times (1 - \alpha\lambda_{prod})$$

where  $\alpha$  is the proportion of the tract that is share leased (if any) and  $\lambda_{prod}$  is the landlord's share of production (if any). These parameters are a part of the farm data.

A local cash price received for crops,  $LOCALP_t$ , is calculated as an affine transformation of a pre-specified national reference price from the agricultural sector baseline (see section 2.2). The parameter values for this transformation are specified in the farm data. As with yield deviates, actual observed local prices are used with priority when they are available in the farm data for a given simulated year. Market receipts for the producer (this excludes any market receipts for a landlord) on the tract are calculated simply as

$$RECEIPTS_t = PROD_t \times LOCALP_t.$$

### 3.3 Variable Costs

For each of the twenty-two categories of variable cost listed in section 2.1, a cost for the tract for each year is calculated by inflating or deflating the per unit cost appearing in the farm data for the data year,  $VC_{data}$ . For some costs, this is based on the quantity of production (total for both tenant and landlord in the case of share leasing):

$$VC_t = HARVAC_t \times YLD_t \times VC_{data} \times \left( \frac{PPI_t}{PPI_{data}} \right) \times (1 - \alpha \lambda_{cost})$$

where  $\lambda_{cost}$  is the landlord's share of costs (which is potentially different than their share of production),  $PPI_t$  is the value of an appropriate producer price index series for this cost, and  $PPI_{data}$  is the value of that PPI series for the farm's data year.

Other variable costs are calculated on a per planted acre basis:

$$VC_t = PLNTAC_t \times VC_{data} \times \left( \frac{PPI_t}{PPI_{data}} \right) \times (1 - \alpha \lambda_{cost}).$$

Custom harvesting and custom hauling costs are calculated without inflating, and allowing for per harvested acre and per yield unit components:

$$(PERHA_{data} + PERUNIT_{data} \times YLD_t) \times HARVAC_t \times (1 - \alpha \lambda_{cost})$$

where  $PERHA_{data}$  and  $PERUNIT_{data}$  are both specified in the farm data.

Table 3.3 shows the PPI series and calculation basis for all variable costs other than custom harvesting and hauling.

Variable cost	PPI series	Calcualtion
Seed	Seed	per planted acre
Seed technology fee		per planted acre
Nitrogen fertilizer	Nitrogen fertilizer	per planted acre
Potash and phosphorus fertilizer	Potash and Phoshorus	per planted acre
Herbicide	Herbicide	per planted acre
Insecticide	Insecticide	per planted acre
Fungicide	Fungicise	per planted acre
Defoliant	Herbicide	per planted acre
Growth regulator	Herbicide	per planted acre
Chemical application costs	Fuel	per planted acre
Boll weevil eradication		per planted acre
Scouting and consultants	Services	per planted acre
Irrigation fuel	Fuel	per planted acre
Fuel	Fuel	per planted acre
Water		per planted acre
Drying	Fuel	per yield unit
Ginning	Services	per yield unit
Hauling	Fuel	per yield unit
Checkoff		per yield unit
Harvesting fuel	Fuel	per yield unit

Table 3.1: PPI series and calculation approaches for crop production variable costs

## 4 Crop Insurance

A large proportion of U.S. crop production is covered by individual crop insurance policies offered by RMA. FarmESP features a detailed representation of these policies, including replicating the premium calculations used by RMA. Both individual (COMBO) policies (YP, RP, and RP-HPE) and area-wide loss policies (SCO and STAX) based on average area yields are represented in the model. This chapter details these features of FarmESP.

A central component in calculation of premiums and indemnities for many of the policies offered by RMA is the individual producer's *Actual Production History* (APH). This is a list of officially recorded historical cultivated areas and corresponding production quantities for individual production units or tracts for past years.

This APH is used to calculate two critical values used in COMBO policy premium calculations: the *Rate Yield* and the *Approved Yield*. At the risk of oversimplification, the Rate Yield is essentially the simple arithmetic mean of the historical yields in the APH, and the Approved Yield is the Rate Yield after zero or more adjustments are applied. Such adjustments might, for example, correspond to the election of the Trend Adjustment or Yield Exclusion option, and generally have the effect of rendering the Approved Yield greater than the Rate Yield.

Before describing the policies available and calculations for each, we discuss some details regarding how individual production histories are handled in FarmESP.

### 4.1 Adjusting Production Histories

As described in section 2.1, a production history of arbitrary length is collected for each crop production tract. A challenge arises in using the farm's production history for calculating crop insurance premiums several years into the future. The production history in the farm data will have a fixed sample mean. Assuming growth in expected yields, the further into the future the farm is simulated, the less representative the historical yield sample mean will be. Using the fixed pro-

duction history for calculating an Approved Yield and Rate Yield for future years will thus tend to understate the farm's actual expected future values for these parameters.

For example, suppose the historical data for a particular farm ends at the year 2019, and those historical yield observations suggest an Approved Yield of 180 bushels per acre. Further suppose that yield is assumed to grow at one percent per year. If we want to simulate this farm for the year 2029, the Approved Yield (as of 2019) of 180 bushels is likely to be substantially below the actual future Approved Yield, and using these historical data to calculate a 2029 premium would be inappropriate.

One approach to solving this problem would be to simply use the future expected yield (*EXPYLD* in the previous chapter) as the Approved Yield. However, this would preclude us from accommodating options that are available to producers that influence how the Approved Yield is calculated. Specifically, the Yield Exclusion option allows the producer, for an increase in their premium, to exclude some historical years from the calculation of the Approved Yield. We could not reflect the farm's decisions regarding their actual production history if we simply used *EXPYLD* as the future Approved Yield.

Another such option is Trend Adjustment. This is specifically designed to adjust a producer's production history to reflect the possibility that the current expected yield will be greater than the historical sample mean yield due to increases in productivity. However, this option is not available in all cases, and assuming that producers always employ this option, when many do not, would result in phantom increases in simulated future premiums.

Instead, we adjust the farm's production history for each year simulated to introduce an artificial increase in the sample mean. This approach preserves the historical record and any corresponding yield exclusion designations, but does not require imposing the assumption that producers always elect the Trend Adjustment option.

Suppose we have specified a year-specific expected yield of  $EXPYLD_t$ , and have a sequence of historical production observations  $\{(PROD_m, ACRES_m)\}$  for  $m = 1, \dots, M$ , where  $PROD_m$  is a historical quantity of the crop produced in year  $m$  and  $ACRES_m$  is the corresponding number of acres employed in that production. We specify a constant additive adjustment  $d$  such that

$$EXPYLD_t = \frac{1}{M} \sum_{m=1}^M \left( \frac{PROD_m + d}{ACRES_m} \right)$$

Solving this for  $d$  implies

$$d = M \left( \frac{1}{\sum_{m=1}^M \left( \frac{1}{ACRES_m} \right)} \right) \left( EXPYLD_t - \frac{1}{M} \sum_{m=1}^M \frac{PROD_m}{ACRES_m} \right)$$

These adjusted historical yield observations

$$ADJYLD_m = \frac{PROD_m + d}{ACRES_m}$$

are then employed in calculating future Approved Yields, Rate Yields, and crop insurance premiums for year  $t$ .

## 4.2 COMBO Programs

Primary individual coverage policies are accommodated in FarmESP: yield protection (YP), revenue protection (RP) and revenue protection with harvest price exclusion (RP-HPE). These are collectively referred to as COMBO policies. The basic, optional and enterprise unit structures are available. Production history and approved yield calculation options are available, including trend adjustment and yield exclusion.

Premiums for COMBO policies are calculated using the exact instructions in RMA's M13 Handbook ([USDA Risk Management Agency, 2020a](#)) using relevant input data in RMA's Actuarial Data Master (ADM; [USDA Risk Management Agency, 2020b](#)). The premium calculations are quite complicated, and their details are not reproduced here. For purposes of describing how these calculations work in FarmESP for future simulated years, note that there are two key inputs that are generally not simply fetched from the ADM, and require special handling. The first is the producers actual production history, as described in the previous section. The second is a *planting price*,  $P_t$ , which is derived from the prices, observed at planting time, of relevant commodity futures specifying delivery at harvest time.

When past years are being simulated, the planting price is simply fetched from the ADM. For future years, this is not possible, and the planting price must be simulated. These are simulated assuming that the log difference between an associated stochastic marketing year average prices ( $MYAP_t$ ) is normally distributed, with a mean and standard deviation fit using historical observations of these values.

Harvest prices,  $H_t$ , are simulated for future years as a log change from the planting price:

$$H_t = P_t \exp(DLNP_t) \quad (4.1)$$

where  $DLNP_t$  is a normally distributed random variable with mean zero and a standard deviation which is fit using historical observations of the log change.

### **4.3 Area-Wide Loss Programs**

The area-wide loss policies Supplemental Coverage Option (SCO) and Stacked Income Protection Program (STAX) are also available and represented in full detail. As with COMBO policies, premiums for these policies are calculated using the exact instructions in RMA's M13 Handbook and ADM.

Simulating indemnities for the area-wide loss policies requires the simulation of relevant area yields. These are simulated using an approach similar to that described in subsection 3.1.1 for simulating individual production tract yields. Note that dependence representation among directly simulated variables (e.g., the individual production tract yield deviate and the county yield deviate) are described in chapter 12.

## 5 Dairy and Ranch Operations

Dairy and ranch operations are reflected in the livestock portion of the FarmESP model. The Dairy component considers all that is necessary to simulate bovine cultivation for the primary purpose of production of fluid milk. The ranch component allows for bovine cultivation and maintenance for the purpose of beef calf production. Dairy operations derive the majority of their receipts from the sale of milk, and ranch operations derive the majority of their income from sales of beef calves and cull animals. The following sections describe bovine notation, herd dynamics, and dairy and ranch specific receipts, respectively.

### 5.1 Bovine Notation

Primary variable names used in the bovine component are as follows:

- COUNT
- BORN
- DIED
- SOLD
- PURCH
- WEIGHT (pounds)
- PRPAID (\$/head)
- PRRCVD (\$/pound)

Bovine genders are indexed using  $g$ , which can take the following values:

- $m$ : male
- $f$ : female

Bovine life stages are indexed using  $s$ , which can take the following values:

- $s=0$ : 0 days to 2 days
- $s=1$ : 3 days to 1 year
- $s=2$ : 1 year to 2 years
- $s=3$ : 2 years+, has not reproduced
- $s=4$ : 2 years+, reproducing

Stock variables are defined as values at the *beginning* of a year. For example, using a variable name and indexes from above, the variable  $COUNT_{g,s,t}$  is the number of animals of gender  $g$  in life stage  $s$  at the beginning of year  $t$ . All flow variables for year  $t$  (e.g.,  $PURCH_{g,s,t}$ ) reflect flows during year  $t$ . For example,  $SOLD_{f,4,t}$  is the number of females in life stage 4 sold in year  $t$ . Values from the visit data are denoted with a superscript dagger (e.g.,  $BORN_{f,2}^\dagger$ ).

## 5.2 Herd Dynamics

$COUNT_{f,4,t}$  is deterministic, having been derived from the visit data.

### 5.2.1 First Year

Birth ratios are

$$BORN_{g,0} = \frac{BORN_{g,0}^\dagger}{COUNT_{f,4}^\dagger} \quad \text{for } g = m, f$$

New births are

$$BORN_{g,0,t} = COUNT_{f,4,t} \times BORN_{g,0} \quad \text{for } g = m, f \quad (5.1)$$

Animals may be sold at life stage 0. The numbers sold are assumed proportional to the numbers born.

$$SOLDRATIO_{g,0} = \frac{SOLD_{g,0}^\dagger}{BORN_{g,0}^\dagger} \quad \text{for } g = m, f$$

$$SOLD_{g,0,t} = BORN_{g,0,t} \times SOLDRATIO_{g,0} \quad \text{for } g = m, f \quad (5.2)$$

Sales of life stage 1 animals works similarly:

$$SOLDRATIO_{g,1} = \frac{SOLD_{g,1}^{\dagger}}{BORN_{g,0}^{\dagger}} \quad \text{for } g = m, f$$

$$SOLD_{g,1,t} = BORN_{g,0,t} \times SOLDRATIO_{g,1} \quad \text{for } g = m, f \quad (5.3)$$

Life stage 1 animals can also die:

$$DIEDRATIO_{g,1} = \frac{DIED_{g,1}^{\dagger}}{BORN_{g,0}^{\dagger}} \quad \text{for } g = m, f$$

$$DIED_{g,1,t} = BORN_{g,0,t} \times DIEDRATIO_{g,1} \quad \text{for } g = m, f \quad (5.4)$$

Some life stage 1 animals will be diverted from the normal development flow to go to our feedlot:

$$TOFEEDINGRATIO_{g,1} = \frac{TOFEEDING_{g,1}^{\dagger}}{BORN_{g,0}^{\dagger}} \quad \text{for } g = m, f$$

$$TOFEEDING_{g,1,t} = BORN_{g,0,t} \times TOFEEDINGRATIO_{g,1} \quad \text{for } g = m, f \quad (5.5)$$

Some life stage 1 animals will be sent away for external raising:

$$TORAISINGRATIO_{g,1} = \frac{TORAISING_{g,1}^{\dagger}}{BORN_{g,0}^{\dagger}} \quad \text{for } g = m, f$$

$$TORAISING_{g,1,t} = BORN_{g,0,t} \times TORAISINGRATIO_{g,1} \quad \text{for } g = m, f \quad (5.6)$$

### 5.2.2 Second Year

Life stages 0 and 1 are assumed to both occur within a single year. Therefore, the numbers of animals in life stage 2 at the beginning of year  $t$  are

$$\begin{aligned} COUNT_{g,2,t} = & BORN_{g,0,t-1} - SOLD_{g,0,t-1} - SOLD_{g,1,t-1} \\ & - TOFEEDING_{g,1,t-1} - TORAISING_{g,1,t-1} - DIED_{g,1,t-1} \quad \text{for } g = m, f \end{aligned} \quad (5.7)$$

Assume that deaths of animals at life stage 2 are proportional to the number of such animals. Assume that any changes to herd size occur after the visit data year. By substituting into equation 5.7 the prior expressions, we derive steady

state numbers of animals at life stage 2 prior to any herd size changes (based on the number of reproducing females in the visit data year):

$$\begin{aligned}
COUNT_{g,2,ss} &= COUNT_{f,4}^{\dagger} \times BORN_{g,0} \times \\
& [1 - SOLDRATIO_{g,0} - SOLDRATIO_{g,1} - DIEDRATIO_{g,1} - \\
& TOFEEDINGRATIO_{g,1} - TORAISINGRATIO_{g,1}] \\
& = BORN_{g,0}^{\dagger} - SOLD_{g,0}^{\dagger} - SOLD_{g,1}^{\dagger} - DIED_{g,1}^{\dagger} \\
& \quad - TOFEEDING_{g,1}^{\dagger} - TORAISING_{g,1}^{\dagger}
\end{aligned}$$

for  $g = m, f$  (5.8)

The ratio of life stage 2 deaths to number of life stage 2 animals is then

$$DIEDRATIO_{g,2} = \frac{DIED_{g,2}^{\dagger}}{COUNT_{g,2,ss}} \quad \text{for } g = m, f$$

and deaths at life stage 2 are

$$DIED_{g,2,t} = COUNT_{g,2,t} \times DIEDRATIO_{g,2} \quad \text{for } g = m, f \quad (5.9)$$

Sales of animals at life stage 2 are also assumed proportional to number of animals at that stage:

$$SOLDRATIO_{g,2} = \frac{SOLD_{g,2}^{\dagger}}{COUNT_{g,2,ss}} \quad \text{for } g = m, f$$

$$SOLD_{g,2,t} = COUNT_{g,2,t} \times SOLDRATIO_{g,2} \quad \text{for } g = m, f \quad (5.10)$$

### 5.2.3 Third and Later Years

Reproducing animals that are die are

$$DIEDRATIO_{g,4} = \frac{DIED_{g,4}^{\dagger}}{COUNT_{f,4}^{\dagger}} \quad \text{for } g = m, f$$

$$DIED_{g,4,t} = DIEDRATIO_{g,4} \times COUNT_{g,4,t} \quad \text{for } g = m, f \quad (5.11)$$

Assume that all animals nominally reach stage 3 (even if the calving age for the farm is less than 24 months). The number of animals that reach life stage 3

are

$$COUNT_{g,3,t} = COUNT_{g,2,t-1} - SOLD_{g,2,t-1} - DIED_{g,2,t-1} + TORAISING_{g,1,t-2}$$

for  $g = m, f$  (5.12)

Define a minimum, standard rate of sales of life stage 4 animals due to normal aging and retirement(standard cull rate).

$$RETIRERATIO_{g,4} = \frac{SOLD_{g,4}^{\dagger}}{COUNT_{g,4}^{\dagger}} \text{ for } g = m, f$$

Suppose there were no purchases or sales of life stage 3 animals, no purchases of life stage 4 animals, and sales of life stage 4 animals reflect only the minimum retirement rate. Then, given a desired animal count of  $COUNT_{g,4,t}$ , the required exogenous change (to be achieved via purchases and sales) in animal count is

$$EXOGCHANGE_{g,4,t} = COUNT_{g,4,t} - COUNT_{g,4,t-1} \times (1 - DIEDRATIO_{g,4} - RETIRERATIO_{g,4}) \text{ for } g = m, f$$

(5.13)

Assume that all purchases will be life stage 3 animals (we never purchase life stage 4 animals). Further assume that we will always sell life stage 4 at at least the retirement rate. Further assumptions reflecting how we affect a change in herd size and handle an excess or deficiency of life stage 3 animals ("replacements") are reflected in the table below.

	$EXOGCHANGE_{g,4,t} > 0$	$EXOGCHANGE_{g,4,t} \leq 0$
$COUNT_{g,3,t} > 0$	purchase OR sell stage 3 animals; sell stage 4 animals at only the retirement rate	sell all stage 3 animals; sell stage 4 animals beyond the retirement rate
$COUNT_{g,3,t} = 0$	purchase stage 3 animals; sell stage 4 animals at only the retirement rate	purchase zero stage 3 animals; sell stage 4 animals beyond the retirement rate

The number of life stage 4 animals in year  $t$  is

$$COUNT_{g,4,t} = COUNT_{g,4,t-1} - DIED_{g,4,t-1} - SOLD_{g,4,t-1} + COUNT_{g,3,t} + PURCH_{g,3,t} - SOLD_{g,3,t} \quad \text{for } g = m, f \quad (5.14)$$

where either  $PURCH_{g,3,t} = 0$  or  $SOLD_{g,3,t} = 0$ . Note, however, that  $COUNT_{f,4}$  is deterministic (and  $COUNT_{m,4}$  is almost deterministic, following closely from  $COUNT_{f,4}$  and  $MFRATIO_4$ ). This dynamic equation can therefore serve as a check that the dynamic system is working correctly—this equation should recover the values in the corresponding deterministic variable.

Given this last equation, and all assumptions above, the quantities of stage 4 sales and stage 3 purchases and sales needed to hit the target level of  $COUNT_{g,4,t+1}$  follow.

$$SOLD_{g,4,t} = COUNT_{g,4,t} \times RETIRERATIO_{g,4} + \max(0, -EXOGCHANGE_{g,4,t}) \quad \text{for } g = m, f \quad (5.15)$$

$$PURCH_{g,3,t} = \max(0, EXOGCHANGE_{g,4,t} - COUNT_{g,3,t}) \quad \text{for } g = m, f \quad (5.16)$$

$$SOLD_{g,3,t} = \min[COUNT_{g,3,t}, \max(0, COUNT_{g,3,t} - EXOGCHANGE_{g,4,t})] \quad \text{for } g = m, f \quad (5.17)$$

### 5.3 Dairy-specific Details

The dairy operations derive the majority of their income from milk receipts. Each dairy herd has an average per cow milk production.

$$MILKPROD_t = MILKPERDAY^\dagger \times COUNT_{f,4,t} \times (365 - DRYDAYS^\dagger) \quad (5.18)$$

where  $MILKPROD_t$  is total annual milk production in pounds,  $MILKPERDAY^\dagger$  is the average pounds of milk produced per cow per day, and  $DRYDAYS^\dagger$  is the average number of days per year that a cow is not producing milk (e.g., due to pregnancy, illness, etc.).

The primary income on the dairy farms comes from the sale of milk. The equation for total milk receipt is as follows

$$MILKRCPT_t = MILKPROD_t \times LOCALP_t \quad (5.19)$$

where  $MILKRCPT_t$  is the total cash receipts from milk sales in year  $t$  and  $LOCALP_t$  is the local cash price received for milk in year  $t$ .  $LOCALP_t$  is the affine transformation of a pre-specified all milk price from the agricultural sector baseline (see section 2.2). The parameter values for this transformation are specified in the farm data. Actual observed local prices are used with priority when they are available in the farm data for a given simulated year.

#### 5.4 Ranch-specific Details

The ranch operations derive the majority of their income from marketing various classes of animals (bovine receipts). The equation for total bovine receipts is as follows

$$BOVINERCPT_t = \sum WEIGHT_{g,s} \times (SOLD_{g,s,t} \times LOCALP_{g,s,t}) \quad (\text{for all } g \text{ and } s) \quad (5.20)$$

where  $BOVINERCPT_t$  is the total cash receipts from bovine sales in year  $t$ ,  $WEIGHT_{g,s}$  is the average weight (in pounds) at which bovines are sold,  $SOLD_{g,s,t}$  is the number of bovines sold in year  $t$ , and  $LOCALP_{g,s,t}$  is the local cash price received for bovines in year  $t$ . Each gender and life stage classification has its own values for  $WEIGHT_{g,s}$ ,  $SOLD_{g,s,t}$ , and  $LOCALP_{g,s,t}$ .  $LOCALP_{g,s,t}$  is calculated as an affine transformation of a pre-specified national price from the agricultural sector baseline (see section 2.2). The parameter values for this transformation are specified in the farm data. Actual observed local prices are used with priority when they are available in the farm data for a given simulated year. Sale weights for each gender and life stage are collected from the farm panels.

## 6 Agricultural Policy

The agricultural policies included in FarmESPar are discussed in this chapter.

### 6.1 Loan Deficiency Payments (LDPs)

Loan Deficiency Payments (LDPs) help facilitate the orderly marketing of crops. For a producer that maintains ownership of the crop after harvest, LDPs may be paid to farmers when a commodity's market price is below the loan rate. This option can be exercised only once for producers who, although eligible to obtain a loan from the Commodity Credit Corporation (CCC), forgo the loan in reform for the option to exercise the LDP. Loan rates are statutorily fixed for each eligible commodity by the 2018 farm bill. The 2018 farm bill excluded LDP benefits from payment limits ([Congressional Research Service, 2022](#)). For each crop produced by an entity, LDPs are calculated:

$$LDPPMT_t = PROD_{t-1} \times \max(0, LR - MYAP_{t-1})$$

where  $LDPPMT_t$  is the LDP payment in year  $t$ ,  $PROD_{t-1}$  is the quantity of the commodity produced and owned by the producer in the previous year,  $LR$  is the loan rate of the commodity and  $MYAP_{t-1}$  is the marketing year average price of the commodity in the previous year. Marketing year average price is used as a proxy for the posted county price (PCP).

### 6.2 6.2 Effective Reference Prices

Reference prices were statutorily fixed in the 2014 Farm Bill for each commodity eligible for Title I programs, Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC) – see 6.3 and 6.4. Variable effective reference prices were introduced in the 2018 Farm Bill and allow for adjustment of the “effective” reference prices used to calculate ARC and PLC payments. The effective reference price is the greater of the statutory reference price and 85% of the Marketing Year Average (MYA) price from the previous 5 years for each commodity (not to exceed 115% of

the statutory reference price). Both statutory and effective reference prices were updated in the One Big Beautiful Bill Act of 2025 and will be kept up to date within FarmESP.

### 6.3 Price Loss Coverage (PLC)

The Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC) programs were established by the 2014 farm bill and reauthorized by the 2018 farm bill. For each crop and FSN with assigned base acres, producers can choose to enroll in either PLC or ARC (described in in the subsequent section). PLC payments are issued to farmers when the market price of a crop is less than the effective reference price for that crop. In the 2014 farm bill, fixed reference prices were set for each eligible crop. The 2018 farm bill introduced a variable effective reference price equal to the greater of the reference price or 85 percent of the previous 5-year Olympic average marketing year average (MYA) price, capped at 115 percent of the reference price. PLC support is tied to a producer’s historical FSA base acres, not actual production, of covered commodities.

FarmESP accounts for PLC payments in the income statement. For each crop and FSN for which base acres are assigned and enrolled in PLC, PLC payments are calculated:

$$PLCPMT_t = (1 - LANDLORDSHR_t) \times PLCACRES_t \times PLCPERAC_t$$

where  $PLCPMT_t$  is the PLC payment in a given year,  $LANDLORDSHR_t$  is the FSA payment for landlords (used to reflect proportions of each tract that is share leased and production shares),  $PLCACRES_t$  is the producer’s number of base acres in year  $t$  for calculating PLC payments, and  $PLCPERAC_t$  the PLC payment per base acre. The per-base acre PLC payment is calculated:

$$PLCPERAC_t = PLCPAYYLD_{t-1} \times \max(0, ERP_{t-1} - MYAP_{t-1})$$

where  $PLCPAYYLD_{t-1}$  is the PLC payment yield assigned to the crop and FSN in the previous year,  $ERP_{t-1}$  is the effective reference price for the crop in the previous year, and  $MYAP_{t-1}$  is the MYA price of the crop in the previous year.

### 6.4 Agriculture Revenue Coverage (ARC)

ARC provides income support which, like PLC, is tied to a producer’s historical base acres, not production, of covered commodities. ARC is available at the county-level and individual-level. ARC-County (ARC-CO) enrollment is significantly higher than enrollment in ARC-Individual (ARC-IC), therefore FarmESP

incorporates ARC-CO but not ARC-IC. ARC-CO payments are issued to farmers when the actual county revenue for a crop is less than the ARC-CO revenue guarantee. For each crop and county, the ARC-CO revenue guarantee is equal to 86 percent of the ARC-CO benchmark revenue. The ARC-CO benchmark is the product of the previous 5-year (lagged one year) Olympic average MYA price and the previous 5-year (lagged one year) Olympic average county yield. The actual county revenue is equal to the product of the current-year MYA price and county yield. ARC-CO payments are capped at 10% of the ARC-CO benchmark revenue.

FarmESP accounts for ARC payments in the income statement. For each crop for which base acres are assigned and enrolled in ARC, ARC payments are calculated:

$$ARCPMT_t = (1 - LANDLORDSHR_t) \times ARCACRES_t \times ARCPERAC_t$$

where  $ARCPMT_t$  is the ARC payment in a given year,  $LANDLORDSHR_t$  is the FSA payment for landlords (used to reflect proportions of each tract that is share leased and production shares),  $ARCACRES_t$  is the number of base acres for calculating ARC payments, and  $ARCPERAC_t$  the ARC payment per base acre. The per-base acre ARC payment is calculated:

$$ARCPERAC_t = \min(0.1 \times BENCH_{t-1}, \max(0, GUAR_{t-1} - ACTL_{t-1}))$$

where  $BENCH_{t-1}$  is the previous year benchmark revenue, equal to the previous 5-year (lagged 1 year) Olympic average MYA price multiplied by the previous 5-year (lagged 1 year) Olympic average county yield. For year  $t$ , the years included in the benchmark revenue calculation are  $t - 3$ ,  $t - 4$ ,  $t - 5$ ,  $t - 6$ , and  $t - 7$ . The  $GUAR_{t-1}$  is the previous-year revenue guarantee, equal to 86 percent of the previous-year benchmark revenue.  $ACTL_{t-1}$  is the actual county revenue from the previous year, equal to the product of the previous-year MYA price and a stochastic ARC county yield ( $YLDARC_t$ ). ARC county yields are simulated in a manner similar to that of the county yields used for calculating area-wide loss indemnities, as described in 4.3.

Changes to ARC in the One Big Beautiful Bill Act of 2025 include the following. The ARC-CO revenue guarantee is equal to 90 percent (previously 86 percent) of the ARC-CO benchmark revenue. The maximum ARC-CO payment is equal to 12 percent (previously 10%) of the ARC-CO benchmark revenue.

## 6.5 One-time Payments

This section describes one-time, or ad-hoc, payments accounted for in the income statement. These include the Coronavirus Food Assistance Program (CFAP), the

Market Facilitation Program (MFP), the Emergency Commodity Assistance Program (ECAP), and the Farmer Bridge Assistance Program (FBA).

### 6.5.1 CFAP

CFAP was implemented by USDA to provide financial support to agricultural commodity producers to help offset sales losses and increased marketing costs associated with the COVID-19 pandemic. Two tranches of CFAP payments were administered, designated as CFAP and CFAP2. CFAP payment calculations vary for each crop, each livestock category, and of other commodities such as milk. The CFAP calculations used by FarmESP (only when  $YEAR_t = 2020$ ) are as follows:

- For crops ([U.S. Department of Agriculture, 2020a](#)):

$$CFAPPMT_t = 0.8 \times PROD_t \times CFAPFRAC \times CFAPRATES$$

where  $PROD_t$  is the quantity of the crop produced and owned by the producer,  $CFAPFRAC$  is the assumed fraction of production that is unmarketed as of January 15, 2020 (not to exceed 50%), and  $CFAPRATES$  is equal to the sum of two payment rates: the CARES Act Payment Rate and the CCC Payment Rate. The  $CFAPFRAC$  and  $CFAPRATES$  are specific to each crop.

- For beef cattle ([U.S. Department of Agriculture, 2020b](#)):

A single CFAP payment for livestock was calculated using the sum of the number of livestock sold between January 15 and April 15, 2020, multiplied by the CARES Act Payment Rates per head, and the highest inventory number of livestock between April 16 and May 14, 2020, multiplied by the CCC Payment Rates per head. For cattle, CARES Act Payment Rates and CCC Payment Rates vary for different classes; these classes include

- feeder cattle: less than 600 pounds
- feeder cattle: 600 pounds or more
- slaughter cattle: fed cattle
- slaughter cattle: mature cattle
- all other cattle

For each class, FarmESP calculates the CFAP payment (only when  $YEAR_t = 2020$ ):

$$CFAPPMT_t = 0.8 \times [0.25 \times SOLD_t \times (CARESRATE - CCCRATE) + CCCRATE \times COUNT_t]$$

where  $SOLD_t$  is the number of bovines sold in the current year,  $CARESRATE$  is the CARES Act Payment Rate,  $CCCRATE$  is the CCC Payment Rate, and  $COUNT_t$  is the inventory number of bovines in the current year.  $SOLD_t$  is multiplied by 0.25, the assumed fraction of each class of bovines that is sold between January 15 and April 15.  $SOLD_t$  is multiplied by the difference between the  $CARESRATE$  and the  $CCCRATE$  to ensure that the  $CCCRATE$  is not applied to bovines sold (the product of 0.25 and  $SOLD_t$  is included in  $COUNT_t$ ).

- For dairy ([U.S. Department of Agriculture, 2020c](#)):

A single CFAP payment for milk was composed of two parts and calculated based on a producer's milk production in the first quarter of 2020 multiplied by \$4.71/cwt (part 1) and \$1.47/cwt (part 2). The CFAP payment for milk came from two sources: the CARES Act, which compensated producers for price losses during the first quarter of 2020, and CCC Funds, which compensated producers for marketing channel and demand losses in the second quarter of 2020, due to COVID-19. Dairy producers also received the CARES Act payment rate for mature slaughter cattle (cull cows and bulls) sold in the first quarter of 2020 equal to \$92. FarmESP calculates the CFAP payment for dairy (only when  $YEAR_t = 2020$ ):

$$CFAPPMT_t = 0.8 \times [0.25 \times MILKPROD_t \times (4.71 + 1.47) + 0.25 \times SOLD_{m,4,t} \times 92.0 + 0.25 \times SOLD_{m,4,t} \times 92.0]$$

where  $MILKPROD_t$  is hundred weights of milk produced in year t,  $SOLD_{m,4,t}$  is the number of mature cows sold in year t, and  $SOLD_{m,4,t}$  is the number of mature bulls sold in year t.

### 6.5.2 CFAP2

The second tranche of CFAP payments (CFAP2) also varies for different crops, livestock, and other commodities. The CFAP2 calculations used by FarmESP (only when  $YEAR_t = 2020$ ) are as follows:

- For crops ([U.S. Department of Agriculture, 2021a](#)):

$$CFAP2PMT_{2020} = PLNTAC_t \times \max(15, PTRATE * APPYLD_t)$$

where  $PLNTAC_t$  is the number of planted acres of a crop, the  $PTRATE$  is the product of a nation wide crop marketing percentage and a crop-specific payment rate, and  $APPYLD_t$  is the producer's weighted Actual Production History (APH) approved yield for the crop. The maximum CFAP2 payment for all crops is \$15 per acre.

- For beef cattle ([U.S. Department of Agriculture, 2021b](#)):

A second CFAP payment for livestock was calculated using the sum of the highest owned inventory of livestock on a date chosen by the producer between April 16 and August 20, 2020, multiplied by the per head payment rate of \$55. For cattle, this payment rate applied to all classes.

FarmESP calculates the CFAP2 payment for beef cattle (only when  $YEAR_t = 2020$ ):

$$CFAP2PMT_{2020} = 55.0 \times COUNT_{g,s,2020}$$

where  $COUNT_{g,s,2020}$  is the inventory number of bovines for  $s \in 1, 2$  and all  $g$  in 2020.

- For dairy ([U.S. Department of Agriculture, 2021c](#)):

The CFAP2 payment for milk is equal to the sum of actual milk production from April to August of 2020 and estimated milk production for September to December of 2020, multiplied by the payment rate of \$1.20. FarmESP calculates the CFAP2 payment for dairy (only when  $YEAR_t = 2020$ ):

$$CFAP2PMT_t = 1.20 \times 0.75 \times MILKPROD_t$$

### 6.5.3 MFP

In 2018, USDA announced MFP as a trade aid program to provide assistance to producers affected by retaliatory tariffs ([Congressional Research Service, 2019](#)). MFP eligible commodities included non-specialty crops (corn, cotton, sorghum, soybeans), and wheat as well as some cover crops, specialty crops, hogs, and dairy (milk). MFP was distributed in two tranches: distribution of the first half of the payment began in September of 2018, the second half began in December of 2018 (FarmESP realizes the first half of the payment in 2018 and the second half in 2019). An MFP payment rate was established for each commodity, and the MFP payment is equal to the payment rate, multiplied by a producer's payment base. For non-specialty crops, the payment base is 2018 harvested production. For dairy,

the payment base is milk production history in hundredweights (cwt). FarmESP calculates the two tranches of MFP payments:

$$MFPPMT_t = 0.5 \times MFPRATE \times MFPPROD_t, t = 2018$$

$$MFPPMT_t = 0.5 \times MFPRATE \times MFPPROD_{t-1}, t = 2019$$

where *MFPRATE* varies by commodity and is the MFP payment rate in dollars per unit of production and *MFPPROD* is the payment base (production).

#### 6.5.4 MFP2 (source - MFP)

In 2019, a second round of MFP (MFP2) was announced to provide further assistance to producers amid continued trade disruptions. MFP2 eligible commodities included additional specialty and non-specialty crops relative to MFP and continued to include cover crops, hogs, and dairy (milk). MFP2 was distributed in three tranches: distribution of the first tranche (equal to 50% of the total MFP2 payment) began in August of 2019, the second tranche (equal to 25% of the total MFP2 payment) began in November of 2019, and the third (equal to the final 25% of the total MFP2 payment) began in January of 2020. Therefore, FarmESP realizes 75% of the MFP2 payment in 2019 and the remaining 25% in 2020. MFP2 differed from MFP for non-specialty crops; MFP2 used planted acres rather than production to calculate payments. For non-specialty crops, a non-crop-specific county payment rate between \$15 and \$150 was determined for each county. FarmESP calculates MFP2 payments for non-specialty crops in 2019 and 2020:

$$MFP2PMT_t = 0.75 \times MFP2RATE \times PLNTAC_t, t = 2019$$

$$MFP2PMT_t = 0.25 \times MFP2RATE \times PLNTAC_{t-1}, t = 2020$$

where *MFP2RATE* varies by county and is the MFP2 payment rate in dollars per planted acre in 2019 and *PLNTAC* is number of planted acres for all crops. MFP2 payments for dairy were determined similarly to MFP payments for dairy but used an updated payment rate.

#### 6.5.5 ECAP

In 2024, the American Relief Act of 2025 authorized ECAP as an economic assistance program to provide payments to agricultural commodity producers for the 2024 crop year to help mitigate the impacts of high input costs and low commodity prices. An ECAP payment rate (per acre) was established for each commodity, and the ECAP payment is equal to the payment rate, multiplied by a producer's planted acres. FarmESP calculates the ECAP payment for eligible commodities:

$$ECAPPMT_t = ECAPRATE \times PLNTAC_{t-1}, t = 2025$$

where ECAPRATE varies by commodity and is the ECAP payment rate in dollars per acre planted and PLNTAC is the number of acres planted.

### 6.5.6 FBA

In 2025, USDA announced FBA as an economic bridge assistance program to provide financial support to agricultural commodity producers in response to temporary trade market disruptions and increased production costs. An FBA payment rate (per acre) was established for each commodity, and the FBA payment is equal to the payment rate, multiplied by a producer's planted acres. FarmESP calculates the FBA payment for eligible commodities:

$$FBAPMT_t = FBARATE \times PLNTAC_{t-1}, t = 2026$$

where FBARATE varies by commodity and is the FBA payment rate in dollars per acre planted and PLNTAC is the number of acres planted.

## 6.6 Payment Limits

General	Peanuts	MFP	CFAP	CFAP <sub>2</sub>
LDP*	LDP <sup>†</sup>	MFP	CFAP	CFAP <sub>2</sub>
ARC*	ARC <sup>†</sup>			
PLC*	PLC <sup>†</sup>			
MFP <sub>2</sub>				

\*Commodities other than peanuts. <sup>†</sup>Peanuts only.

Table 6.1: Payment Limit Buckets

FSA programs have payment limits. Different program payments fit into different payment limit buckets. The payment limit buckets in FarmESP are shown in table 6.1.

For each program, the payment amount reflected in the FarmESP income statement is:

$$PMTLMT_t = PAYFRAC_t \times PMT_t$$

where  $PMTLMT_t$  is the payment after payment limits are imposed,  $PAYFRAC_t$  is the payment fraction for the associated payment limit bucket, and  $PMT_t$  is the

payment before payment limits are imposed. For each payment limit bucket,  $PAYFRAC_t$  is calculated:

$$PAYFRAC_t = \frac{TOTPMTLMT}{\max(TOTPMTLMT, TOTPMTS_t)}$$

where  $TOTPMTLMT_t$  is the total payment limit for the bucket and  $TOTPMTS$  is the sum of  $PMT_t$  for each program in the bucket.

The One Big Beautiful Bill Act of 2025 added inflation indexing to farm program payment limits. Payment limits are kept up to date in FarmESP.

## 7 Simple Activities

Simple activities are a flexible section within FarmESP that may be used to describe additional enterprises or costs that fall outside of the typical representative farm. For instance, the typical farm has row crop budgets, and/or bovine herd dynamics for beef or dairy production. There are instances, however where enterprises on the farm do not fall under those categories. This could include management of conservation reserve program (CRP) acres, or accounting for a cover crop program. Alternatively, production of another commodity on the operation, such as poultry or crawfish would be entered as a simple activity.

The items that the panelists may utilize to create a simple activity are as follows: productive units, yield per productive unit, price per unit of output, variable cost per productive unit (\$/unit), variable cost per output unit (\$/unit), fixed revenue (total \$), and fixed cost (total \$).

Functionally, the simple activity section does not utilize risk, or indexing as the other components of FarmESP do when projecting future outcomes of an operation. Therefore, as an example, if a farm has CRP on 300 acres that receives \$30/acre and costs \$10/acre to maintain then the simple activity entry for that operation would look like this:

- Productive units (number of acres, head, ...): 300
- Yield per productive unit: 1
- Price per unit of output: \$30
- Variable cost per productive unit (\$/unit): \$10
- Variable cost per output unit (\$/unit): 0
- Fixed revenue (total \$): 0
- Fixed cost (total \$): 0

This simple activity would result in \$9,000 of revenue on the operation, and \$3,000 of cost to the operation each year of the simulation. Simple activities are not used to characterize the primary income driver on any operation but they are useful in describing certain activities on some operations.

## 8 Equipment

Farm ESP maintains a log of equipment that is unique to each representative farm, ranch, and dairy. Each piece of machinery within this section is considered purchased, as opposed to being leased. For reference, leased equipment would qualify as a simple activity and the details of simple activities are found in chapter 7.

Each representative farm producer panel compiles a list of equipment needed to run the size of operation that is being represented. That said, it is common that each producer does not replace equipment on the same schedule. For example, some may typically replace things more frequently to keep primary items within the manufacturer warranty, while others may keep equipment longer, but expect to spend more money in repairs. In the case that producers use a differing approach in their machinery management, the group is asked to build the farm in the way that is most representative of the area.

The following data is collected or calculated for each item of equipment.

- Name
- Year purchased
- Loan term
- Interest rate
- Market value
- Replacement cost
- Useful life
- How replaced? (new or used)
- Years of depreciation

A name of each piece of machinery is saved as an identifier. The year purchased is saved to know when each piece of machinery was brought onto the farm. For used equipment this does not refer to year model of the machinery, just the year it arrived on the farm. The loan term represents the number of years that equipment is amortized over. The interest rate for equipment is gathered from the panel, and applied to each piece of machinery. The market value is calculated within FarmESP based on the original purchase price, the number of years the item has been used on the farm, and the equipment value decay rate. For reference the equipment value decay rate is currently set at 6.5% across all operations.

The replacement value of each item is the cost the producer would incur to replace that item in the current year being discussed. For example, if the meeting is taking place in 2026, and the data collected is all in reference to the 2025 crop year, then the replacement cost should reflect what replacement would have costed in 2025. Replacement values are indexed based on the machinery category index provided in the agricultural sector baseline. That is, the replacement cost in future years considers projected inflation or deflation.

The useful life of each item describes the number of years that item will be used on the farm before it is sold, and replaced. An indication of how each item is replaced, new versus used, is gathered in order to provide information to the panel about the item at future meetings. The number of years each item is depreciated is established for each item. The default value for this is 5 years, but the length of depreciation may not exceed the useful life. Therefore, if the useful life is only 3 years, the depreciation length will be set to 3 years. Additionally, the depreciation length may be overridden if the item is selected to be immediately expensed. This is explained further in section 8.3.

## 8.1 Replacement

Within the model, the farm machinery is all replaced on a rolling replacement schedule. Based on the year purchased, and the the useful life of that machinery, a replacement year is established for each item. Descriptions of the following variables aid in the explanation of machinery replacement within FarmESP.

$$\begin{aligned}
 \text{OriginalPrincipal}_t &= \text{ReplacementIndicator}_t \\
 &\quad \times (\text{ReplacementIndicator}_t - \text{DownPayment}_t) \\
 &\quad + (1.0 - \text{ReplacementIndicator}_t) \\
 &\quad \times \text{OriginalPrincipal}_{t-1}
 \end{aligned} \tag{8.1}$$

In equation 8.1 the original principal is the original amount of principal of the loan when it is taken out, i.e. when the item is purchased.

$$\begin{aligned} \text{PrincipalBalance}_t &= \text{ReplacementIndicator}_t \\ &\quad \times \text{OriginalPrincipal}_t \\ &\quad + (1.0 - \text{ReplacementIndicator}_t) \\ &\quad - \text{PrincipalPayment}_t \end{aligned} \quad (8.2)$$

The principal balance, as shown in equation 8.2 is the remaining or outstanding principal balance on the loan in year  $t$ .

$$\text{InterestPayment}_t = r \times \text{PrincipalBalance}_{t-1} \quad (8.3)$$

Equation 8.3 shows the calculation for interest paid in year  $t$ . The variable  $r$  in this equation represents the interest rate on the particular item to which it refers.

$$\begin{aligned} \text{DownPayment}_t &= \text{ReplacementIndicator}_t \\ &\quad \times \max(\text{MarketValue}_{t-1}, (57\% \times \text{ReplacementValue}_t)) \end{aligned} \quad (8.4)$$

Equation 8.4 shows how the down payment for a piece of machinery is calculated.

$$\begin{aligned} \text{MarketValue}_t &= \text{PurchasePrice}_t \\ &\quad \times (1 - \text{EquipmentDecayRate})^{(1 + \text{EquipmentAge}_t)} \end{aligned} \quad (8.5)$$

Equation 8.5 shows how the market value for a piece of machinery is calculated. Equipment decay rate is currently assumed to be 6.5% on all machinery and all farms. The equipment age in this equation represents the number of years that item has been on the operation.

$$\begin{aligned} \text{PrincipalPayment}_t &= \text{OriginalPrincipal}_t \times \frac{r(1+r)^n}{(1+r)^n - 1} \\ &\quad - \text{InterestPayment}_t \end{aligned} \quad (8.6)$$

where  $r$  is the interest rate on the loan and  $n$  is the length of the loan in years. This equation applies the typical loan payment calculation formula to the *OriginalPrincipal* described above.

## 8.2 Financing

It is assumed that each piece of farm machinery is financed for 5 years and 57% of the purchase price is paid as a down payment, unless the panel explicitly changes these terms for a specific item. For the loan balance a typical amortization schedule is used to calculate the principal paid, interest paid, and remaining loan balance for each year in the simulation. This process is done for every item that is replaced within the simulation window. For example, if there is an item that is not replaced in the simulation window, it will have no explicit cost to the operation.

Details of the principal, interest, and outstanding balance on each loan for each of the simulated years is all available in farm output. Principal owed on each equipment loan is summed and added into total liabilities for the farm. Interest paid on each equipment loan in a given year is summed and added into total cash expenses.

## 8.3 Depreciation

FarmESP considers depreciation of on farm machinery which has major implications on the overall income tax owed on the operation. Farm income taxes are paid within the model based on the amount of net farm income in each year. The equation for net farm income is as follows

$$NetFarmIncome_t = NetCashFarmIncome_t - TotalDepreciation_t$$

The dollar amount of depreciation on a given piece of farm machinery is calculated in equation 8.7

$$\begin{aligned} Depreciation_t = & ReplacementIndicator_t \\ & \times \frac{ReplacementValue_t}{DepreciationYears_t} \\ & + (1 - ReplacementIndicator_t) \\ & \times DepreciationIndicator_t \\ & \times Depreciation_{t-1} \end{aligned} \quad (8.7)$$

where the replacement indicator is a binary variable, equal to 1 when  $t$  is the year of replacement and 0 in all other years.  $ReplacementValue_t$  reflects the replacement value of the item in the year it is replaced.  $DepreciationYears_t$  represents the number of years over which the equipment is depreciated. The next part of equation 8.7 sets the depreciation dollar amount equal to the depreciation

in the previous year, over the number of years the item is to be depreciated. The depreciation indicator is also a binary variable to indicate which years the item is depreciated.

As an example, suppose a \$100,000 tractor is to be depreciated over 5 years. The first portion of equation 8.7 sets the depreciation in year 1 at \$20,000. The second portion then establishes that for years 2 - 5 the depreciation should equal that of year 1. To follow this example, year 6 would have a 0 as the depreciation indicator and therefore the depreciation dollar amount in year 6 would be \$0.

To account for the use of section 179 immediate expensing on agricultural operations, FarmESP dynamically considers the financial state of the operation before determining the depreciation length of all machinery purchased in the current year. The machinery replacement schedule is held constant, but the number of pieces of machinery immediately expensed is dynamically chosen for each trial based on net cash farm income. Net farm income is shown in equation 8.8 the help explain.

$$\begin{aligned}
 \text{NetFarmIncome}_t = & \text{NetCashFarmIncome}_t \\
 & - (\text{DepreciationPrelim}_t + \text{Depreciation179}_t)
 \end{aligned}
 \tag{8.8}$$

where  $\text{DepreciationPrelim}_t$  is sum of the depreciation on all items purchased in a previous year that were already on a straight-line depreciation schedule. In equation 8.8,  $\text{Depreciation179}_t$  is the bundle of equipment that is designated for immediate expensing. This variable is optimized to lower the amount of income tax paid in each individual trial. Thus, the model dynamically sets the equipment that is included by pooling all of the equipment that is replaced in the current year, then selects from that list the combination of items that achieves the lowest positive net farm income. For the immediate expensing selection, the machinery is considered in the order of highest replacement cost to lowest. For further information, if  $\text{NetCashFarmIncome}_t - \text{DepreciationPrelim}_t < 0$  then  $\text{Depreciation179}_t = 0$ . The maximum amount that may be expensed under section 179 in a single is incorporated into FarmESP.

## 9 Fixed Costs

This chapter outlines the fixed costs within FarmESP. These cost categories are fixed in that they are attributed to the entire operation, and are not allocated on a per acre basis. Some of the costs in this section are truly fixed in that they are not inflated or deflated throughout the simulation. However, most are inflated or deflated based on price indices that are either general, or specific to a category. Categorized price index projections are provided in the agricultural sector baseline (see section 2.2). The specific price index categories include: wages, taxes, machinery, services, repairs, electricity, fuel, and items. The list below provides the fixed costs within the model along with a price index to which each cost is tied, if applicable.

- Rent on cropland - N/A
- Rent on private pastureland - N/A
- Rent on public pastureland - N/A
- Salaries paid - Wages
- Part time wages paid - Wages
- Property tax - Taxes
- Personal property tax - Machinery
- Accounting and legal - Services
- Maintenance and repairs - Repairs
- Utilities - Electricity
- Fuel and lubricant - Fuel
- Liability insurance - Services

- Miscellaneous - General
- Conservation and environmental - Items
- Horse - N/A
- Other - General
- Simple activity fixed costs - N/A

An explanation of each of the cost categories in the list is provided below. Rent on cropland is the per acre cropland rental rate multiplied by the number of cropland acres cash rented. Rent on private pastureland is the per acre private pastureland rental rate multiplied by the number of pastureland acres cash rented. Rent on public pastureland is the public pastureland rental rate multiplied by the number of public pastureland acres cash rented. Several of the representative ranches rent both private and public pastureland.

Salaries paid is the total salary paid for each employee multiplied by the number of full-time employees the operation hires. The salary considered here includes payroll taxes, as well as any benefits the operation pays on behalf of the employee. However, this does not include housing for the employees, if provided. Part-time wages paid are the sum of the total amount of part time wages paid for all part time employees. For many operations this labor covers seasonal employees only on the operation for high man-hour seasons such as harvest time on a crop farm.

Property taxes are the sum of real estate taxes paid by the operation on all owned assets in this category. This is a flexible category that may include taxes on owned land, farm buildings, or grain storage facilities depending on what the representative operation owns. We do not track to whom this category is paid i.e. state, county, or school district. Personal property taxes are the sum of personal property taxes paid by the operation. This is relevant in certain states that tax personal property such as equipment, especially vehicles.

Accounting and legal is the sum of all accounting and legal fees paid by the operation. This primarily includes the cost to prepare the taxes for the operation; therefore, the size and complexity of the operation can affect this value dramatically.

Maintenance and repairs are the sum of the cost of maintenance and repairs for all farm equipment on the operation. This is a major cost for most operations and can be more variable than other categories based on the unpredictability of machinery breakdowns. On ranches, this cost also includes fence repairs.

Utilities are the sum of all farm utility costs. This includes electricity or natural gas to power and/or heat farm buildings or shops. This also includes work cell

phones for the owner/operator as well as any employees. This would not include electricity or fuel to dry grain, or pump water for irrigation. Those charges are attributed directly to the appropriate crop in the individual crop budget. Additionally, this does not include personal housing utilities; if the producer lives on the farm, the housing utilities are not charged to the farm.

Fuel and lubricant is the sum of all costs of fuel and oil the operation uses in a year. This includes farm vehicle fuel, as well as any field work that is performed by the operation. Additionally, this category includes all the oil and hydraulic fluid used on the farm equipment. This does not include fuel to run grain drying facilities, if applicable, that fuel would be charged to the appropriate crop in the individual crop budget.

Miscellaneous is the sum of all miscellaneous costs on the operation. This may include subscriptions for farm machinery technologies. Conservation and environmental is the sum of costs the operation pays for conservation or environmental fees or permits. This category often includes manure management fees paid by dairy operations, or water runoff management costs on operations in certain regions.

Horse costs are the total annual costs associated with feeding and maintaining horses. This category is included for the beef cattle ranches that own horses to work their cattle. This does not include replacing horses, only feeding and maintaining them.

Other costs are the sum of any other costs that should to be included on an operation. An example of a cost that may fit in this category would be any work the operation hires out annually.

In addition to the costs above, representative farms with livestock may also have the following fixed costs related to their bovine herds.

- Bovine feed purchases
- Bovine Feed grown
- Bovine Custom Raising
- Bovine Feedlot
- Bovine Other

Bovine purchases is the sum of the cost of all bovines purchased throughout the year. This often includes herd sire and dam replacements. Bovine feed purchases is the total bill for all feed purchased that is not grown on the operation. Bovine feed grown is the cost of all feed that is grown and fed on the operation. The

model acknowledges the cost of the feed grown by charging and crediting the operation with the feed that is grown on the operation.

Bovine custom raising is the the total amount spent by the operation for custom raising. Bovine feedlot costs are the total amount spent by the operation to feed feedlot animals. Bovine other costs includes all other bovine costs. More detailed descriptions of the bovine variables may be found in chapter 5.

The following insurance programs are each available within FarmESP. The premium paid for each program that is purchased is included in the list of fixed costs as well.

- Dairy Margin Coverage (DMC) premiums
- COMBO insurance premiums
- Cottonseed Endorsement premiums
- Supplemental Coverage Option (SCO) premiums
- Stacked Income Protection Plan (STAX) premiums

The amount of each insurance premium that is listed in the fixed costs is the total premium paid by the operation for that policy in a given year. All of the fixed costs outlined in this section are summed to arrive at a *total fixed costs* value for the farm.

## 10 Debts

Within FarmESP, there are four categories of debt: long-term, equipment, operating, and carryover.

### 10.1 Long-Term Debt

Long term debt includes all debt on land, farm buildings and structures (including grain storage). For dairies, the milking barn is considered long-term debt. In order to apply a cost of servicing long-term debt on the representative farms, debt level assumptions are established for each type of operation for uniformity.

- Crop Farms: 20%
- Beef Cattle Ranches: 1%
- Dairies: 30%

Additionally, all long term debts are 20 years in length across all operation types. In order to establish an accurate amortization schedule for each loan on each operation, the following values are defined for each operation. In the list below, each item is either collected from the panel of producers that provides the data for each representative farm, or is assumed.

- Name - Collected
- Loan Start Year - Assumed
- Loan Term in Years - Assumed
- Loan Interest Rate - Collected
- Loan Principal Percentage (debt level) - Assumed
- Acres of Land - Collected
- Market Value of Land Per Acre - Collected
- Market Value of Buildings - Collected

For the entire dataset of representative operations, the loan start year is set to the same year for all operations, and is determined such that the long-term debt is not completely paid off within the simulation horizon. The amount of principal on the loan is calculated within the model to ensure that the operation owes the correct amount of principal on their long-term debts in the simulation start year. For example, on a crop farm, the debt level assumption of 20% means that if the farm owns \$500,000 in farm land in 2025, the principal balance on the loan in 2025 will be \$100,000. The loan start year will be before 2025, and the original loan balance is calculated within FarmESP so that the debt levels are correct (20%) in 2025. For each long term loan, principal, interest, and outstanding balance are calculated using an annual amortization schedule.

## 10.2 Equipment Debt

Equipment debt is maintained for each item of machinery on each operation. The details and assumptions regarding equipment debt are found in chapter 8.

## 10.3 Operating Debt

In order to model operating debt, an interest rate and length (in months) for an operating loan in the data year are collected. In FarmESP, the operating loan amount balance is equal to the subtotal of cash costs.

$$SubtotalCashCosts_t = TotalCashProductionCosts_t + TotalFixedCosts_t \quad (10.1)$$

Operating interest is calculated as follows

$$OperatingLoanInterest_t = SubtotalCashCosts_t \times (1.0 - e^{-r\tau}) \quad (10.2)$$

where  $r$  is the interest rate on operating loans, and  $\tau$  represents the length of the loan (in months). For example, if an operation draws their operating loan for 6 months out of the year, then  $\tau = 6/12$ . The primary purpose of including the operating debt in the model is to account for the short-term interest costs that producers face.

## 10.4 Carryover Debt

A carryover loan is automatically generated for each farm to capture the debt accumulated from negative net ending cash in each year of the simulation. If an

operation has positive ending cash, then their carryover loan balance and resulting interest are \$0.

However, when a farm has a negative ending cash balance in year  $t - 1$ , carryover loan interest is paid in year  $t$  along with all other debts. In the case where a farm is in poor financial standing, the carryover amount may build dramatically throughout the simulation period. The carryover loan interest rate is the same interest rate as the operating loan collected from the representative farm panel. Carryover interest owed is accounted for in total cash expenses. Carryover principal owed or carryover debt, is accounted for in total liabilities.

# 11 Financial Statements and Taxes

FarmESP displays a detailed income statement, cashflow statement, and balance sheet in the output for each representative farm.

## 11.1 Income Statement

Organization of the income statement is consistent with typical financial reporting, beginning with sources of income. Total crop receipts are the sum of receipts from all crops grown on all entities on the operation. Total bovine cash receipts are the sum of all receipts from non-feedlot bovine sales. Bovine related variables only pertain to operations that sell livestock.

Total feedlot cash receipts are the sum of all receipts from feedlot-fed bovine sales. These are only applicable to operations that utilize a feedlot enterprise to finish calves. Total milk cash receipts are the sum of all receipts from annual milk sales, applicable only to the dairies.

Total simple activity revenue is the sum of all revenue from simple activities. Simple activities are a flexible category to allow FarmESP to document additional on-farm enterprises as explained in chapter 7. This category is frequently used to document revenue from custom farming, or other on-farm activities that are not considered as a standard across all operations.

Total PLC, ARC-C, LDP, DMC payments are included in the income statement. For PLC, ARC-CO, and LDP these totals are all subject to the payment limits outlined in chapter 6.

Total SCO, STAX, and COMBO indemnities are also included in the income statement.

Total Other Income is the sum of all other farm income. This may include income from custom farming or a hunting lease.

Total Lump Sum Payment is the sum of all lump sum payments paid or charged to the farm. Note that a positive lump sum payment is a payment received by the farm, and a negative lump sum payment is paid by the farm. This category allows farms to be charged or paid a one-time lump sum for abnormal occurrences. For

instance, ad-hoc payments not modeled within the FarmESPbe added to a farm by means of a lump-sum payment.

Interest on cash reserves is included as cash income and is paid to the farm based on the total reserves in the prior year (t-1) as shown in equation 11.1.

$$InterestCashReserves_t = TotalCashReserves_{t-1} \times SavingsRate_t \quad (11.1)$$

Interest is earned, and charged, annually within the model. Total cash receipts are further outlined in equation 11.2.

$$\begin{aligned}
 TotalCashReceipts_t = & TotalCropReceipts_t \\
 & + TotalBovineCashReceipts_t \\
 & + TotalFeedlotCashReceipts_t \\
 & + TotalMilkCashReceipts_t \\
 & + TotalSimpleActivityRevenue_t \\
 & + TotalPLCPayments_t \\
 & + TotalARC-CPayments_t \\
 & + TotalLDPPayments_t \\
 & + TotalDMCPayments_t \\
 & + TotalSCOIndemnities_t \\
 & + TotalSTAXIndemnities_t \\
 & + TotalCOMBOIndemnities_t \\
 & + TotalOtherIncome_t \\
 & + TotalLumpSumPayment_t \\
 & + InterestCashReserves_t
 \end{aligned} \quad (11.2)$$

The crop production costs are follow income in the income statement. Each category of production costs are totaled for all crops grown on the operation. Total production costs are calculated as shown in equation 11.3.

$$\begin{aligned}
TotalProductionCosts_t = & TotalSeedCosts_t \\
& + TotalFertilizerCosts_t \\
& + TotalHerbicideCosts_t \\
& + TotalInsecticideCosts_t \\
& + TotalIrrigationCosts_t & (11.3) \\
& + TotalOtherProductionCosts_t \\
& + TotalFuelLubricantCosts_t \\
& + TotalHarvestingCosts_t \\
& + TotalSimpleActivityCosts_t
\end{aligned}$$

The next section of the income statement is the summary of fixed costs. Refer to chapter 9 for the list of items included in total fixed costs, along with descriptions of each variable.

The last section of the income statement lists the remaining items needed to calculate overall net farm income. First the sub-total of cash costs which is the sum of all cash costs in equation 11.3 and all fixed costs in chapter 9.

$$Sub-TotalCashCosts_t = TotalCashCosts_t + TotalFixedCosts_t \quad (11.4)$$

Next are the various interest charges for the operation. These include total interest on farm buildings and land loans, equipment loans, operating loans, and carryover loans. See chapter 10 for more information on the various types of loans and interest charges.

Total cash expenses are calculated as shown in equation 11.5

$$\begin{aligned}
TotalCashExpenses_t = & Sub-TotalCashCosts_t \\
& + InterestLandLoans_t \\
& + InterestEquipmentLoans_t & (11.5) \\
& + InterestOperatingLoans_t \\
& + InterestCarryoverLoans_t
\end{aligned}$$

Net cash farm income is calculated by subtracting total cash expenses from total cash receipts as shown in equation 11.6.

$$NetCashFarmIncome_t = TotalCashReceipts_t - TotalCashExpenses_t \quad (11.6)$$

Once net cash farm income is established, depreciation of farm machinery is considered in order to calculate net farm income. FarmESP includes straight line depreciation, and depreciation via immediate expensing. The immediate expensing is referred to as Section 179 depreciation as explained in section 8.3. Equation 11.7 shows the net farm income calculation.

$$\begin{aligned}
 NetFarmIncome_t &= NetCashFarmIncome_t \\
 &\quad - Depreciation_t \\
 &\quad - Depreciation179_t
 \end{aligned}
 \tag{11.7}$$

where  $Depreciation_t$  is the sum of the straight-line depreciation on all machinery currently in the depreciation schedule, and  $Depreciation179_t$  is the sum of the immediate expensing (depreciation via 179).

## 11.2 Cash Flow Statement

The cash flow statement is available for each farm in the typical FarmESP output. In general, the purpose of a cash flow statement is to evaluate whether an operation has the cash on hand to meet its operating expenses. The cash inflows include starting cash, net cash farm income, and total cash available.

$$StartingCash_t = EndingCash_{t-1} \tag{11.8}$$

starting cash is always specified as \$0 in the simulation starting year.

Total cash available is an annual measure of total cash available to the operation and is calculated as follows

$$TotalCashAvailable_t = StartingCash_t + NetCashFarmIncome_t \tag{11.9}$$

Once total cash available is calculated, total cash outflows must be calculated in order to establish overall ending cash. There are several items included in cash outflows: total equipment down payments (the sum of all down payments on equipment); the total principal on land loans (includes all principal paid on any building and land loan on the operation as described in section 10); the total principal on equipment loans (described in chapter 8); total family withdrawals or dividends (the amount of income taken off of the farm by the operator); and the total state and federal income tax paid by the operation.

$$\begin{aligned}
TotalCashOutflows_t = & TotalEquipmentDownPayments_t \\
& + TotalPrincipalLandLoans_t \\
& + TotalPrincipalEquipmentLoans_t \\
& + TotalDividends \\
& + TotalStateIncomeTax \\
& + TotalFederalIncomeTax
\end{aligned} \tag{11.10}$$

The total available cash, and total cash outflows are used in calculating ending cash as shown in equation 11.11.

$$EndingCash_t = TotalCashAvailable_t - TotalCashOutflows_t \tag{11.11}$$

Ending cash in this context is a cumulative metric, meaning starting cash in the current year considers ending cash in the year prior. Therefore, the ending cash at the end of the simulation horizon indicates how much cash surplus (or deficit) has accumulated throughout the simulation.

### 11.3 Balance Sheet

A balance sheet is also provided in the FarmESP output. It summarizes many of the variables previously discussed in order to calculate total assets, total liabilities, and net worth across each operation.

The variables that make up total assets include total cash reserves, total bovine market value, total land market value, and total equipment market value. The calculation for total cash reserves is found in equation 11.12.

$$TotalCashReserves_t = \max(EndingCash_t, 0) \tag{11.12}$$

Therefore, total cash reserves are the positive occurrences of ending cash. Total bovine market value is the sum of the market value of each class of bovines that are kept year over year. Therefore, this figure excludes calves that are raised and sold within the year.

Total land market value is calculated as

$$TotalLandMarketValue_t = LandPricePerAcre \times TotalOwnedAcres \tag{11.13}$$

where the land price per acre is indexed annually using a region-specific land price index.

Total equipment market value is the sum of the current market value of all owned equipment on the operation. Each piece of farm equipment has a current market value based on the original purchase price, year, and machinery value decay rate. This rate is set for all farms across all machinery (see chapter 8).

Total assets are calculated as follows:

$$\begin{aligned}
 TotalAssets_t &= TotalCashReserves_t \\
 &+ TotalBovineMarketValue_t \\
 &+ TotalLandMarketValue_t \\
 &+ TotalEquipmentMarketValue_t
 \end{aligned}
 \tag{11.14}$$

The components of total liabilities are total land debt, total equipment debt, and carryover debt. Total land debt is the sum of all unpaid principal on building and land loans. Detail regarding what may be included in land debt is explained in chapter 10.

Total equipment debt is the total unpaid principal balance on all farm machinery. Chapter 8 outlines how FarmESP utilizes amortization and the overall machinery replacement methodology used. Carryover debt is the cumulative cash deficit of the operation, therefore it is a factor when the operation has a negative ending cash balance. More information on carryover debt is outlined in chapter 10. Total liabilities are calculated as follows:

$$\begin{aligned}
 TotalLiabilities_t &= TotalLandDebt_t \\
 &+ TotalEquipmentDebt_t \\
 &+ CarryoverDebt_t
 \end{aligned}
 \tag{11.15}$$

Using the total assets and liabilities from above, the following equation is used to calculate net worth for each year in the simulation.

$$NetWorth_t = TotalAssets_t - TotalLiabilities_t$$

The financial statements described in this chapter provide insight into the state of each representative farm.

## 12 Simulation Process

In this chapter, we describe the process by which FarmESP simulates future values for variables in the model. We first describe the core stochastic variables that are directly sampled during the simulation process, then describe how dependence between those variables is represented. Finally, we describe the intermediate (non-stochastic) variables that are computed during the simulation process.

### 12.1 Core Stochastic Variables

Stochastic variables in FarmESP are of two types: those that are randomly sampled during the simulation process, and those that are pre-simulated in the agricultural sector baseline (see section 2.2). Sampling for these two categories of variables is performed differently.

Directly sampled variables are sampled from their respective marginal distributions during the simulation process. These variables include the following:

- Yield deviates for individual RMA tracts, *YDEV*, as described in section 3.1.1. These are sampled from a marginal distribution represented by a kernel density estimate (KDE) fit to historical yield deviates, as described in section 3.1.2.
- The log change in the discovered price from planting time to harvest time, *DLNP*, used in calculating revenue protection (RP) program indemnities, as described in section 4.2. These are sampled from a normal marginal, with a zero mean and variance fit to corresponding historical log price changes.
- County yield deviates, *AREADEV*, used in calculating area-wide loss program indemnities, as described in section 4.3. These are sampled from a normal marginal, with parameters fit to historical RMA area-wide loss county yield deviates.
- County yield deviates, *ARCDEV*, used in calculating agricultural risk coverage (ARC) program payments, as described in section 6.4. These are also

sampled from a normal marginal, but calibrated to historical county ARC yield deviates.

Stochastic marketing year average prices (*MYAP*) for row crops are provided in the agricultural sector baseline that is an input to FarmESP. Stochastic draws for all such variables for all future years for all trials are provided. Dependence among draws for these variables is already reflected in the baseline. However, these draws are not used directly. To accommodate the dependence structure among the various stochastic variables described in the next section, the draws provided for these variables are used to fit KDE marginals for each time period for each variable, and then new draws are sampled from those KDEs during the simulation process.

## 12.2 Dependence Representation

Specifying a process for correctly representing dependence among all of the various stochastic variables that may appear for any arbitrary farm is made challenging for several reasons. First, the stochastic variables will generally reflect multiple geographic levels (tract-level, county-level, and national-level) for multiple crops. Second, for some variables, there will be a generous amount of historical data to use for fitting some dependence structure, while for others we cannot rely on such availability. In particular, we sometimes are able to collect only a limited number of tract-level yield observations. Third, the dependence approach must be able to work with pre-simulated draws for some variables coming from the agricultural sector baseline, which already reflect dependence among those variables, but those must then be appropriately related to the other variables that are directly sampled during the simulation process. Given the varying regions and different crops that may appear on a farm, the dependence between some local variables (e.g. tract-level yield deviates) and the national variables (e.g. marketing year average prices) will vary substantially. For example, for a corn and soybean farm in the Corn Belt, there may be some non-trivial dependence between tract-level yield deviates for one crop, say corn, and the marketing year average price for another crop like soybeans. For a farm in Texas with cotton and corn, there will likely be very little or zero dependence between analogous variables.

We describe a somewhat complex process in the section below. The process is designed to be flexible enough to accommodate the various challenges described above, while also relying on a minimal number of assumptions that are reasonably defensible.

### 12.2.1 Overall approach: Gaussian copula

Dependence among the various stochastic variables in FarmESP is represented using Gaussian copulas. The Gaussian copula is a flexible method for representing dependence among random variables, and allows for arbitrary marginal distributions for each variable. The Gaussian copula is parameterized by a correlation matrix, which captures the dependence structure among the variables. During the simulation process, we first sample from the Gaussian copula to obtain correlated draws for standard normal variables (hereafter, “ $Z$ ” variables). We use the standard normal cumulative distribution function (CDF) to calculate draws for corresponding standard uniform random variables (hereafter, “ $U$ ” variables), and then transform those uniform draws to the final values for each stochastic variable using the percent point function (a.k.a., inverse CDF) for its individual marginal distribution.

A single, monolithic Gaussian copula is not used, however. Doing so would require specifying elements of a sometimes quite large overall correlation matrix that would encounter the challenges described above. Instead, we use a series of copulas. A core copula is used to represent dependence among variables where a generous amount of historical data is reliably available, and then we use two additional copulas, linked by correlation induction processes to the variables in the core copula. One of these reflects dependence among the variables where historical data is often limited, and a second reflects dependence between the core variables and the national marketing year average prices. Through this process, challenging aspects of dependence described above need not be directly specified, but are instead realized implicitly through the dependence induction process, thereby automatically adapting to the varying dependence structures that may be present for different crop mixes in different regions.

### 12.2.2 Dependence among variables with quality historical data

We reliably can assemble, for any arbitrary collection of crops, a panel of historical data with a reasonable or even generous number of observations, for the the *DLNP*, *SHALLOWDEV*, and *ARCDEV* variables described above. We use such data to fit a core Gaussian copula that captures the dependence among these variables. Specifically, we calculate the standard sample covariance matrix. If the sample covariance matrix is not positive semi-definite, we use the process described in [Higham \(1988\)](#) to find the nearest (in the  $L^2$  norm sense) positive semi-definite matrix. We use the final covariance matrix,  $\hat{\Sigma}$ , to calculate a corresponding correlation matrix,  $\hat{\rho}$ , and calculate the lower triangular Cholesky decomposition,  $\mathbf{L}$ , of that correlation matrix.

Random draws for the  $Z$  variables corresponding to the *DLNP*, *SHALLOWDEV*, and *ARCDEV* variables are calculated as

$$\mathbf{Z} = \mathbf{L}\mathbf{Z}^\perp \quad (12.1)$$

where  $\mathbf{Z}^\perp$  is a vector of independent standard normal random draws and  $\mathbf{Z}$  is a vector of correlated standard normal random draws.

### 12.2.3 Dependence induction process overview

The processes for generating correlated standard normal draws for the secondary Gaussian copulas are operated partially in reverse to induce correlation between the *DLNP* variables from the core copula described above and the remaining variables in the system. This correlation induction process is described in general here before we describe the specific use of this process for the two secondary copulas in the next two sections.

The basic idea is to run half (or less) of a matrix multiplication like that in equation 12.1 backwards, and run the remainder of the calculations in the ordinary direction. Suppose there are  $K$  standard normal random variables in the system, and that:

- $J \leq \lfloor \frac{K}{2} \rfloor$  of the variables are pre-determined, and will work in reverse: calculate  $\mathbf{Z}^\perp$  using  $\mathbf{Z}$
- $K - J$  of the variables will be typical correlated standard normal draws: calculate  $\mathbf{Z}$  using  $\mathbf{Z}^\perp$

Re-write the  $\mathbf{Z}$  and  $\mathbf{Z}^\perp$  relationship using partitioned matrices:

$$\begin{bmatrix} \mathbf{Z}_1 \\ \mathbf{Z}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{L}_{11} & \mathbf{L}_{12} \\ \mathbf{L}_{21} & \mathbf{L}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{Z}_1^\perp \\ \mathbf{Z}_2^\perp \end{bmatrix}$$

with the following dimensions for the sub-matrices:

- $\mathbf{Z}_1$  and  $\mathbf{Z}_1^\perp$  are  $J \times N$ . These reflect the pre-determined values.
- $\mathbf{Z}_2$  and  $\mathbf{Z}_2^\perp$  are  $(K - J) \times N$
- $\mathbf{L}_{11}$  is  $J \times J$
- $\mathbf{L}_{12}$  is  $J \times (K - J)$ . Note that  $\mathbf{L}_{12}$  is composed entirely of zeros because  $\mathbf{L}$  is lower triangular and  $J \leq \lfloor \frac{K}{2} \rfloor$ .
- $\mathbf{L}_{21}$  is  $(K - J) \times J$

- $\mathbf{L}_{22}$  is  $(K - J) \times (K - J)$

The system can then be expressed as a system of two matrix equations:

$$\begin{aligned}\mathbf{Z}_1 &= \mathbf{L}_{11}\mathbf{Z}_1^\perp \\ \mathbf{Z}_2 &= \mathbf{L}_{21}\mathbf{Z}_1^\perp + \mathbf{L}_{22}\mathbf{Z}_2^\perp\end{aligned}\quad (12.2)$$

To generate random draws for the  $K - J$  non-pre-determined variables:

- Solve the top half of the system for the  $\mathbf{Z}_1^\perp$  that would generate the pre-determined draws in  $\mathbf{Z}_1$
- Generate independent standard normal draws  $\mathbf{Z}_2^\perp$
- Use the results of the first two steps to calculate  $\mathbf{Z}_2$ :

$$\mathbf{Z}_2 = \mathbf{L}_{21}\mathbf{L}_{11}^{-1}\mathbf{Z}_1 + \mathbf{L}_{22}\mathbf{Z}_2^\perp$$

#### 12.2.4 Dependence induction for U.S. row crop prices

The first secondary copula is used to induce correlation between the *DLNP* variables from the core copula and the marketing year average price (*MYAP*) variables for row crops. We denote the submatrix of the core variable correlation matrix,  $\hat{\rho}$ , from section 12.2.2 pertaining to the *DLNP* variables as  $\hat{\rho}_{DLNP}$ . We then construct a new correlation matrix for the secondary copula as shown below for an example system reflecting two crops (corn and soybeans), although the approach generalizes in an obvious way to systems with more than two crops.

$$\hat{\rho}_{\text{baseline}} = \begin{array}{l} DLNP_{\text{corn}} \\ DLNP_{\text{beans}} \\ MYAP_{\text{corn}} \\ MYAP_{\text{beans}} \end{array} \left[ \begin{array}{cc|cc} DLNP_{\text{corn}} & DLNP_{\text{beans}} & MYAP_{\text{corn}} & MYAP_{\text{beans}} \\ \hline & \hat{\rho}_{DLNP} & 0.95 & \hat{\rho}_{cb} \\ \hline & & \hat{\rho}_{cb} & 0.95 \\ \hline & & 1 & \hat{\rho}_{cb} \\ \hline & & & 1 \end{array} \right] \quad (12.3)$$

Here,  $\hat{\rho}_{cb}$  is the Pearson correlation coefficient between stochastic draws for  $MYAP_{\text{corn}}$  and  $MYAP_{\text{beans}}$  from the agricultural sector baseline. The value of 0.95 for correlation between a *DLNP* variable and its corresponding *MYAP* variable is assumed. The Cholesky decomposition of a thusly specified  $\hat{\rho}_{\text{baseline}}$  and the draws for the  $Z$  variables corresponding to the *DLNP* variables that were generated in the core Gaussian copula are then the ingredients needed to generate draws for the  $Z$  variables corresponding to the *MYAP* variables using the correlation induction process described in the previous section.

### 12.2.5 Dependence induction for local crop yield deviates

The secondary copula used to generate draws for the  $Z$  variables corresponding to tract-level yield deviates,  $YDEV$ , is implemented in a similar fashion. The correlation matrix for this secondary copula is specified as

$$\hat{\rho}_{\text{tract}} = \begin{array}{c} DLNP_{\text{corn}} \\ DLNP_{\text{beans}} \\ YDEV_{\text{corn}} \\ YDEV_{\text{beans}} \end{array} \left[ \begin{array}{cc|cc} DLNP_{\text{corn}} & DLNP_{\text{beans}} & YDEV_{\text{corn}} & YDEV_{\text{beans}} \\ \hline & \hat{\rho}_{\text{DLNP}} & \rho_{\text{corn}} & 0 \\ \hline & & 0 & \rho_{\text{beans}} \\ \hline & & 1 & 0.8 \\ \hline & & & 1 \end{array} \right] \quad (12.4)$$

Here, the cross-crop tract yield deviate correlation of 0.8 is typical for yields on a farm. The values  $\rho_{\text{corn}}$  and  $\rho_{\text{beans}}$  are fetched from RMA's Actuarial Data Master, and are the values they use with a Gaussian copula to simulate joint  $DNLP$  and  $YDEV$  draws to calculate a multiple that is applied to a Yield Protection (YP) base premium rate to arrive at a Revenue Protection (RP) base rate. The zeroes in the upper right submatrix are assumed. However, a thusly specified preliminary  $\hat{\rho}_{\text{tract}}$  will likely be non-semi-definite for instances where  $\rho_{\text{corn}}$  and  $\rho_{\text{beans}}$  are significantly negative, and after application of the [Higham \(1988\)](#) method, those zeroes will be replaced by small negative values to arrive at the final  $\hat{\rho}_{\text{tract}}$  that we use to generate  $Z$  draws corresponding to the  $YDEV$  variables using the correlation induction method.

### 12.2.6 Final draws for all stochastic variables

The processes described in sections 12.2.2 through 12.2.5 are used to generate stochastic draws for “ $Z$ ” variables corresponding to all stochastic variables in the model. Given those, we get corresponding stochastic draws for the actual stochastic variables themselves using the probability integral transform. For an arbitrary stochastic variable  $X$  with a percent point function  $F^{-1}$  and a corresponding standard normal variable  $Z$ , we calculate the  $i^{\text{th}}$  draw as

$$x_i = F^{-1}(\Phi(z_i))$$

where  $\Phi$  is the standard normal CDF. The marginal distributions that imply the percent point functions for each variable are described in section 12.1.

### **12.3 Intermediate Variables**

There are a handful of price inflation index variables whose deterministic future path is taken from the agricultural sector baseline. Other than those and the stochastic *YDEV*, *DLNP*, *SHALLOWDEV*, and *ARCDEV* variables, whose draws are generated as described above, all remaining variables in the model are intermediate variables that are simply calculated as described in chapters 3 through 11 using the values of the deterministic variables and the draws for the stochastic variables.

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