Rice farming with crop rotation for smallholder farmers in Indonesia

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2023-07-13

Introduction

Overview

Rice is known as one of the main crops and a staple food in Southeast Asia (Yoshida (1981)). Indonesia is one of the largest countries in Southeast Asia, and rice is one of their main staple crops. With an increase in production every year, Indonesia has become the third-largest rice producer in the world, with around 93% of Indonesian farmers possessing small family farms (Fao (2018)).

Crop rotation is a method of cultivating different crops sequentially on the same field that has the benefit of increasing soil fertility, enhancing nutrients in the soil, and reducing pest and weed pressure (Crystal and Whittlesey (2004)). Crop rotation can be implemented by growing several valuable crops, such as rice, soybeans, and chili, and these three crops are commonly grown in Indonesia.

Soybean is one of the legume species that originated in East Asia, and it is widely cultivated to be consumed as beans and for numerous other uses (Wright et al. (2005)). In Indonesia, soybean is known as the third-most important food crop after rice and maize, and the consumption of soybean tends to rise year after year (Harsono et al. (2021)). Chili is a tropical and subtropical regional crop for fleshy fruits (MOALF (2016)), and it is also one of the commodities that is known to have an economic value that is relatively high in Indonesia (Sundari et al. (2021)).

Implementing rice farming with crop rotation could potentially be advantageous for smallholder farmers in Indonesia, as it holds the promise of increased profitability through diversified income from different crops. Therefore, this project is undertaken to determine the profitability of implementing the decision of rice farming with crop rotation for smallholders in Indonesia.

Motivation

Our motivation to conduct the decision analysis of Rice farming with crop rotation in Indonesia is outlined as follows:

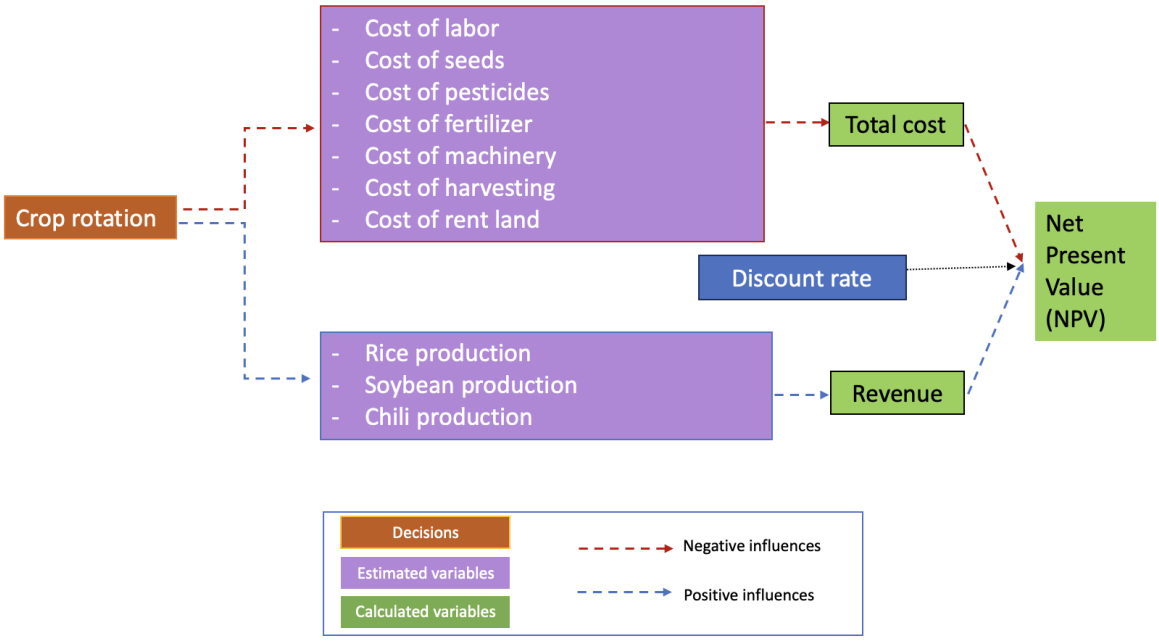
1. Rice stands as the primary staple food in Indonesia and a majority of smallholder farmers cultivate it.
2. The implementation of crop rotation offers several advantages, including: increasing crop yield, improving soil fertility, and reducing infestation of pests and diseases in the field. Thus, it is likely to bring benefits to smallholder farmers. In addition, the farmers can generate income from a diverse range of crops they cultivated within a year, which could potentially result in greater profitability for smallholder farmers.
3. Soybean is one of the valuable crops that is commonly grown by Indonesian farmers. Beyond its economic value, soybean as a legume functioning as a nitrogen-fixing crop, has the potential to enhance field sustainability.
4. Chilli as one of the most highly prized horticultural crops commonly cultivated in Indonesia, potentially gives an opportunity for the smallholder farmers to gain more significant income.

Overview of the project

- Decision → Rice farming with crop rotation
- Decision maker → Farmers
- Baseline comparison → Conventional rice farming
- Time span → 10 years
- Unit of Net Present Value → IDR (Indonesian Rupiah)

Conceptual model

This project analyzes the decision of crop rotation (soybean and chili) with rice farming. The total cost is calculated for each crop, which consists of labor, seeds, pesticides, fertilizer, machinery, and renting land. The revenues are calculated for each crop production by multiplying the yield of each crop by the selling price of each crop per ha. The total cost, revenues, and discount rate are used as variable estimates in order to calculate the Net Present Value (NVP).



Variable used in conceptual model

description	label	variable	distribution	lower	median	upper	unit
Rice production	Rice yield	rice_yield	posnorm	3000		6000	kg/ha
	Rice price	rice_price	posnorm	4000		7000	IDR/kg
Rice cultivation cost	Rent land of rice	rice_land_rental_cost	posnorm	2000000		4000000	IDR/ha
	Cost of rice seeds	rice_seeds_cost	posnorm	400000		600000	IDR/ha
	Cost of fertilizer for rice	rice_fertilizer_cost	posnorm	1000000		1500000	IDR/ha
	Cost of pesticide for rice	rice_pesticide_cost	posnorm	430000		600000	IDR/ha
	Cost of labor for rice	rice_labor_cost	posnorm	5000000		7000000	IDR/ha
	Cost of machinery for rice	rice_machinery_cost	posnorm	200000		500000	IDR/ha
	Cost of harvesting for rice	rice_harvesting_cost	posnorm	100000		200000	IDR/ha
Soybean production	Soybean yield	soybean_yield	posnorm	2000		3000	kg/ha
	Soybean price	soybean_price	posnorm	5000		10000	IDR/kg
Soybean cultivation cost	Rent land of soybean	soybean_land_rental_cost	posnorm	1530000		3000000	IDR/ha
	Cost of seeds for soybean	soybean_seeds_cost	posnorm	500000		650000	IDR/ha
	Cost of fertilizer for soybean	soybean_fertilizer_cost	posnorm	3500000		5500000	IDR/ha
	Cost of pesticide for soybean	soybean_pesticide_cost	posnorm	300000		450000	IDR/ha
	Cost of labor for soybean	soybean_labor_cost	posnorm	3500000		5500000	IDR/ha
	Cost of machinery for soybean	soybean_machinery_cost	posnorm	100000		200000	IDR/ha
	Cost of harvesting for soybean	soybean_harvesting_cost	posnorm	50000		100000	IDR/ha
Chili production	Chili yield	chili_yield	posnorm	8000		10000	kg/ha
	Chili price	chili_price	posnorm	10000		50000	IDR/kg
Chili cultivation cost	Rent land of chili	chili_land_rental_cost	posnorm	3500000		5500000	IDR/ha
	Cost of seeds for chili	chili_seeds_cost	posnorm	2000000		3000000	IDR/ha
	Cost of fertilizer for chili	chili_fertilizer_cost	posnorm	7500000		8500000	IDR/ha
	Cost of pesticide for chili	chili_pesticide_cost	posnorm	4500000		6000000	IDR/ha
	Cost of labor for chili	chili_labor_cost	posnorm	30000000		35000000	IDR/ha
	Cost of machinery for chili	chili_machinery_cost	posnorm	1000000		2700000	IDR/ha
	Cost of mulch	chili_mulch_cost	posnorm	2500000		3500000	IDR/ha
	Cost of growth support (polybag, rope, stick, ne	chili_growing_support_cost	posnorm	2000000		3000000	IDR/ha
	Cost of fuel and electricity	chili_fuel_electricity_cost	posnorm	1000000		3000000	IDR/ha
	Cost of harvesting for chili	chili_harvesting_cost	posnorm	100000		200000	IDR/ha
Discount rate	Discount rate	discount_rate	posnorm	1		5	
Year	Year of observation	n_year	const	1		10	

There are eight main variables that are used to analyze the decision of rice farming and crop rotation for smallholder farmers in Indonesia: rice production, rice cultivation cost, soybean production, soybean cultivation cost, chili production, chili cultivation cost, discount rate, and year of system. Overall, there are 33 variables that are used for this decision analysis.

Source :

BPS (2018), Mucharam et al. (2020), Jagung (2017), Fao (2018), BPS (2022), Amirrullah (2019), Crystal and Whittlesey (2004), Jagung (2017), BRIN (2022), USDA (2012), Setiartiti (2021), Antriyandarti (2015), Krisdiana et al. (2021), Harsono et al. (2020), Schilling (1999), Wandschneider et al. (2019), Sundari et al. (2021)

Estimate Calculation

Incomes:

- Rice = Paddy yield * Market price (rice)
- Soybean = Soybean yield * Market price (soybean)
- Chili = Chili yield * Market price (chili)
- Total = Rice income + soybean income + chili income

Costs:

- Rice = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Soybean = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Chili = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Total = Rice cost + soybean cost + chili cost

$$\text{Net present value} = \frac{(Total\ income - Total\ cost)}{[1-r]^n}$$

- r = discount rate
- n = year of system

In this analysis, the Net Present Value (NPV) is calculated by dividing the difference total income and total outcome from the cultivation in the year of system by the value of 1 minus the 'discount rate' (r) to the power of 'number of years in the system' (n).

NPV (Net Present Value): In financial terms, NPV is the measurement of the profitability of a project or program. This is achieved by subtracting the current values of expenditure from the current values of income over a period of time. Income can be referred to as a benefit, and expenditure can be referred to as a cost.

Discount Rate: The discount rate is the interest rate used in analysis of discounted cash flow (DCF) (Stantec (2005)).

Decision analysis

R code

Cory Whitney, Eike Luedeling et al.

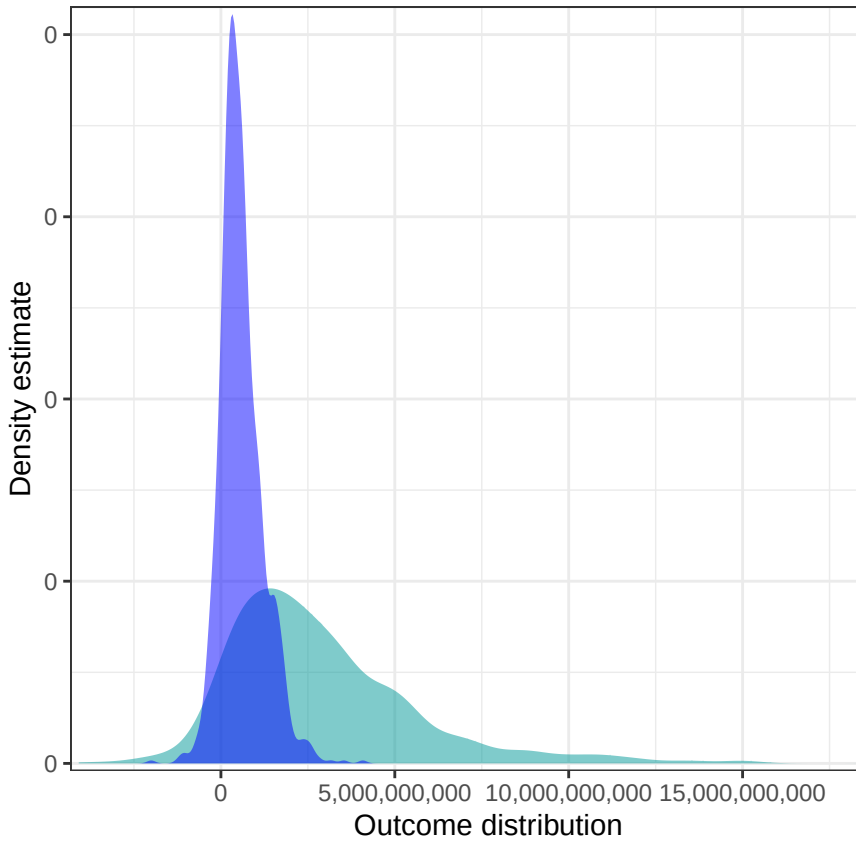
```
crop_rotation_decision <- function(){

  # Estimate the income of rice in a normal season
  rice_income <- vv(rice_yield * rice_price, n=n_year, var_CV=100)

  # Estimate the income of soybean in a normal season
  soybean_income <- vv(soybean_yield * soybean_price, n=n_year, var_CV=100)

  # Estimate the income of chili in a normal season
  chili_income <- vv(chili_yield * chili_price, n=n_year, var_CV=100)

  #Estimate the cost of rice farm in a normal season
  rice_cost_precal <- sum(rice_land_rental_cost, rice_seeds_cost, rice_fertilizer_cost,
                          rice_pesticide_cost, rice_machinery_cost, rice_harvesting_cost)
```

```
rice_cost <- vv(rice_cost_precal, n=n_year, var_CV=100)


#Estimate the cost of soybean farm in a normal season
soybean_cost_precal <- sum(soybean_land_rental_cost, soybean_seeds_cost, soybean_fertilizer_cost,
                           soybean_pesticide_cost, soybean_machinery_cost, soybean_harvesting_cost)
soybean_cost <- vv(soybean_cost_precal, n=n_year, var_CV=100)


#Estimate the cost in a normal season
chili_cost_precal <- sum(chili_land_rental_cost, chili_seeds_cost, chili_fertilizer_cost,
                         chili_pesticide_cost, chili_machinery_cost, chili_harvesting_cost)
chili_cost <- vv(chili_cost_precal, n=n_year, var_CV=100)


# Estimate the profit
rice_profit <- vv(rice_income - rice_cost, n=n_year, var_CV=100)
soybean_profit <- vv(soybean_income - soybean_cost, n=n_year, var_CV=100)
chili_profit <- vv(chili_income - chili_cost, n=n_year, var_CV=100)


# Final result
#assuming rice cultivation is 3 times per year
rice_cultivation_result = vv(rice_profit*3, n=n_year, var_CV=100)

#crop rotation decision scenario
#if crop rotation of 3 crops is done in one year
crop_rotation_result = vv(rice_profit + soybean_profit + chili_profit, n=n_year, var_CV=100)

#if crop rotation of rice and soybean is done in one year (rice-soybean-rice)
rice_soybean_result = vv((rice_profit*2) + soybean_profit, n=n_year, var_CV=100)

#if crop rotation of rice and chili is done in one year (rice-chili)
rice_chili_result = vv(rice_profit + chili_profit, n=n_year, var_CV=100)


# NPV
NPV_rice <- discount(rice_cultivation_result, discount_rate, calculate_NPV = TRUE)
NPV_crop_rotation <- discount(crop_rotation_result, discount_rate, calculate_NPV = TRUE)
NPV_rice_soybean <- discount(rice_soybean_result, discount_rate, calculate_NPV = TRUE)
NPV_rice_chili <- discount(rice_chili_result, discount_rate, calculate_NPV = TRUE)


# Cashflow
cashflow_crop_rotation <- crop_rotation_result - rice_cultivation_result
cashflow_rice_soybean <- rice_soybean_result - rice_cultivation_result
cashflow_rice_chili <- rice_chili_result - rice_cultivation_result


# Generate the list of outputs from the Monte Carlo simulation
return(list(Rice_NPV = NPV_rice,
            crop_rotation_NPV = NPV_crop_rotation,
            rice_soybean_NPV = NPV_rice_soybean,
```

```
              rice_chili_NPV= NPV_rice_chili,
              NPV_decision_crop_rotation = NPV_crop_rotation - NPV_rice,
              NPV_decision_rice_soybean = NPV_rice_soybean - NPV_rice,
              NPV_decision_rice_chili = NPV_rice_chili - NPV_rice,
              cashflow_crop_rotation = cashflow_crop_rotation,
              cashflow_rice_soybean = cashflow_rice_soybean,
              cashflow_rice_chili = cashflow_rice_chili
  ))
}

# Run the Monte Carlo simulation using the model function
input_estimates <- read.csv("new_variable_estimates.csv", sep=";")

crop_rotation_mc_simulation <- mcSimulation(estimate = as.estimate(input_estimates),
                                            model_function = crop_rotation_decision,
                                            numberOfModelRuns = 1000,
                                            functionSyntax = "plainNames")

# Run the Monte Carlo simulation using the model function
input_estimates <- read.csv("new_variable_estimates.csv", sep=";")

crop_rotation_mc_simulation <- mcSimulation(estimate = as.estimate(input_estimates),
                                            model_function = crop_rotation_decision,
                                            numberOfModelRuns = 1000,
                                            functionSyntax = "plainNames")
```

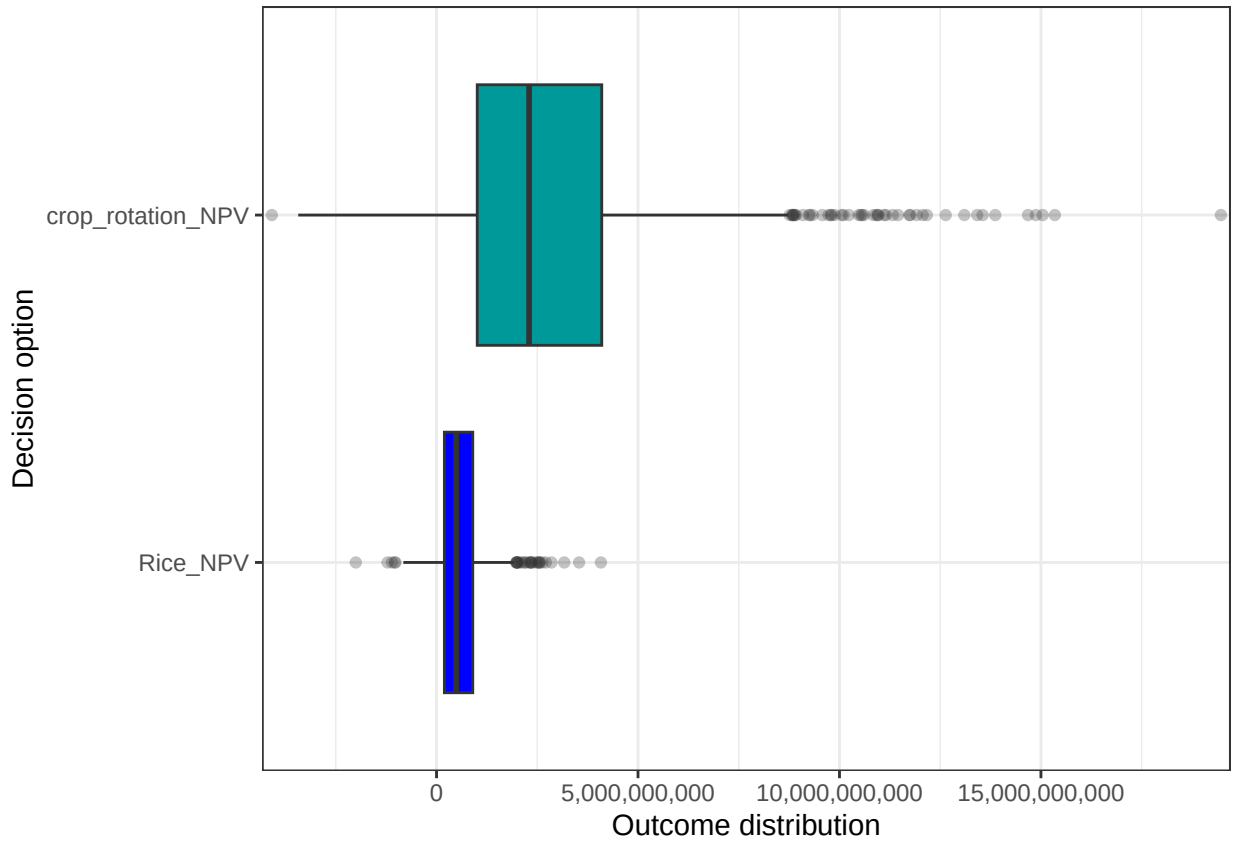
Plot NPV distribution analysis

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("crop_rotation_NPV", "Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



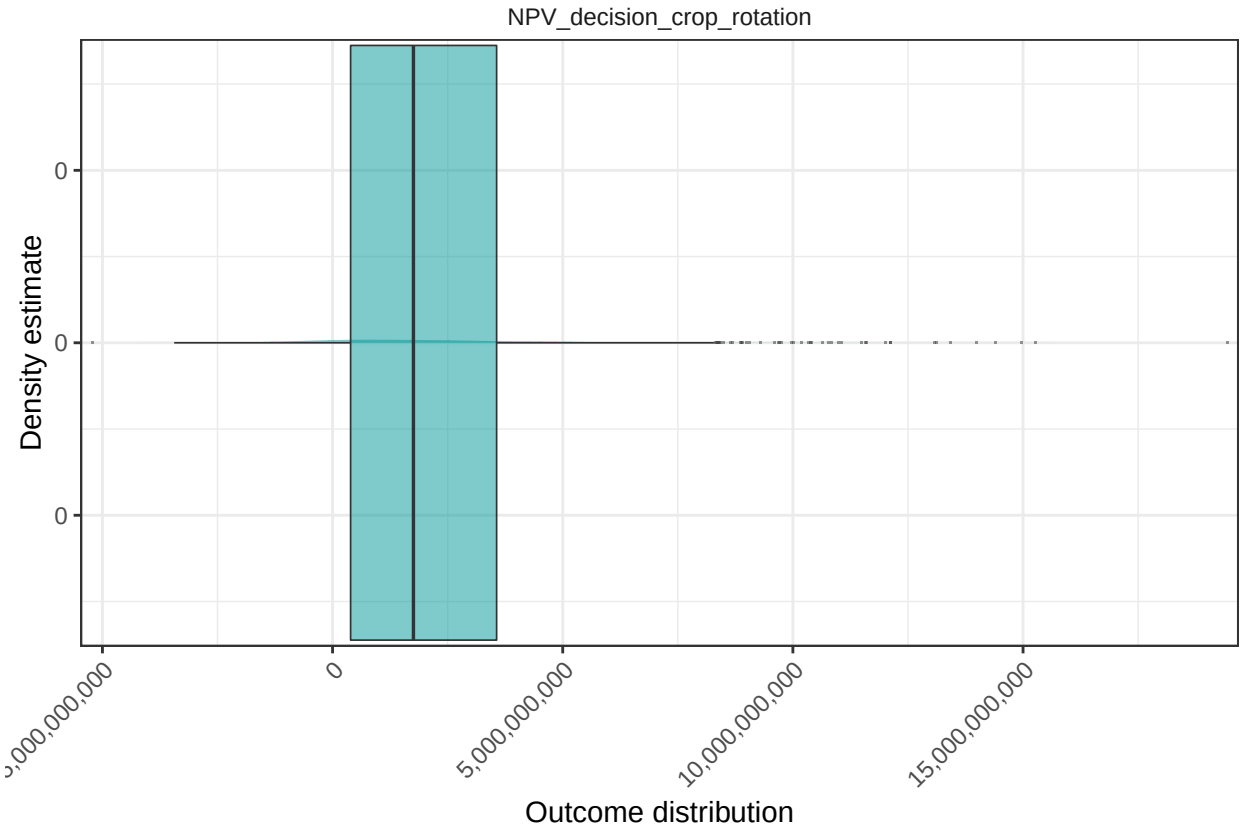
NPV for crop rotation (rice-soybean-chili)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("crop_rotation_NPV", "Rice_NPV"),
                                    method = 'boxplot')
```

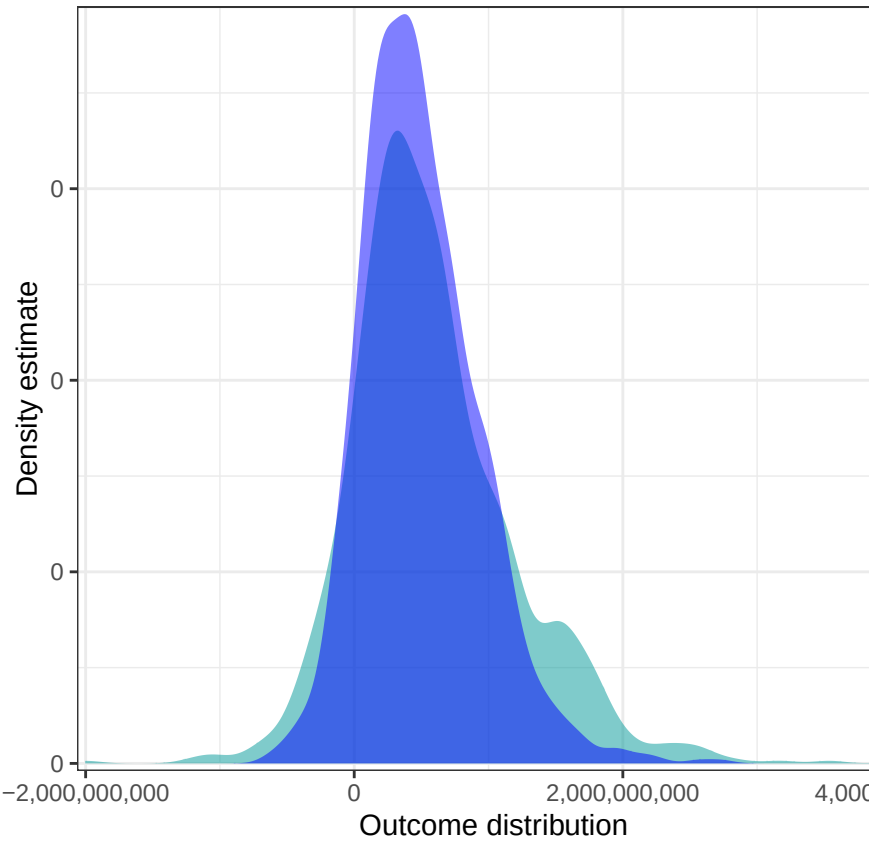



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_crop_rotation"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a ‘group‘ aesthetic or to convert a numerical
##   variable into a factor?
```

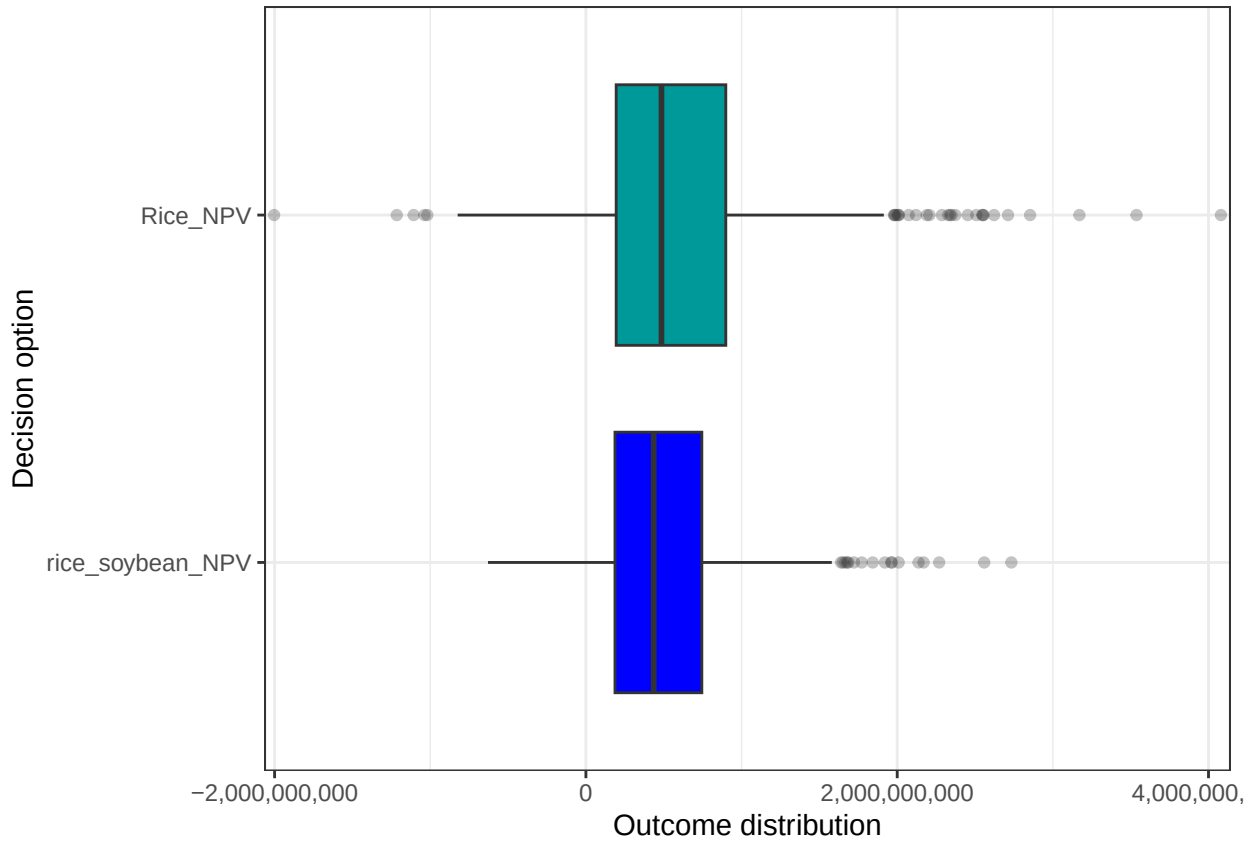



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_soybean_NPV","Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



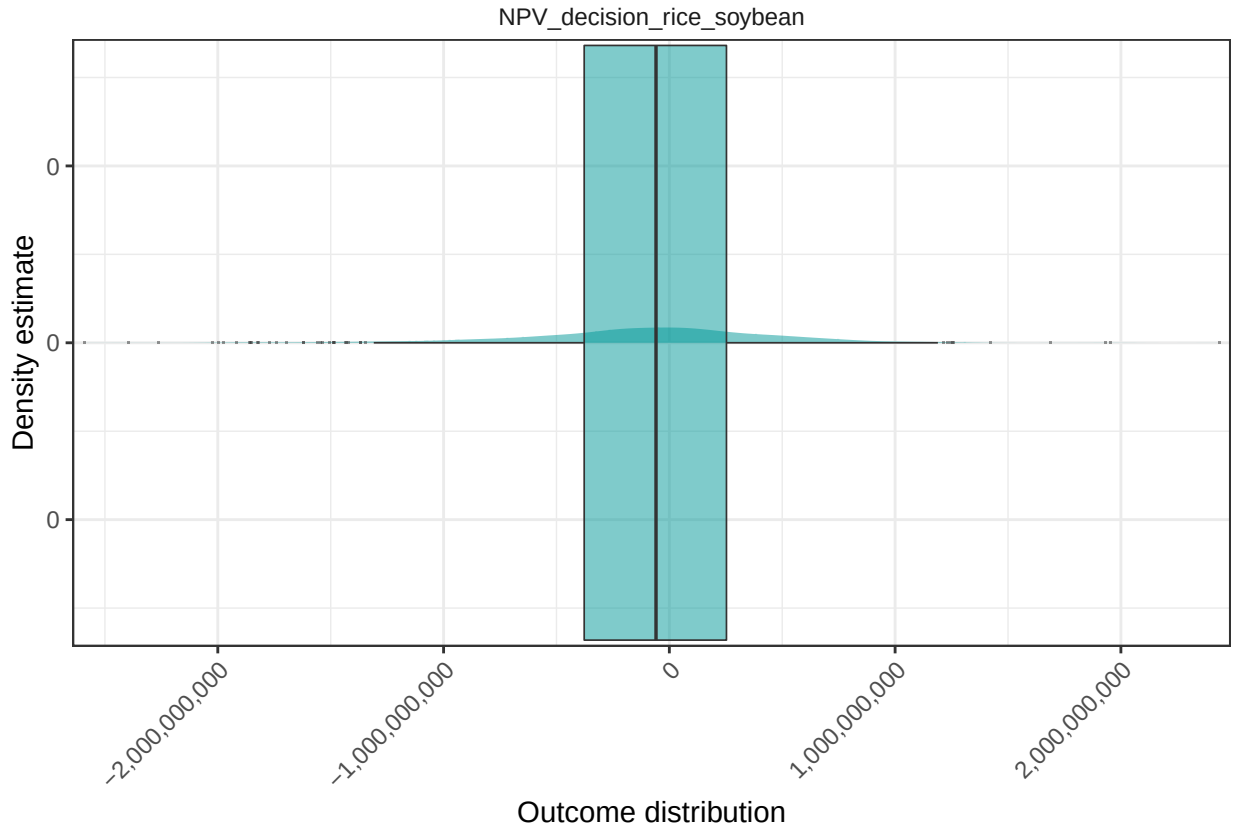
NPV for crop rotation (rice-soybean-rice)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_soybean_NPV","Rice_NPV"),
                                    method = 'boxplot')
```

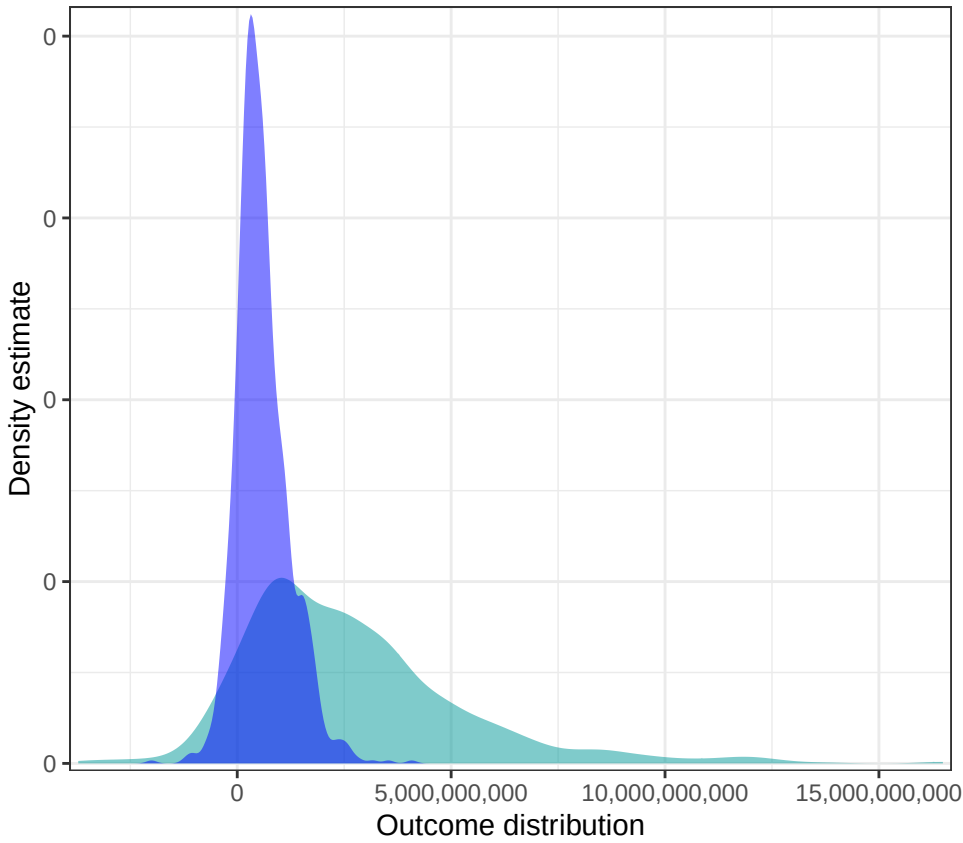



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_rice_soybean"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a ‘group‘ aesthetic or to convert a numerical
##   variable into a factor?
```

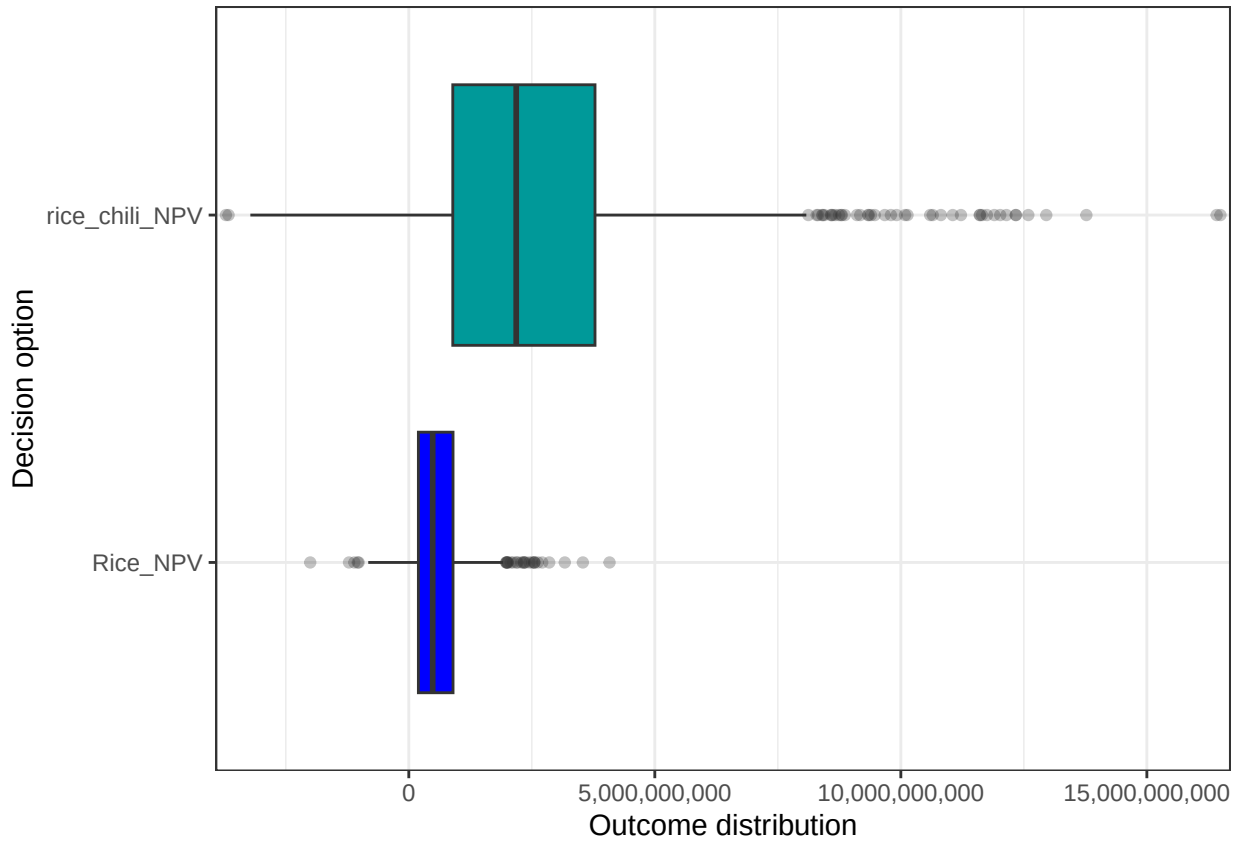



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_chili_NPV","Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



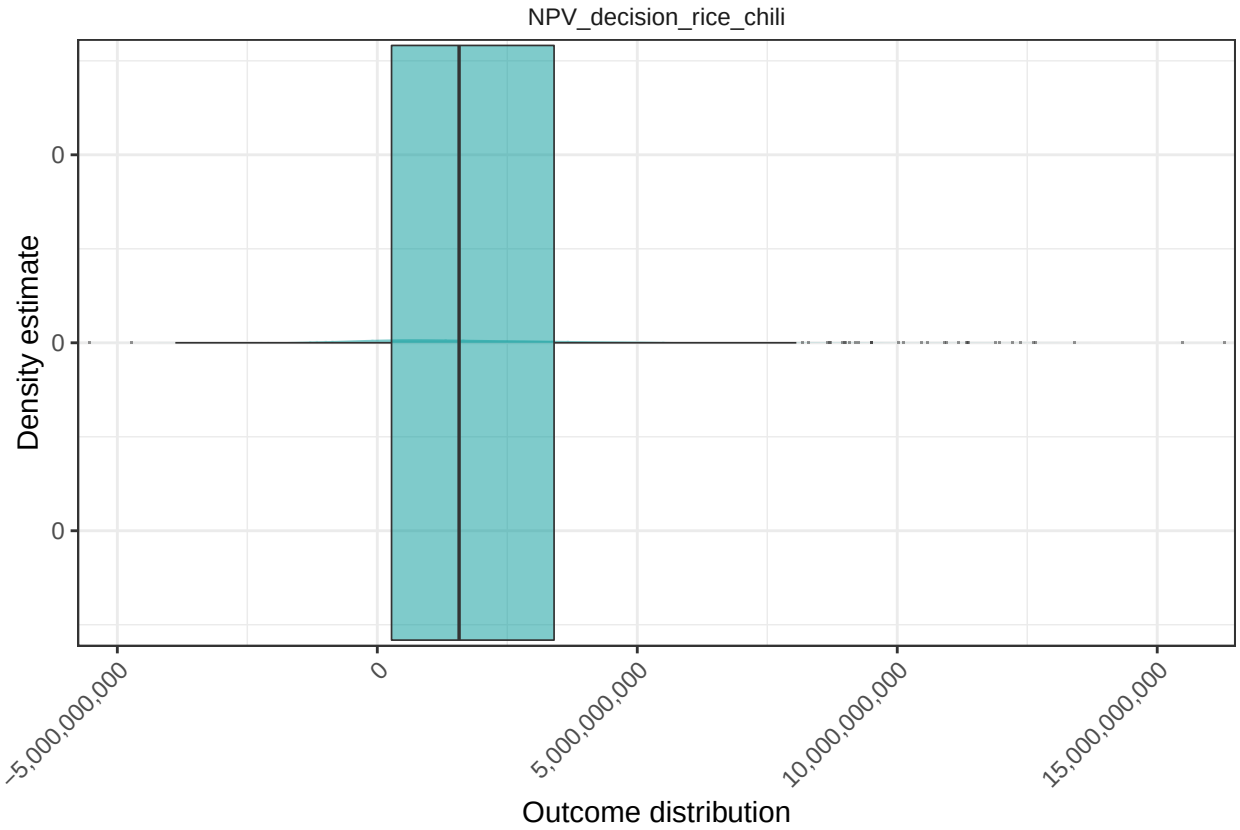
NPV for crop rotation (rice-chilli)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_chili_NPV","Rice_NPV"),
                                    method = 'boxplot')
```



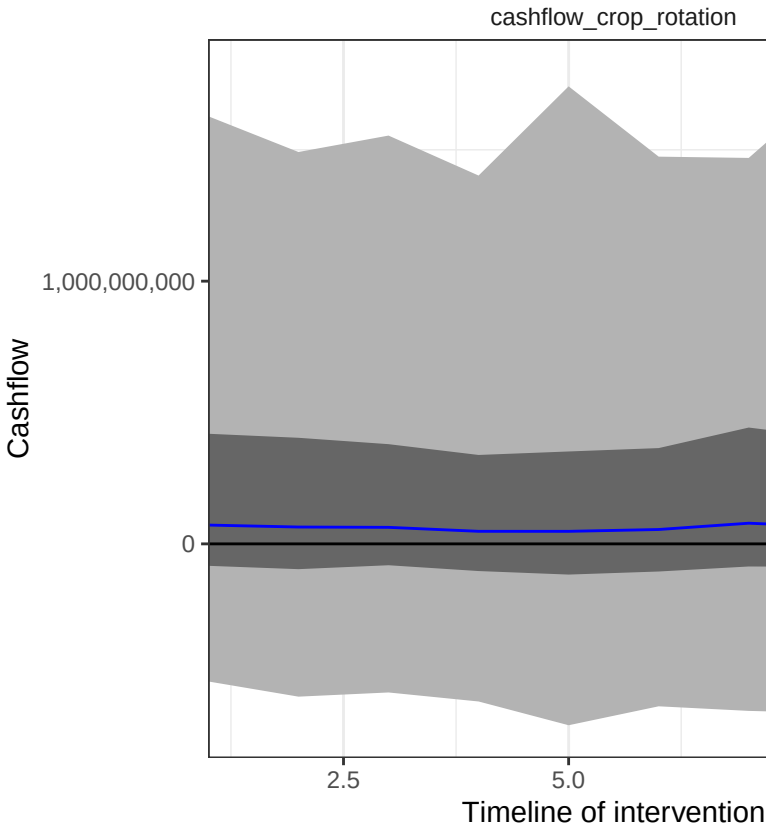

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_rice_chili"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a ‘group‘ aesthetic or to convert a numerical
##   variable into a factor?
```



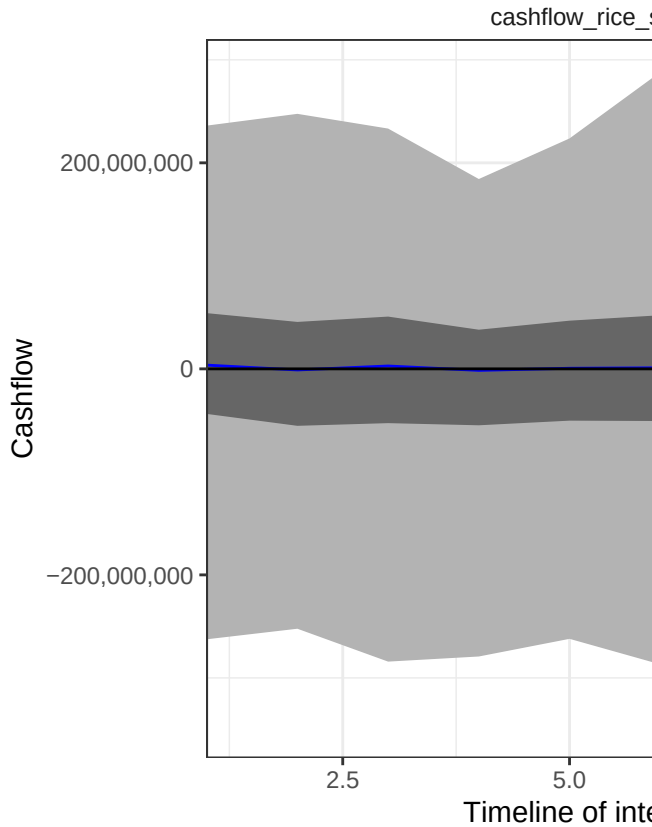
Cashflow analysis

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_crop_rota
```



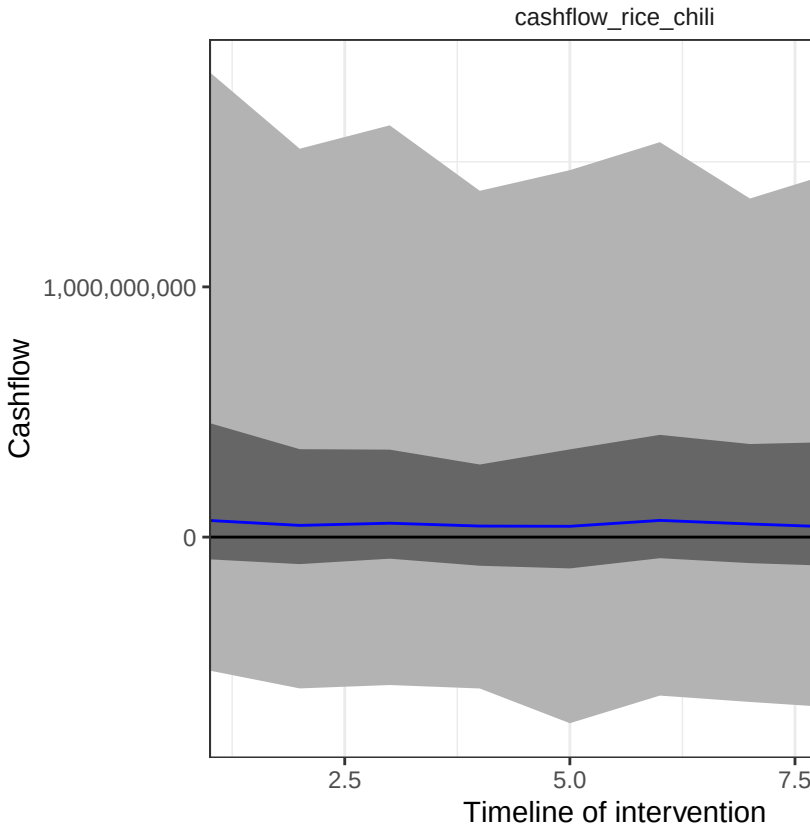
With crop rotation of 3 crops (rice-soybean-chili)

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_rice_soyb
```



With crop rotation of rice and soybean (rice-soybean-rice)

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_rice_chi
```



With crop rotation of rice and chili (rice-chili)

Value of Information (VoI) analysis

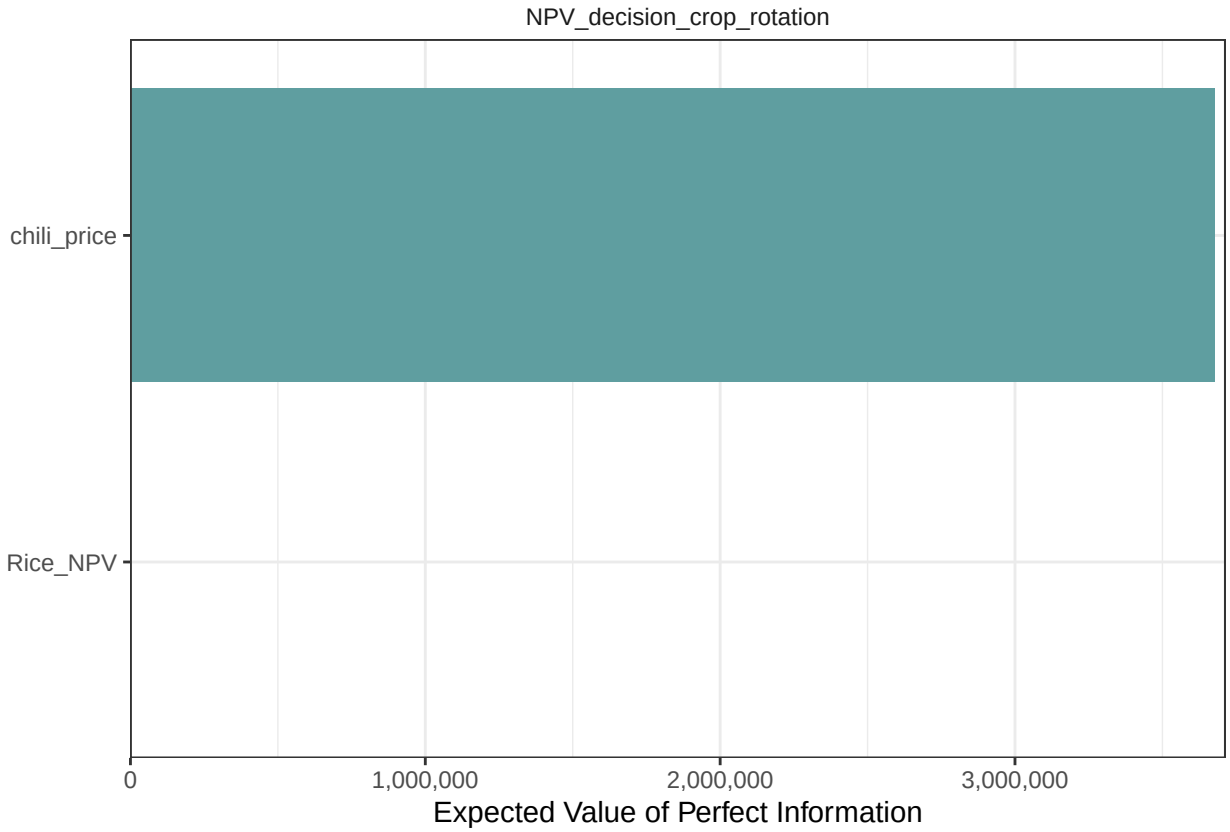
```
mcSimulation_table <- data.frame(crop_rotation_mc_simulation$x, crop_rotation_mc_simulation$y[1:7])
```

```
evpi_crop_rotation <- multi_EVPI(mc = mcSimulation_table, first_out_var = "crop_rotation_NPV")
```

EVPI crop rotation

```
## [1] "Processing 6 output variables. This can take some time."
## [1] "Output variable 1 (crop_rotation_NPV) completed."
## [1] "Output variable 2 (rice_soybean_NPV) completed."
## [1] "Output variable 3 (rice_chili_NPV) completed."
## [1] "Output variable 4 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 5 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 6 (NPV_decision_rice_chili) completed."
```

```
plot_evpi(evpi_crop_rotation, decision_vars = "NPV_decision_crop_rotation")
```

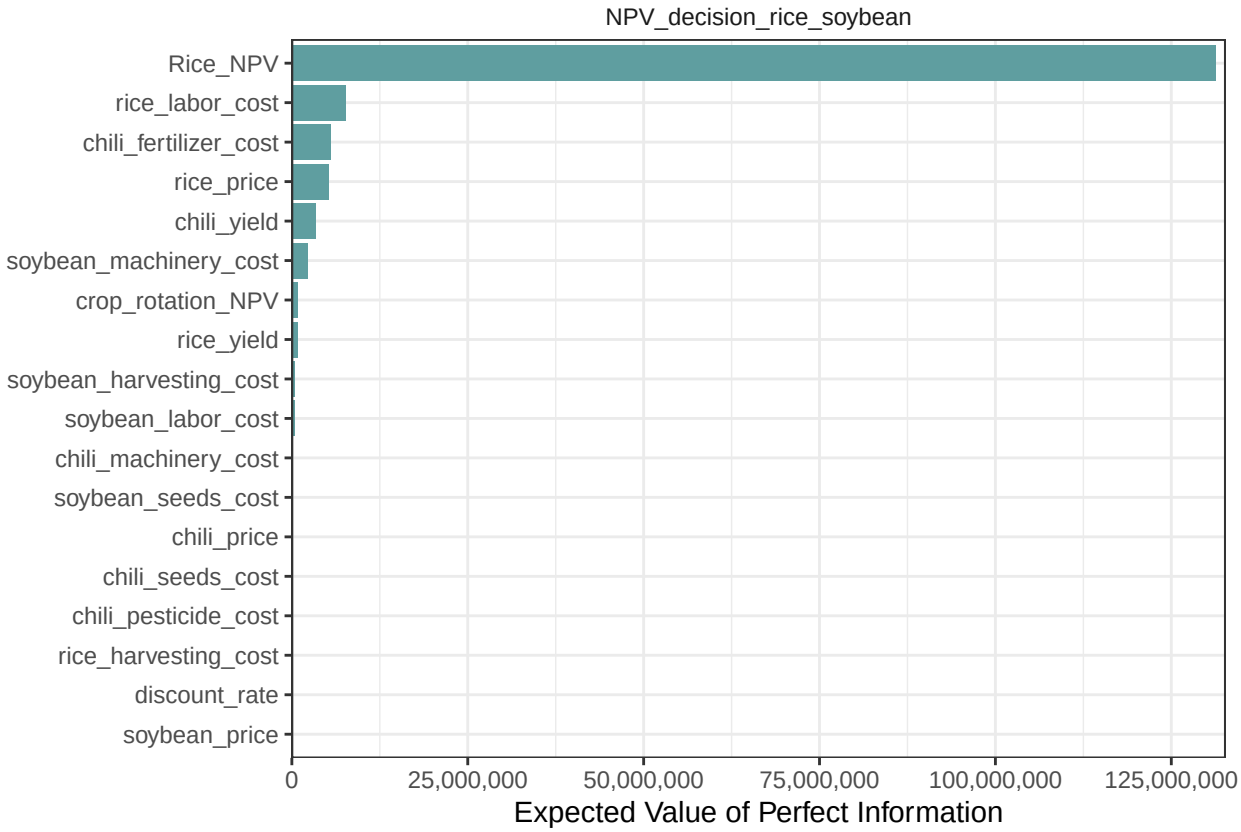



```
evpi_rice_soybean <- multi_EVPI(mc = mcSimulation_table, first_out_var = "rice_soybean_NPV")
```

EVPI rice and soybean

```
## [1] "Processing 5 output variables. This can take some time."
## [1] "Output variable 1 (rice_soybean_NPV) completed."
## [1] "Output variable 2 (rice_chili_NPV) completed."
## [1] "Output variable 3 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 4 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 5 (NPV_decision_rice_chili) completed."
```

```
plot_evpi(evpi_rice_soybean, decision_vars = "NPV_decision_rice_soybean")
```

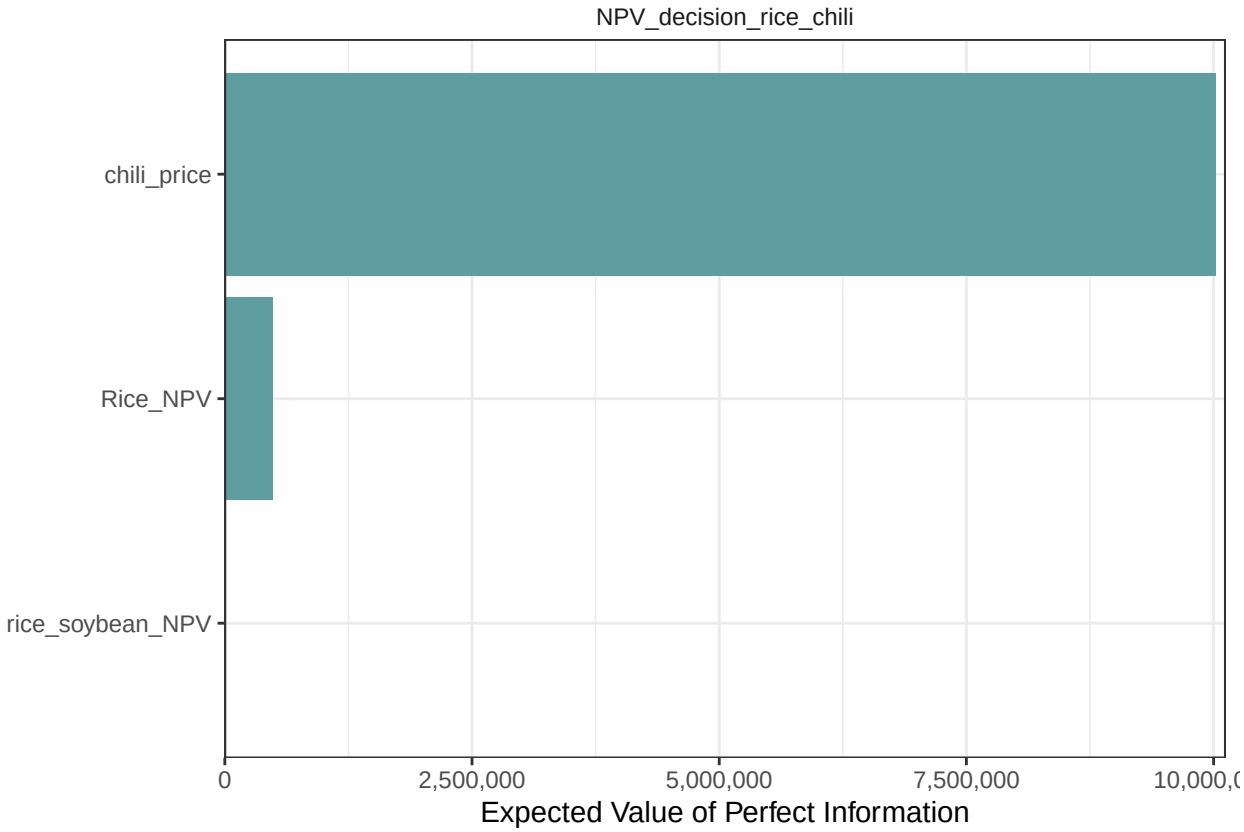



```
evpi_rice_chili <- multi_EVPI(mc = mcSimulation_table, first_out_var = "rice_chili_NPV")
```

EVPI rice and chilli

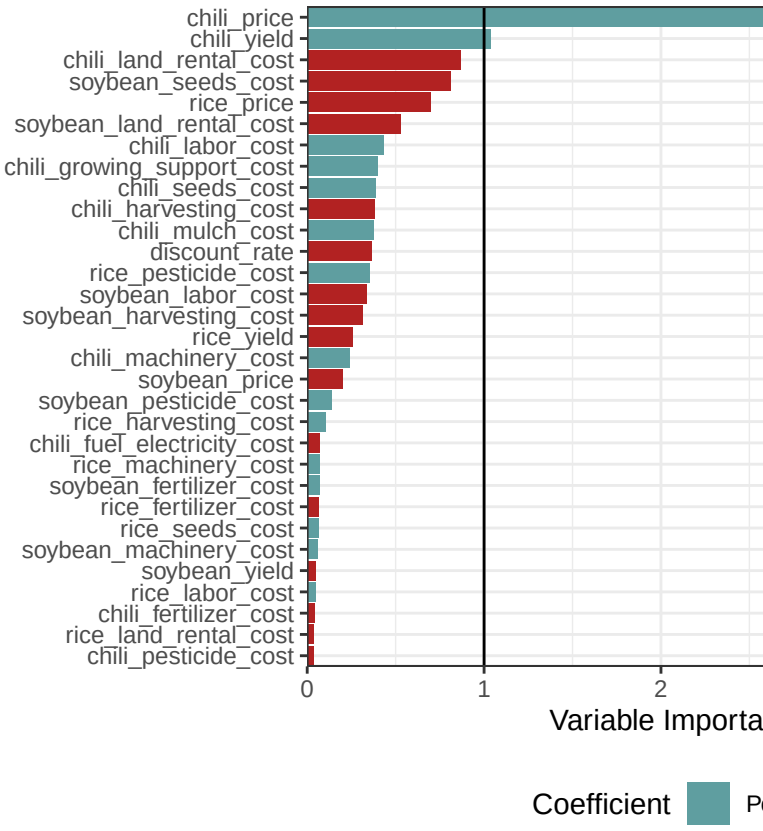
```
## [1] "Processing 4 output variables. This can take some time."
## [1] "Output variable 1 (rice_chili_NPV) completed."
## [1] "Output variable 2 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 3 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 4 (NPV_decision_rice_chili) completed."
```

```
plot_evpi(evpi_rice_chili, decision_vars = "NPV_decision_rice_chili")
```



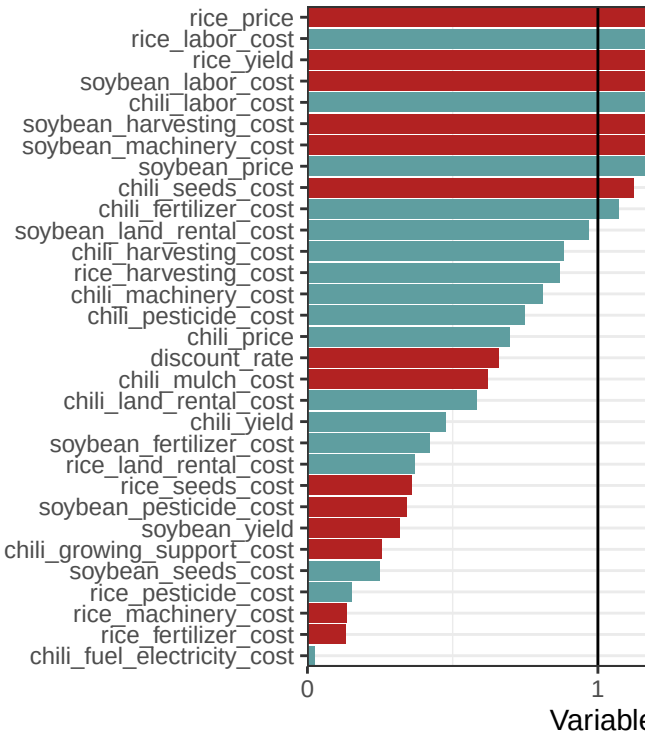
Projection to Latent Structures (PLS) analysis

```
pls_result_crop_rotation <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                              resultName = names(crop_rotation_mc_simulation$y)[5], nco
plot_pls(pls_result_crop_rotation, threshold = 0)
```



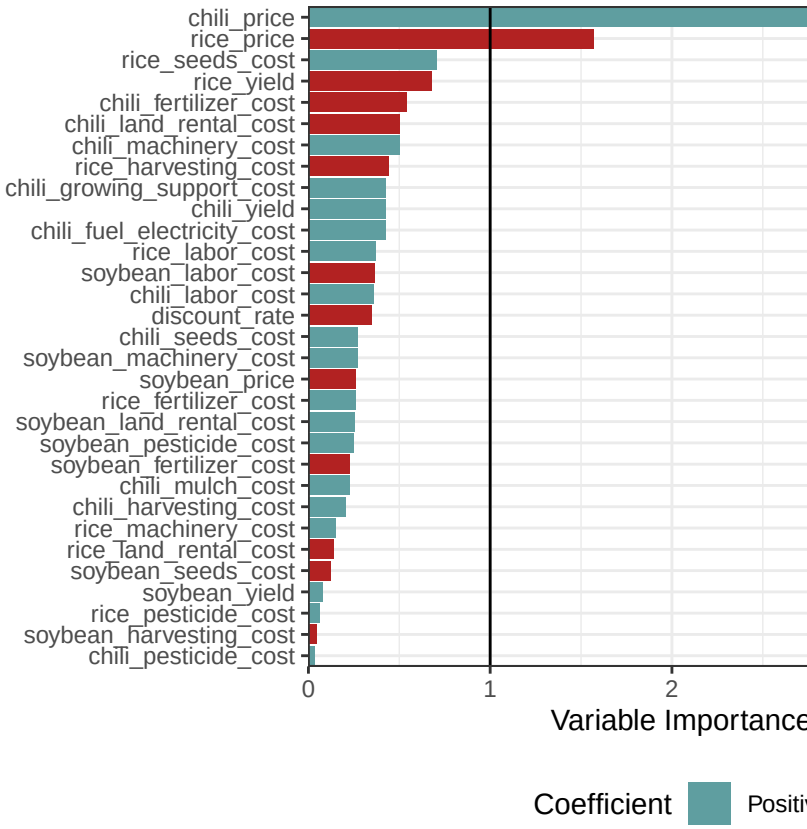
With crop rotation of 3 crops (rice-soybean-chili)

```
pls_result_rice_soybean <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                             resultName = names(crop_rotation_mc_simulation$y)[6], ncomp
plot_pls(pls_result_rice_soybean, threshold = 0)
```



With crop rotation of rice and soybean (rice-soybean-rice)

```
pls_result_rice_chili <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                           resultName = names(crop_rotation_mc_simulation$y)[7], ncomp =
plot_pls(pls_result_rice_chili, threshold = 0)
```

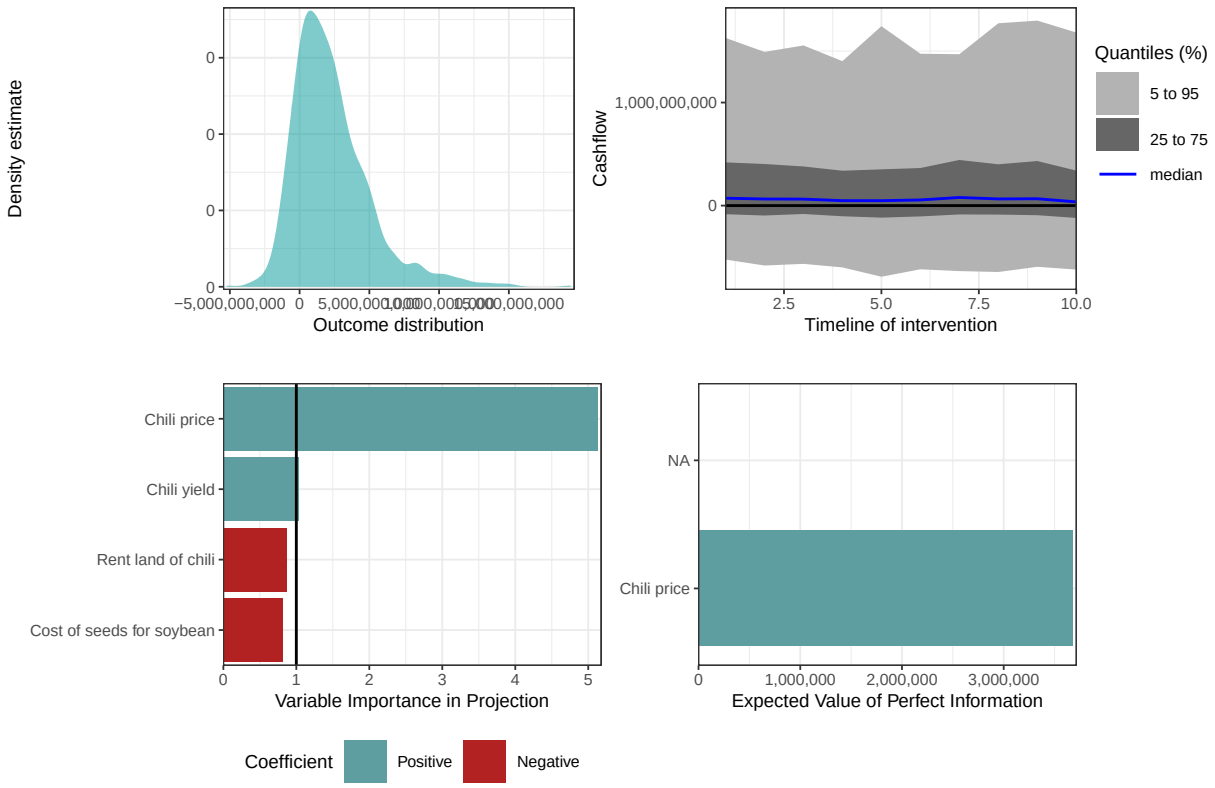


With crop rotation of rice and chili (rice-chili)

Results

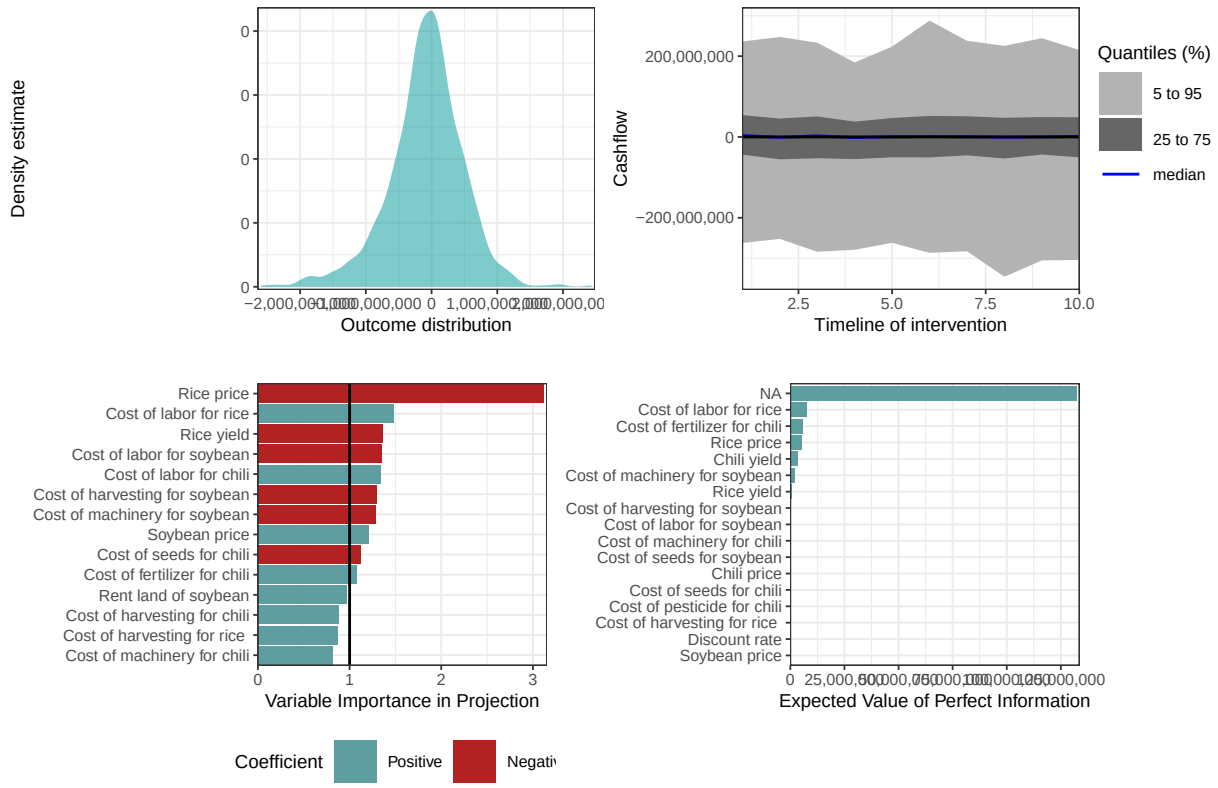
With crop rotation of 3 crops (rice-soybean-chili)

```
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_crop_rotation,
                EVPIresults = evpi_crop_rotation, decision_var_name = "NPV_decision_crop_rotation",
                cashflow_var_name = "cashflow_crop_rotation",
                base_size = 7)
```



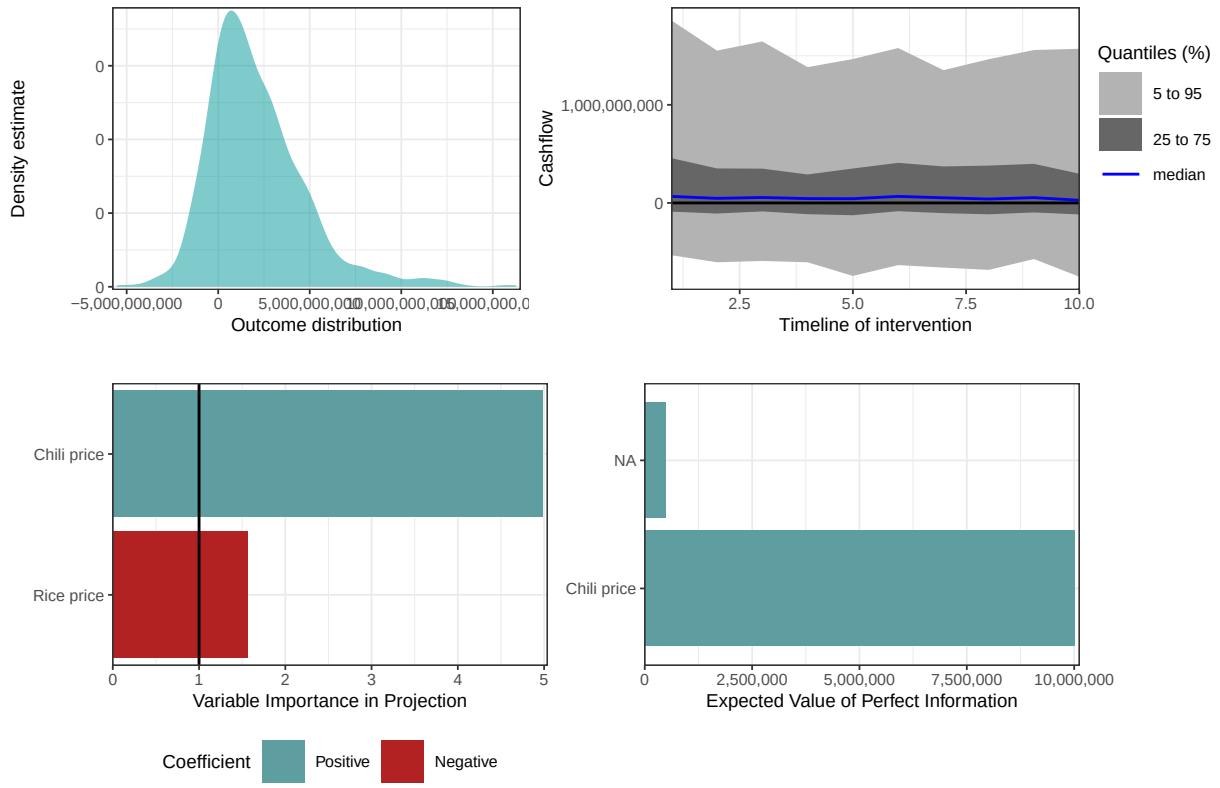
With crop rotation of rice and soybean (rice-soybean-rice)

```
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_rice_soybean,
                EVPIresults = evpi_rice_soybean, decision_var_name = "NPV_decision_rice_soybean",
                cashflow_var_name = "cashflow_rice_soybean",
                base_size = 7)
```



With crop rotation of rice and chili (rice-chili)

```
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_rice_chili,
                EVPIresults = evpi_rice_chili, decision_var_name = "NPV_decision_rice_chili",
                cashflow_var_name = "cashflow_rice_chili",
                base_size = 7)
```



Conclusion

1. This project has proven that selecting the appropriate crop rotation between rice, soybean, and chili seems profitable for achieving optimal results with respect to higher income for rice farming.
2. The decision to rotate crops between rice and chili is still applicable, with slightly smaller profits.
3. Crop rotation between rice and soybean is less efficient than other options with respect to sustainable income.

Recommendation

1.We **recommend** Indonesian smallholder farmers to implement crop rotation either for three crops **(rice, soybean, and chili)** or two crops **(rice and chili)** as it seems more profitable than growing rice only all year around.

2.However, we would **not recommend** to implement crop rotation between **rice and soybean** as it seems not so profitable.

What we have learned from this project?

1. Rice farming with crop rotation of soybean and chili can be implemented by Indonesian smallholder farmers to get a higher income.
2. However, not every crop is profitable to rotate with rice.
3. There are more uncertainties in the crop rotation of rice and soybeans compared to other scenarios. Thus, further data and research are still needed.

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