Week 4: Decisions in Settings with High Uncertainty

- Session 1 – Decision Trees
  - Example: Furniture maker IDEA Chooses a Supplier
- Session 2 – Using Simulation within Decision Trees
  - Example: More Complex Demand Distributions for IDEA
- Session 3 – Using Optimization Together with Simulation
  - Example: IDEA Chooses Order Quantities
- Session 4 – Wrap Up
  - Example: Back to the Newsvendor Problem

Simple Example: IDEA, a Scandinavian furniture retailer

- IDEA plans to introduce a gazebo tent, Krusbär
  - Sold next summer in Scandinavia for a price of (the equivalent of) 150€
  - Manufactured in advance, next spring and summer

- At a 150€ price there is uncertainty regarding the demand for Krusbär
  - There's a 50% / 50% chance that sales will be weak or strong
  - If sales are strong, IDEA will be able to sell 10,000 units
  - If sales are weak, IDEA will be able to sell 5,000 units

- This is demand distribution is simple and lets us focus on the analysis
  - We'll consider more complex distributions later this week.

- IDEA is considering two potential suppliers to manufacture Krusbär
  - One is in Sweden (S) and the other is in Poland (P)
  - Each requires that IDEA uses 100% of its capacity
  - IDEA will contract with at most one of the two suppliers

The choice of supplier affects capacity and costs

- Capacity, fixed up-front cost, and contribution for each supplier

	Sweden (S)	Poland (P)
Supplier Capacity / Order Quantity	5,000 units	10,000 units
Up-Front Charge by Supplier	0€	50,000€
Unit Price	150€	150€
Labor costs	60€	30€
Material Costs	40€	40€
Shipping	20€	30€
Unit Cost	120€	100€
Unit Contribution	30€	50€

(all currency translated into euros)

A decision tree is useful for representing IDEA's choices

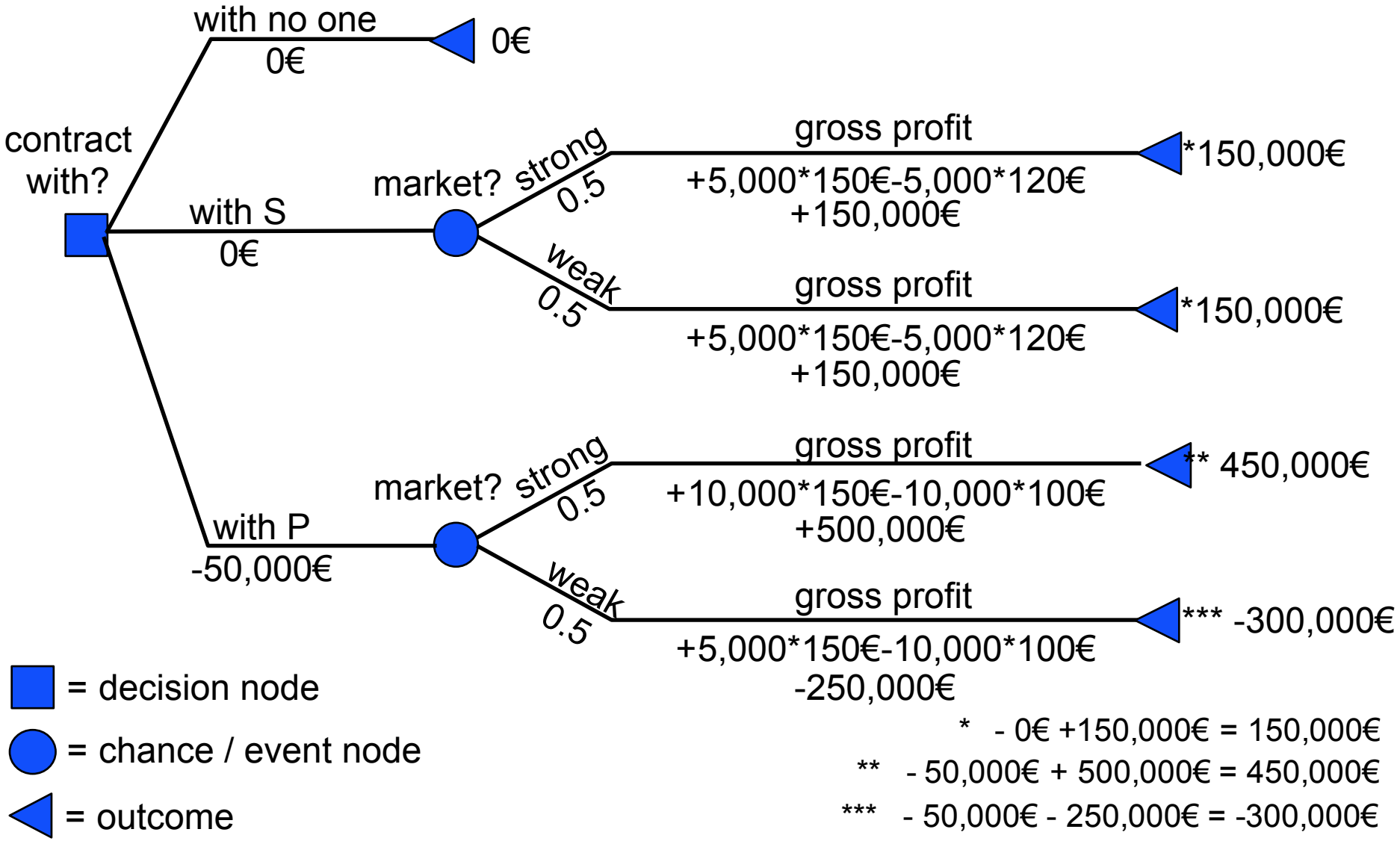
- The structure of the tree is made of three building blocks

- "Decision" Nodes 
  - Points at which a decision-maker must decide on an action
  - For IDEA this is which supplier to select, if any

- "Event" or "Chance" nodes 
  - Points of uncertainty at which the outcome is random
  - For IDEA these are whether the market is weak or strong

- Outcomes 
  - Payouts that occur due to specific sequences of decisions and events
  - For IDEA these are its profits
    - Profits depend on which supplier is chosen
    - And profits also depend on whether the market is weak or strong.

A decision tree is useful to represent IDEA's choices

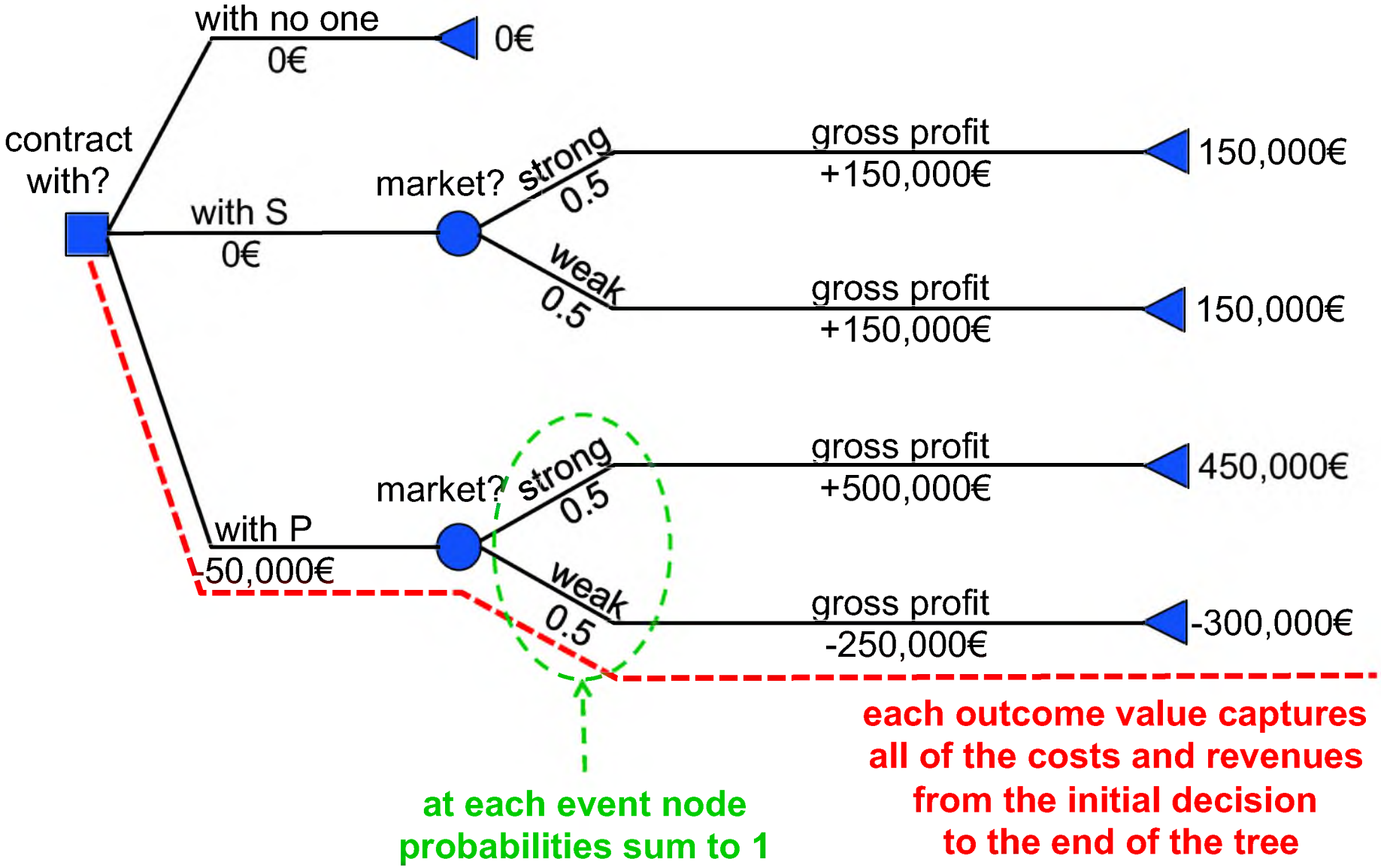


* - 0€ +150,000€ = 150,000€

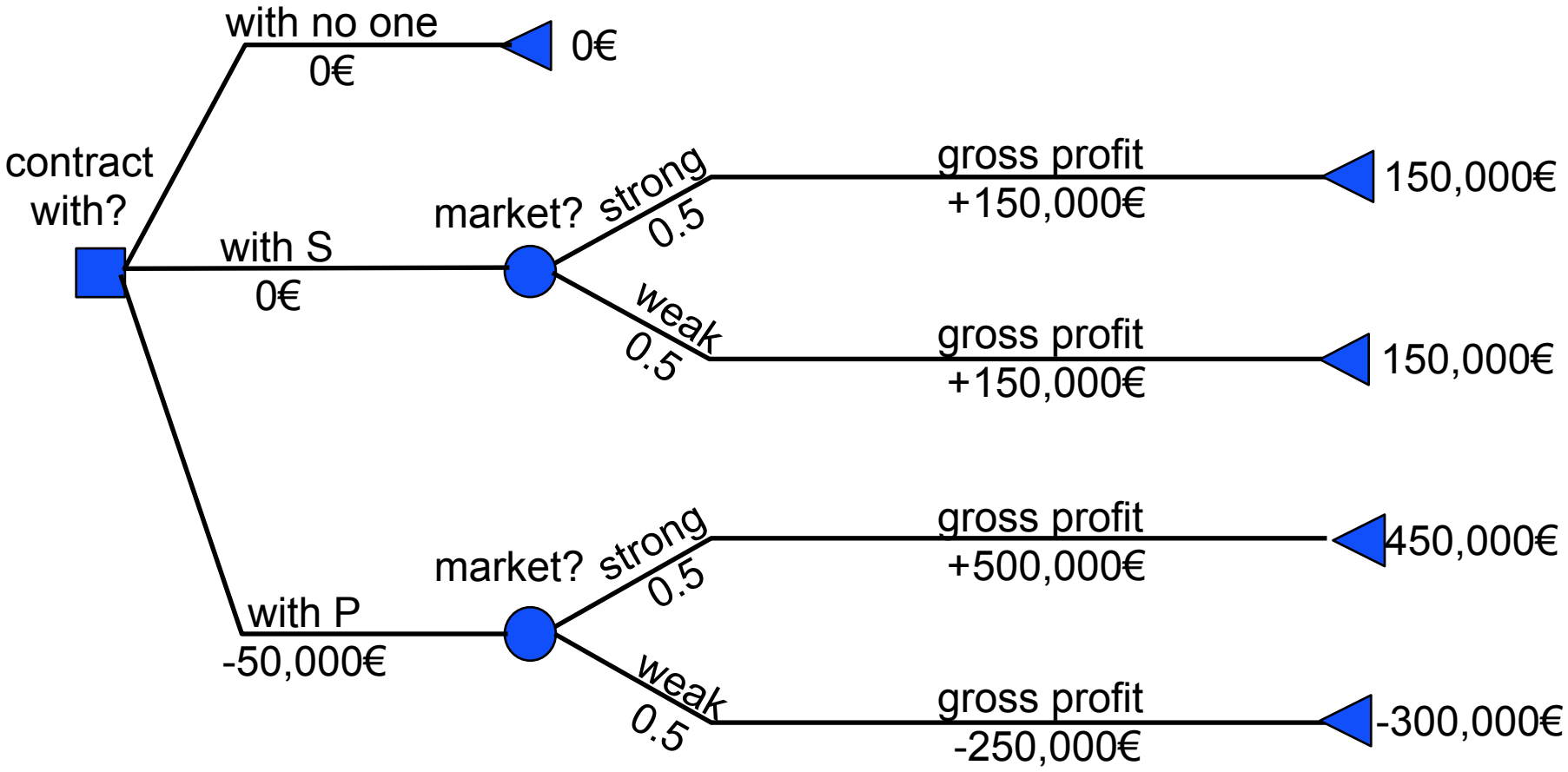
** - 50,000€ + 500,000€ = 450,000€

*** - 50,000€ - 250,000€ = -300,000€

Two facts to remember when constructing a tree



Just looking at a finished tree provides information



- Outcome ranges and probabilities give a sense of the riskiness of a choice

Three common approaches for evaluating the options

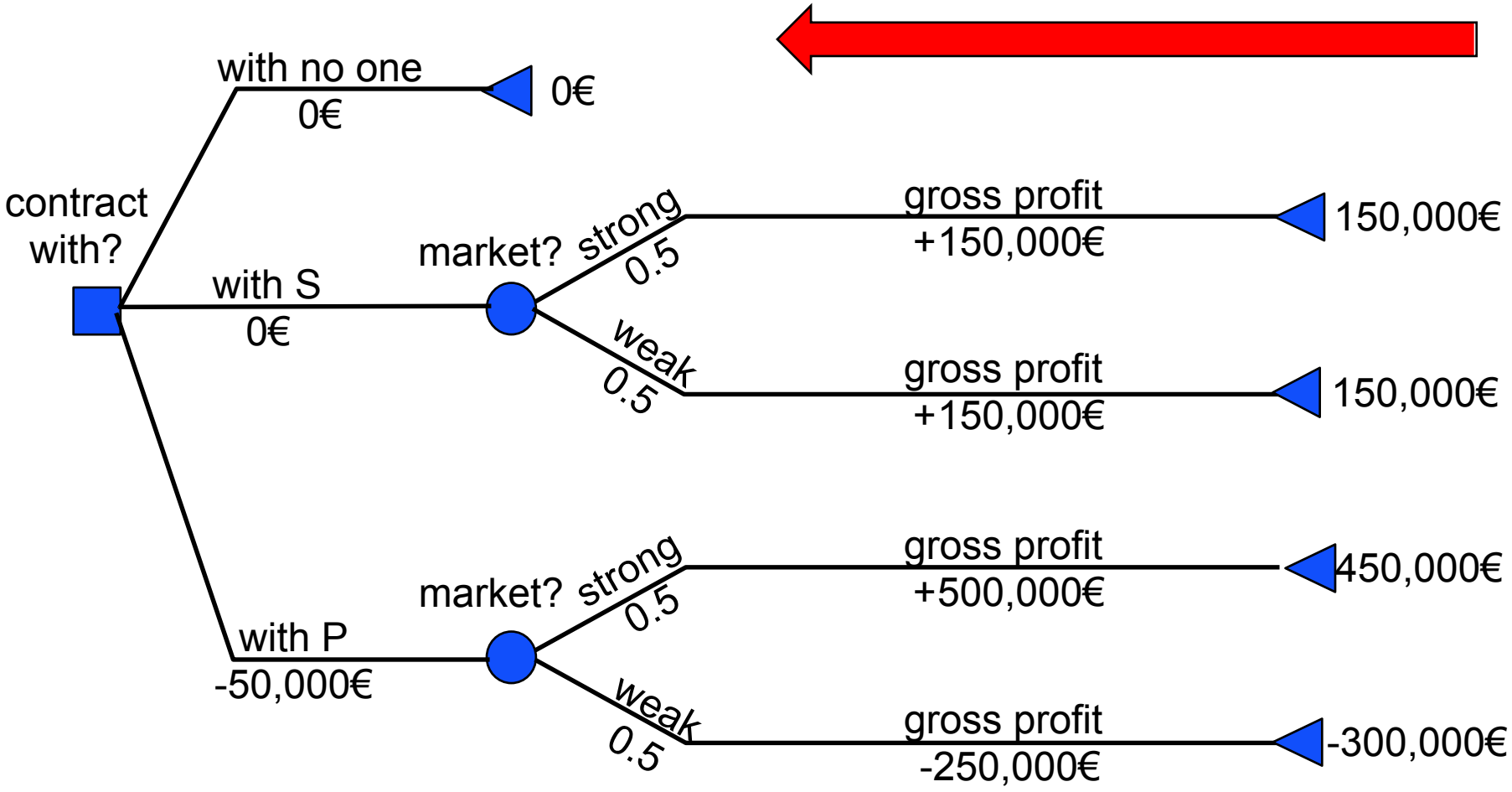
- "Maxi-min" strategy
  - Choose the actions that maximize the minimum outcome
  - Avoids bad outcomes…and…ignores the possibility of good outcomes
  - "Risk averse" strategy
- "Maxi-max" strategy
  - Choose the actions that maximize the maximum outcome
  - Seeks good outcomes...and…ignores the possibility of bad outcomes
  - "Risk seeking" strategy
- Maximize the expected value of the outcomes
  - Gives equal weight to good and bad outcomes
  - "Risk neutral" strategy
- We can use IDEA's decision tree to determine each strategy

How to determine the maxi-min set of decisions

- Maxi-min decisions maximize the value of the minimum outcome
- We start at the tree's outcomes and work backward to its root
- At each event node, we find the outcome with the minimum value and replace the event node with that minimum value
- At each decision node, we choose the action that maximizes the associated value
- We can illustrate using IDEA's decision tree

How to determine the maxi-min set of decisions

- We start at the tree's outcomes and work backward to its root



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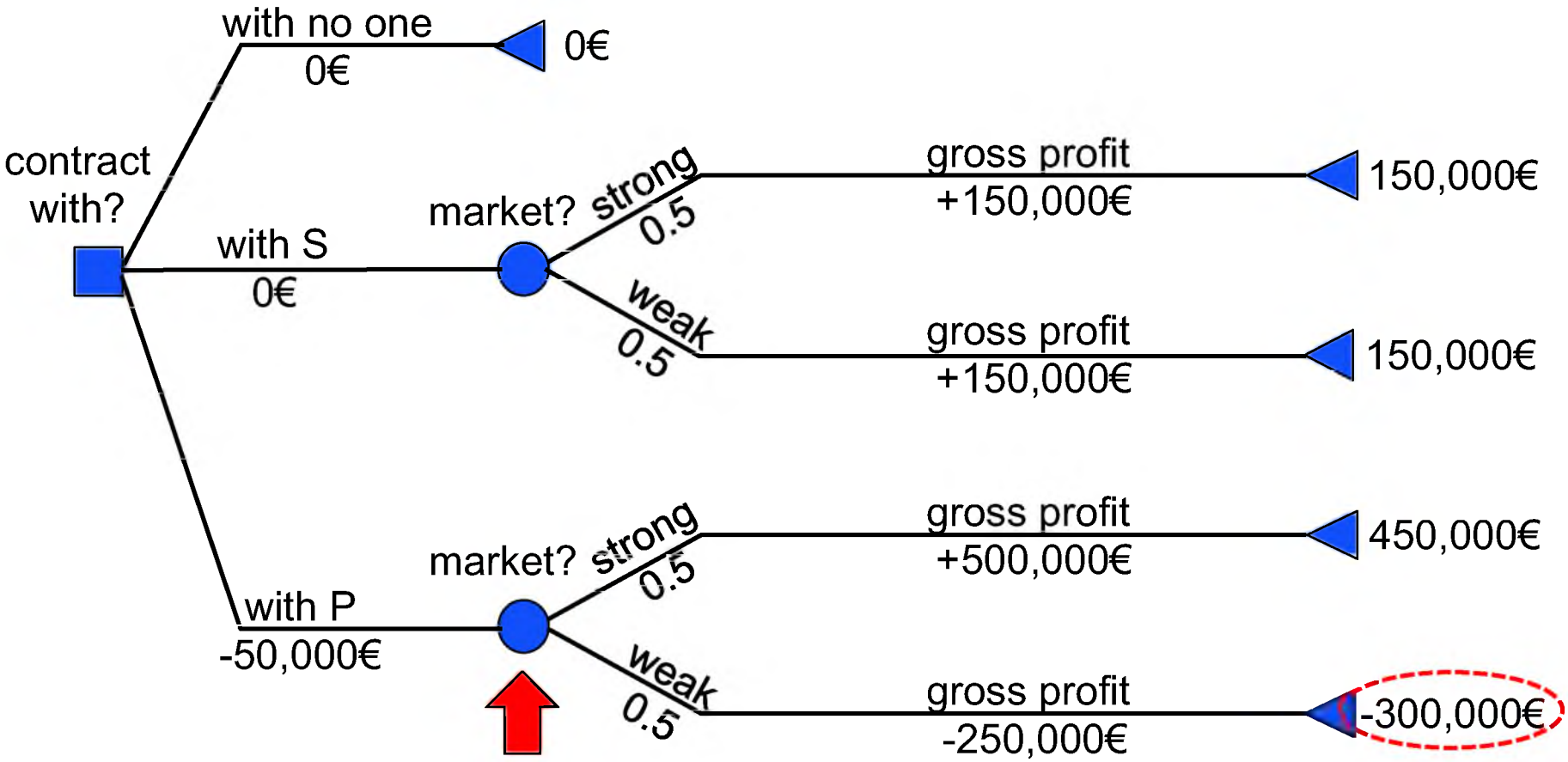

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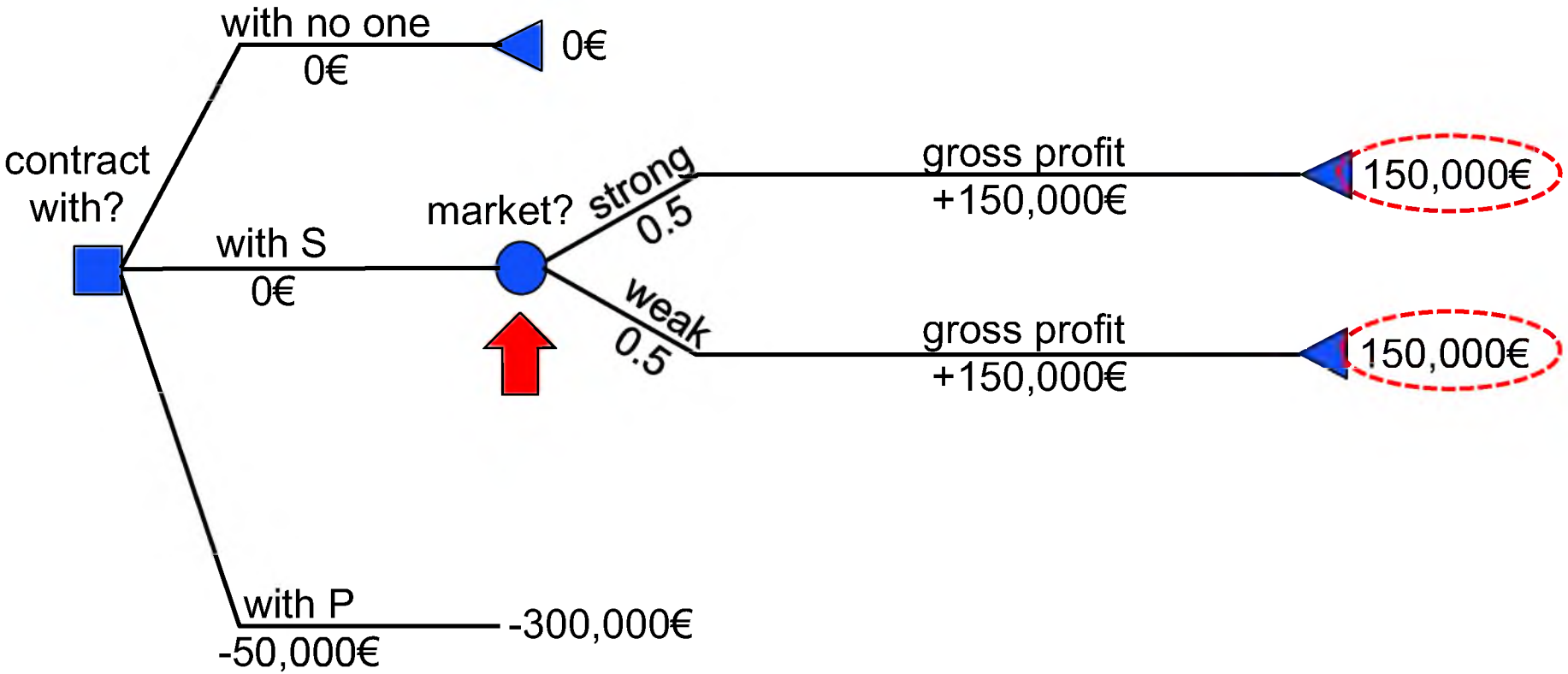

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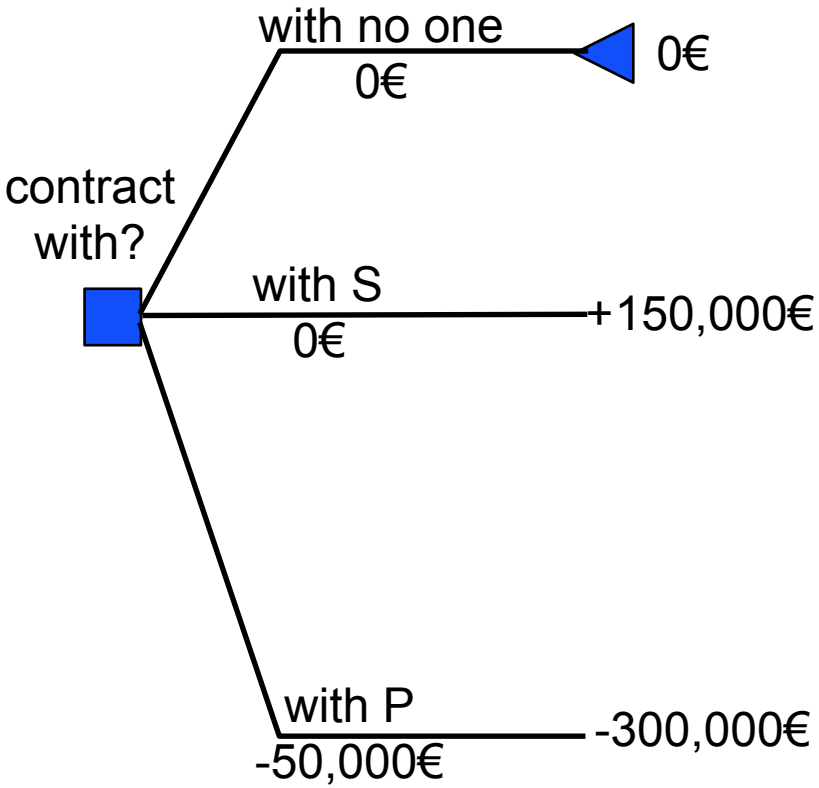

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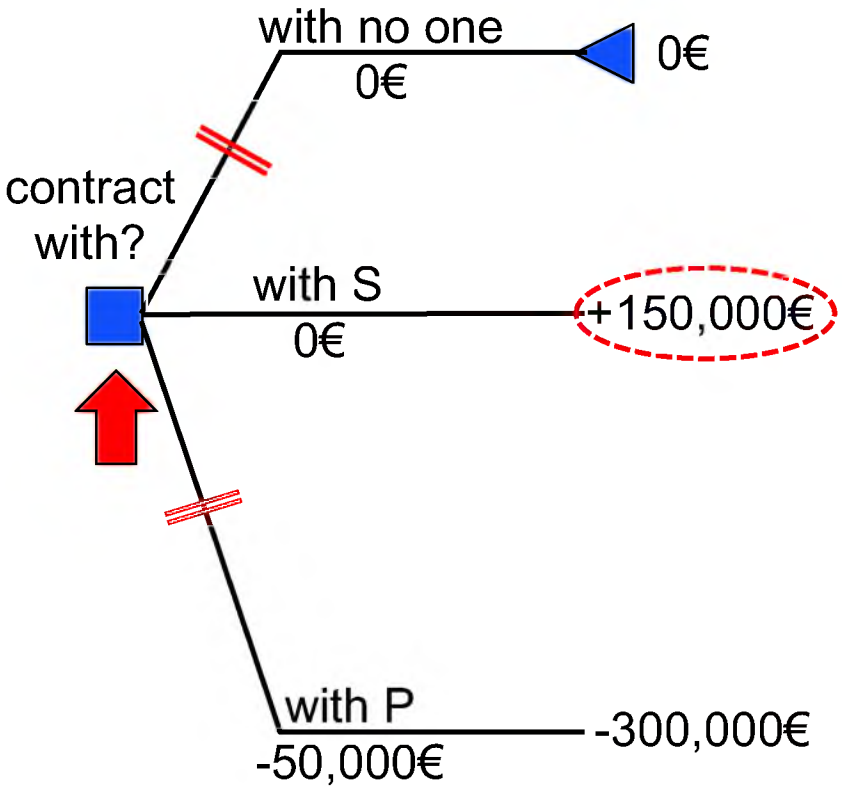
- At each decision node, we choose the action that maximizes the associated value



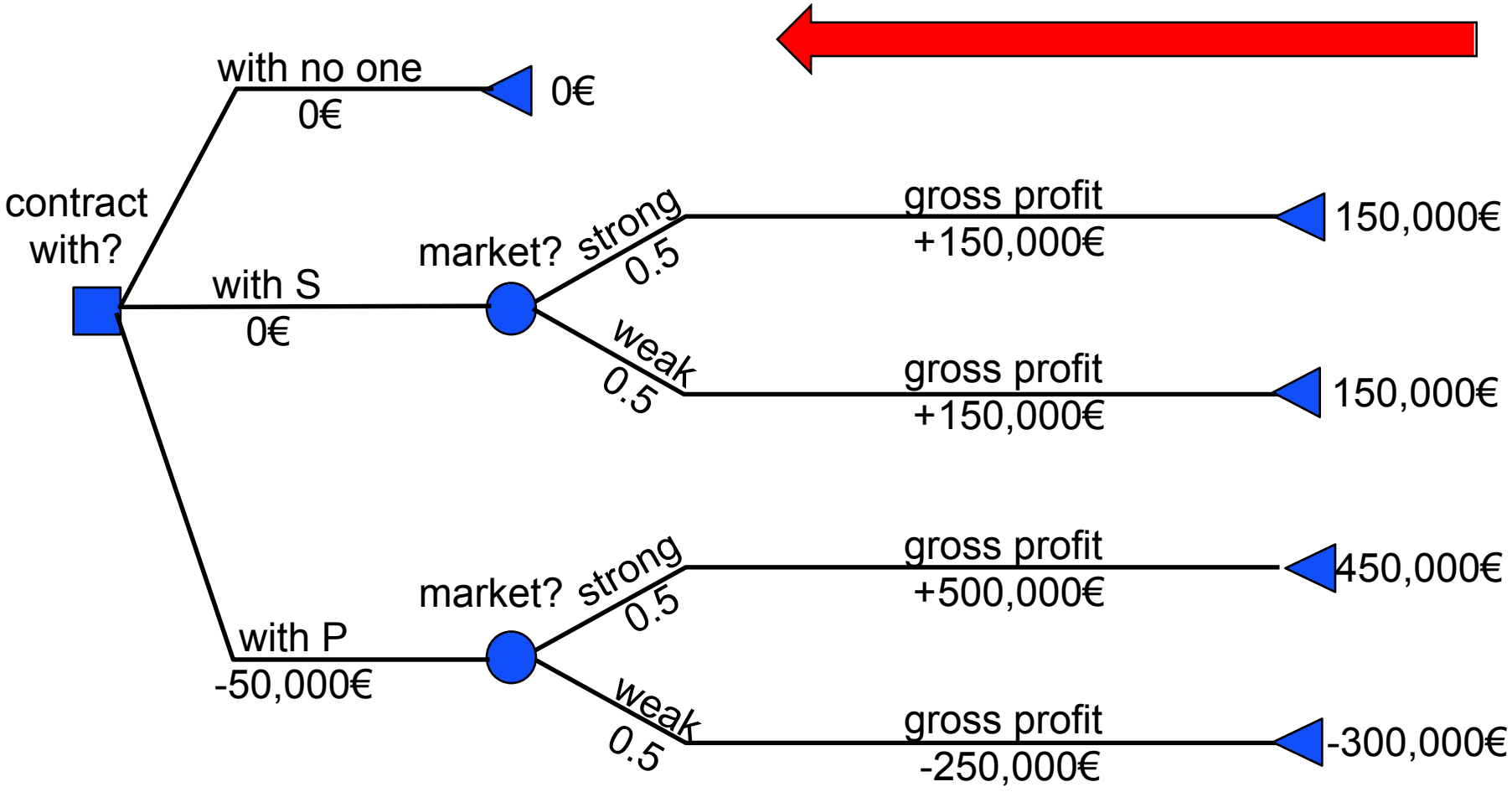
- The maxi-min strategy is to contract with Supplier S

How to determine the maxi-max set of decisions

- Maxi-max decisions maximize the value of the maximum outcome
- We start at the tree's outcomes and work backward to its root
- At each event node, we find the outcome with the maximum value and replace the event node with that maximum value
- At each decision node, we choose the action that maximizes the associated value

How to determine the maxi-max set of decisions

- As before, we start at the tree's outcomes and work backward to its root



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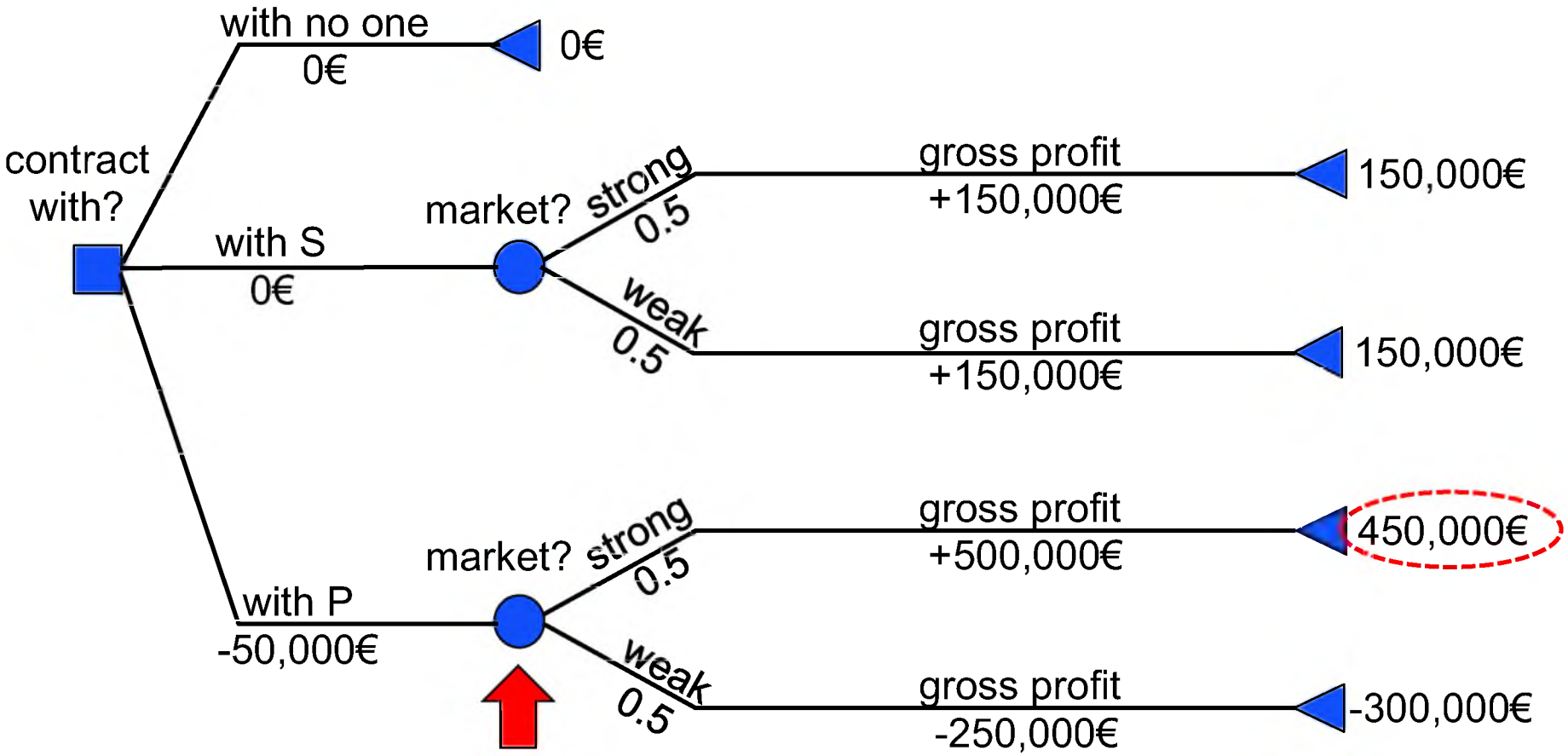

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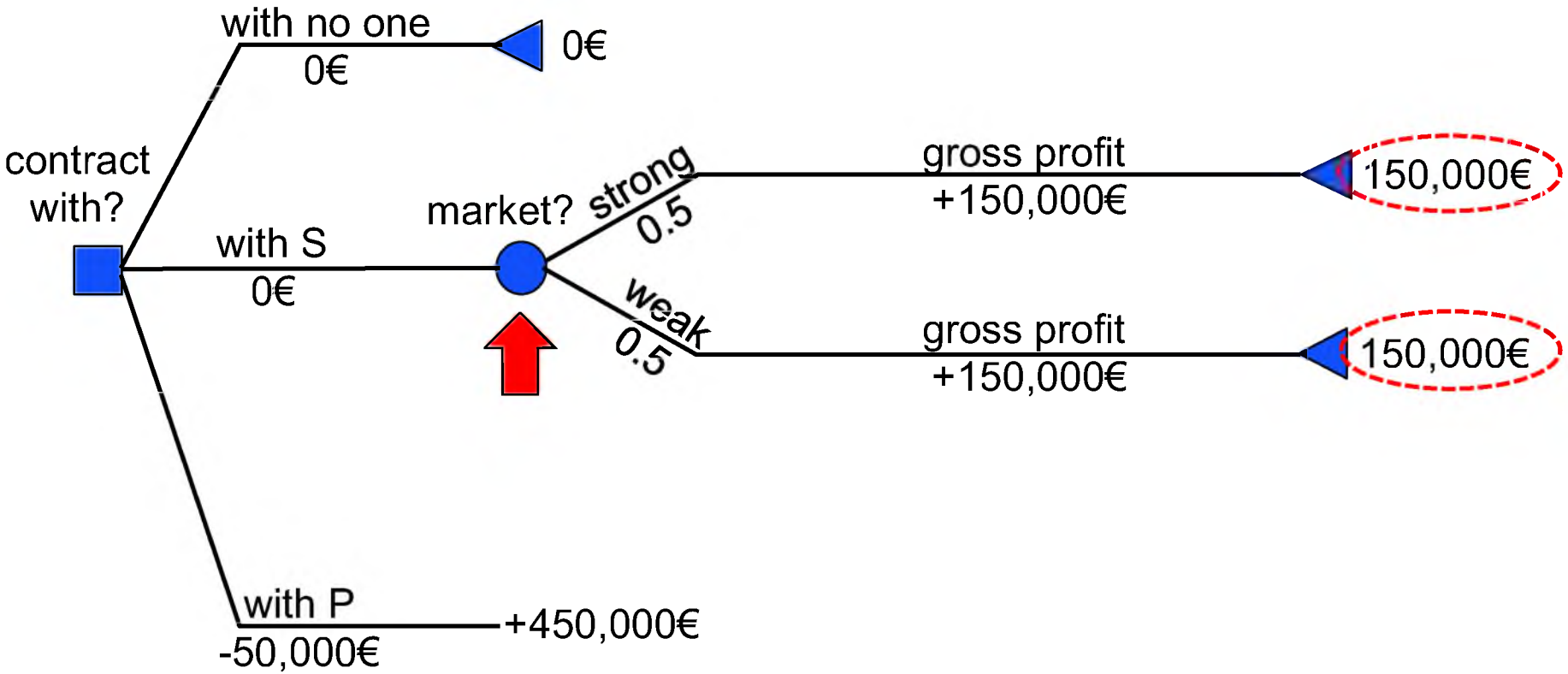

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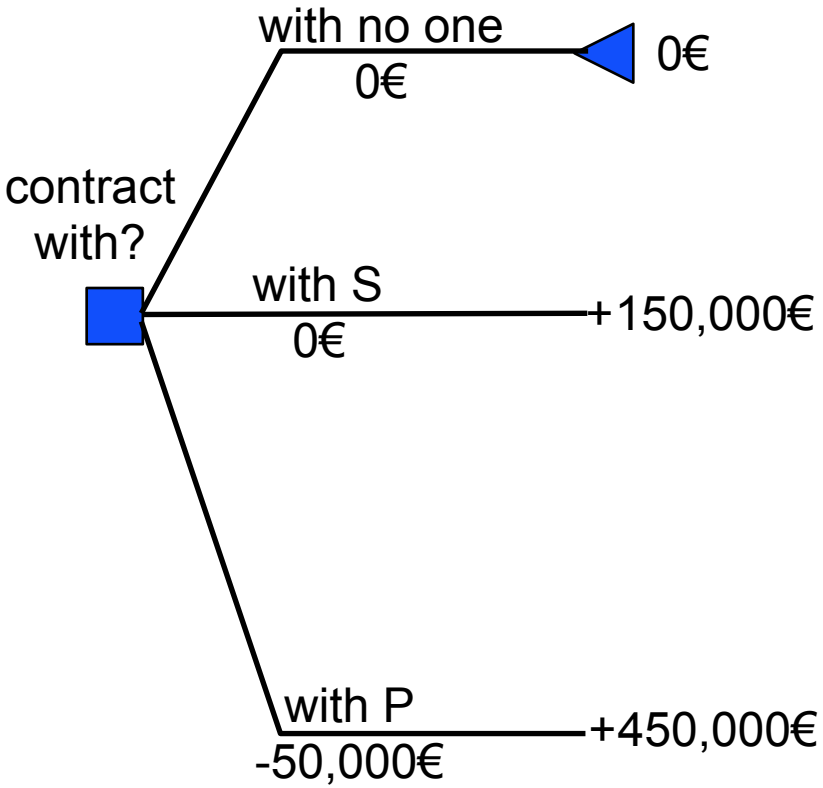

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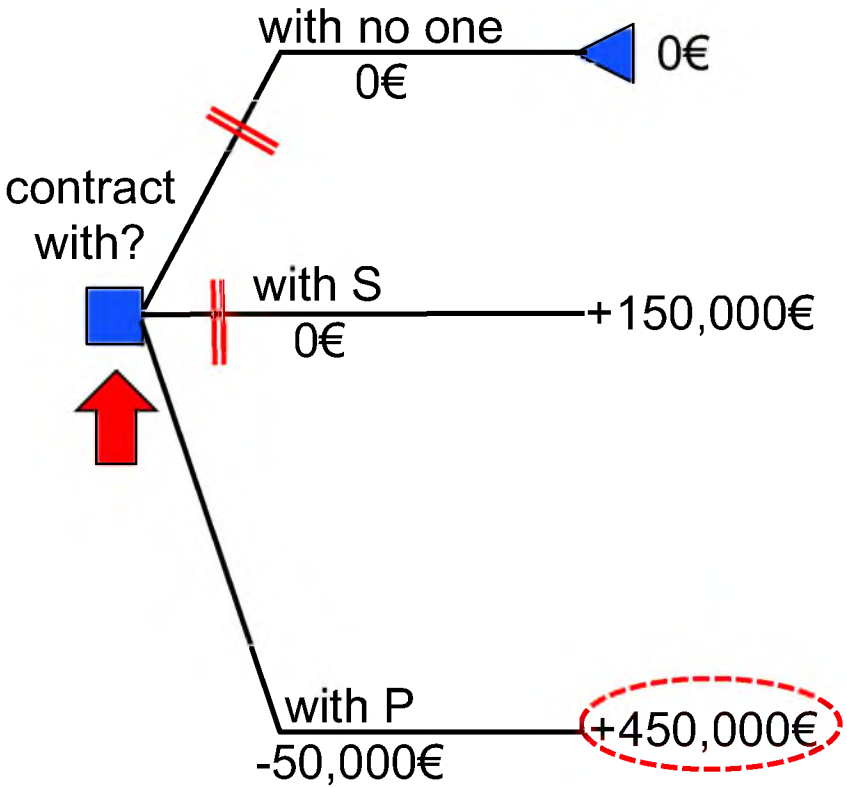


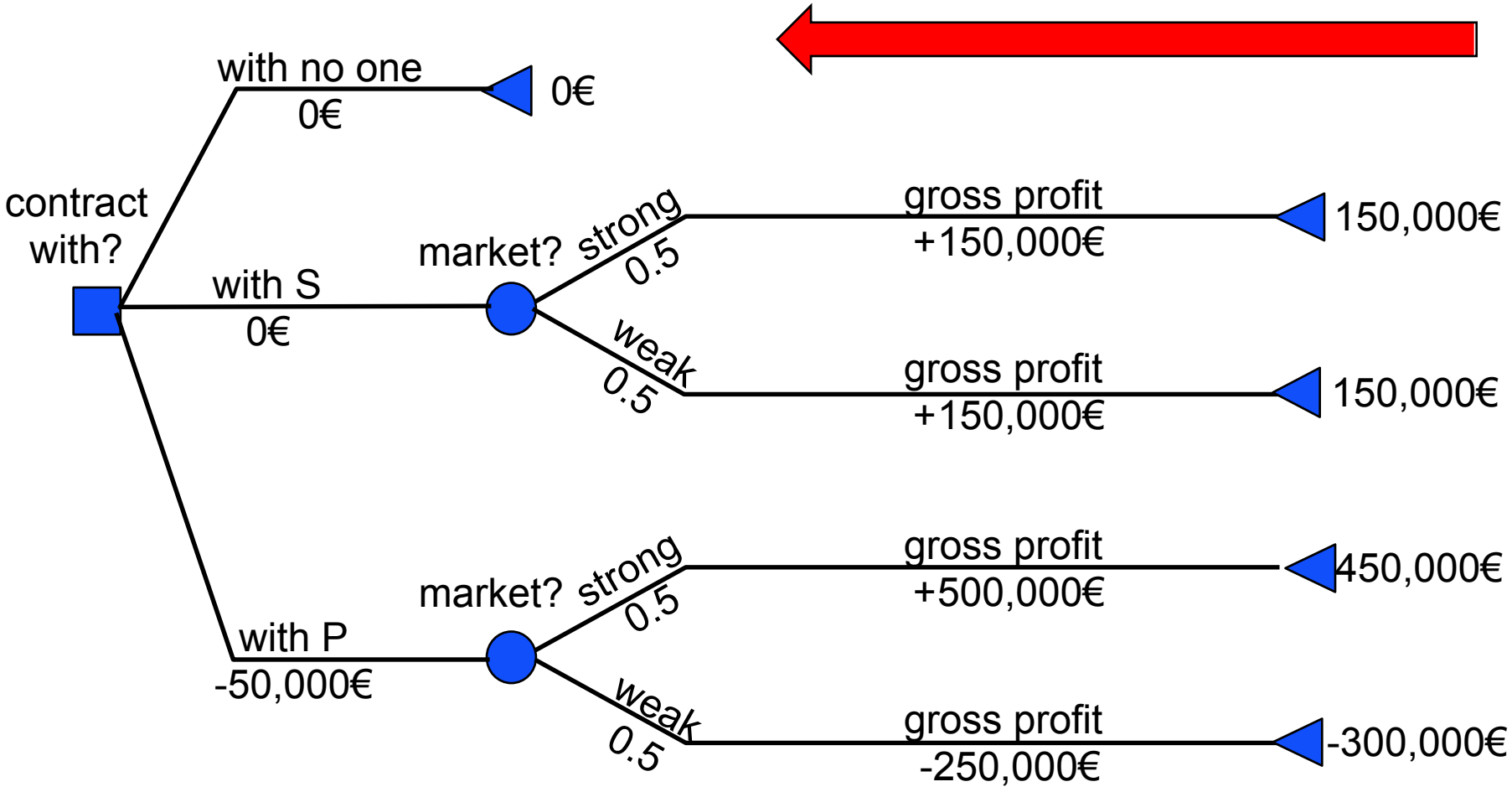
- The maxi-max strategy is to contract with Supplier P

Determining the expected value maximizing strategy

- We start at the tree's outcomes and work backward to its root
- At each event node, we calculate the expected value of the outcomes and replace the event node with the expected value
  - The expected value weights each outcome by the estimate estimate of the probability it will occur
- At each decision node, we choose the action that maximizes the associated value

Determining the expected value maximizing strategy

- As usual, we start at the tree's outcomes and work backward to its root



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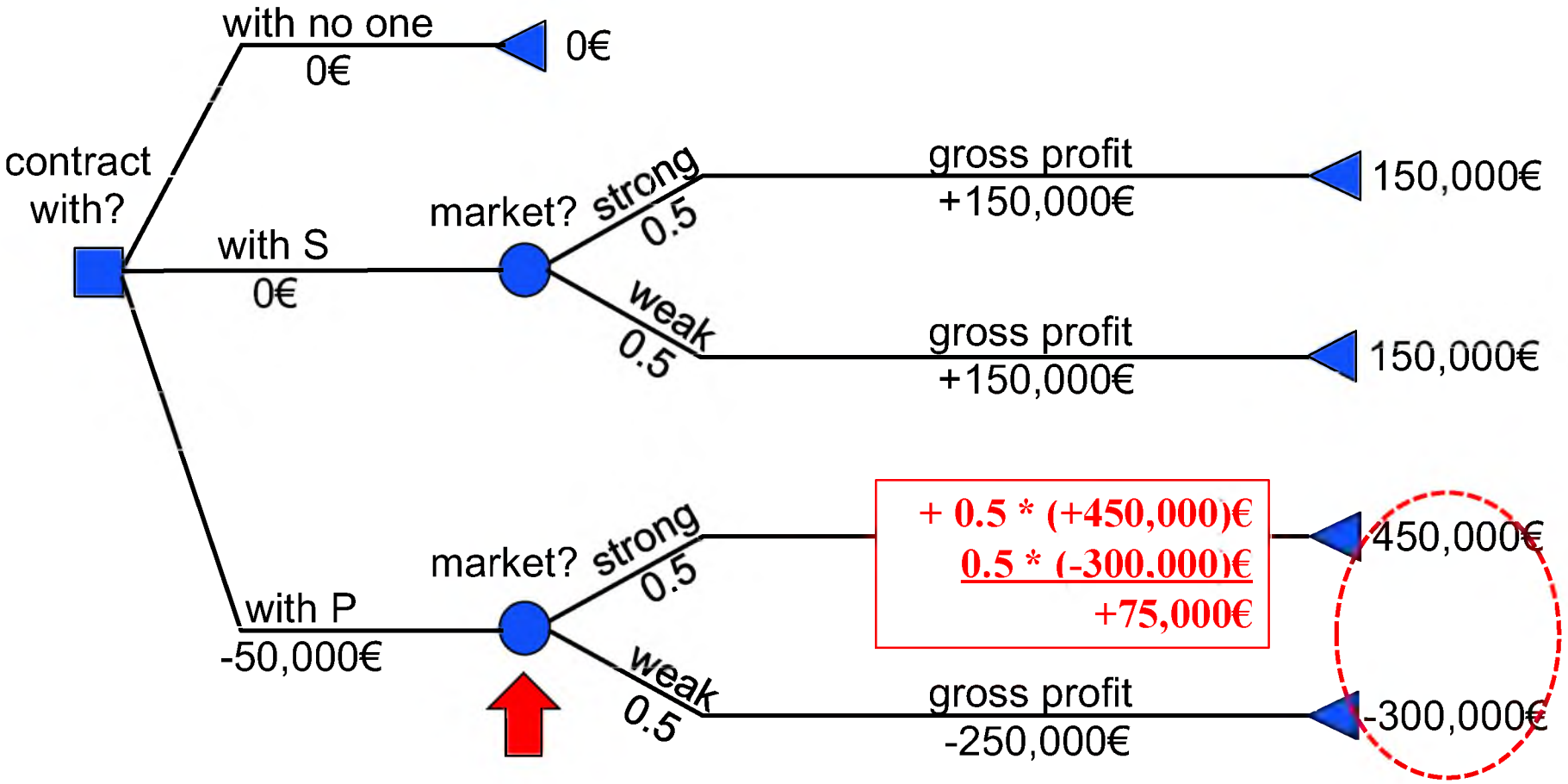

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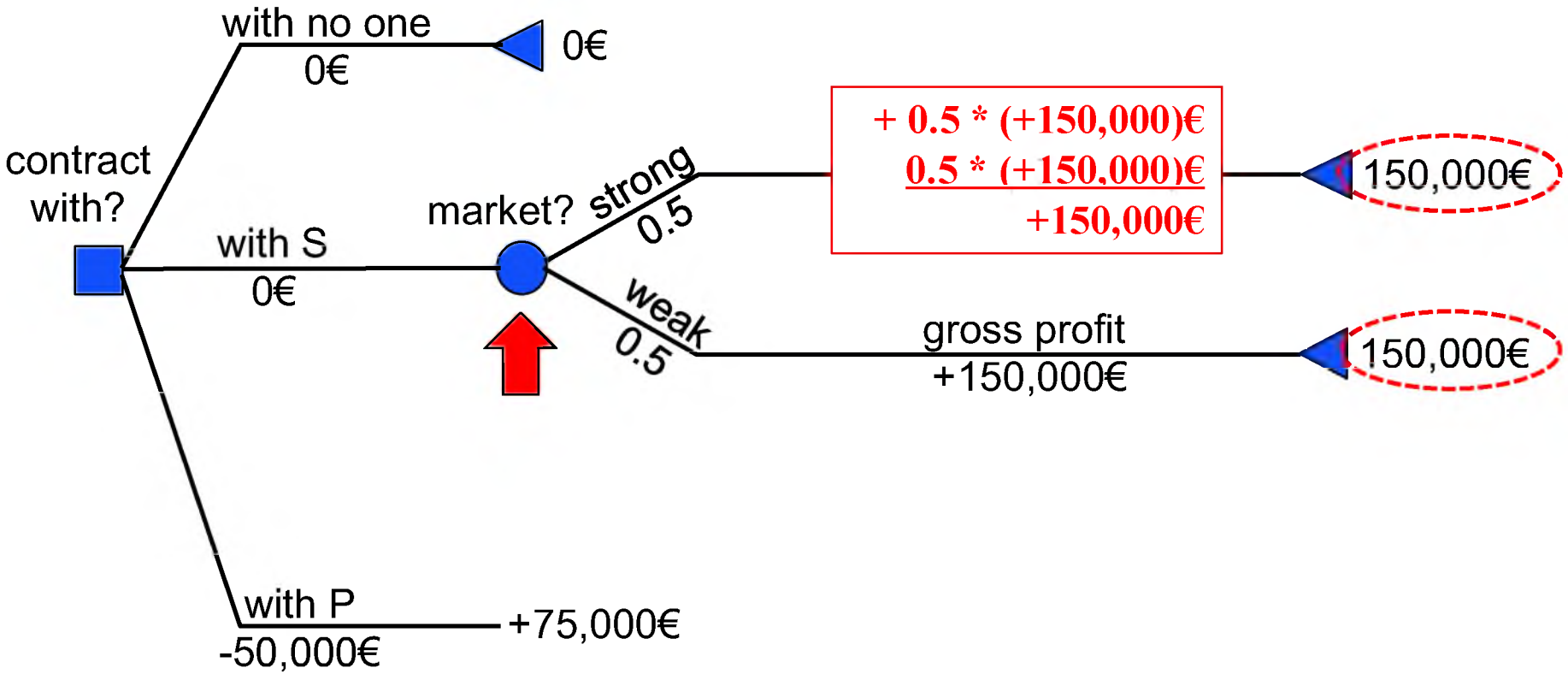

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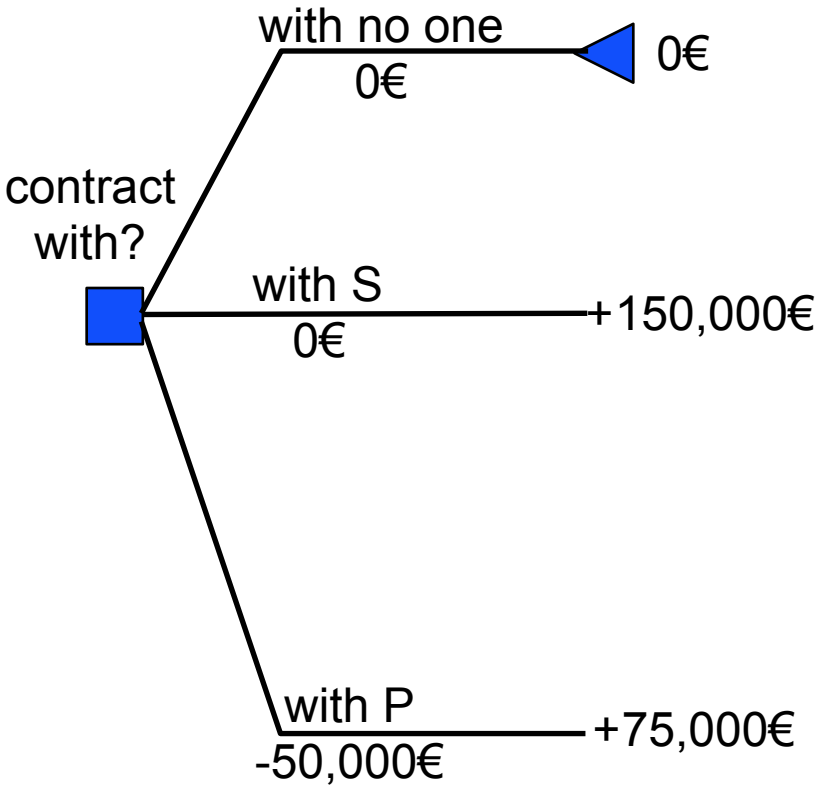

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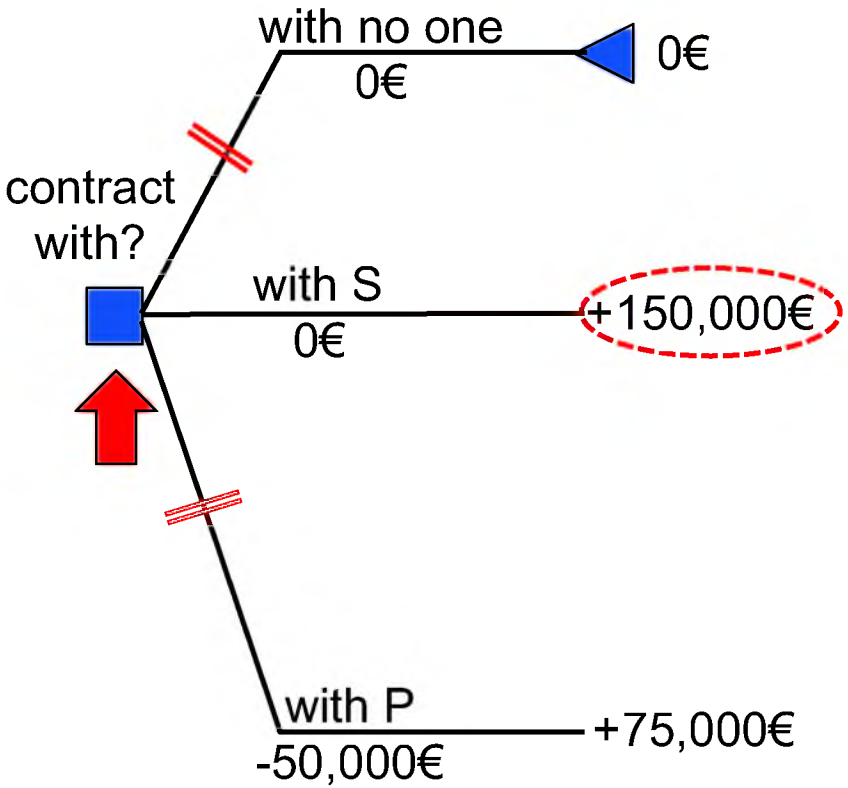

- The expected value maximizing strategy is to contract with Supplier S

Comparing the three stratgies

- The maxi-min strategy
  - Chose supplier S
  - Had a maxi-min value of 150,000€
- The maxi-max strategy
  - Chose supplier P
  - Had a maxi-max value of 450,000€
- The risk-neutral strategy
  - Chose supplier S
  - Had an expected value of 150,000€
- In this example, the risk-neutral strategy also minimizes risk
  - IDEA's profit with Supplier S is always 150,000€
  - No matter what the market outcome

Review of the mechanics of analyzing decision trees

- Constructing a decision tree
  - Decision nodes – points at which you make a choice among options
  - Event nodes – probabilities at each event node sum to one
  - Outcomes– capture all costs and rewards leading to each leaf of the tree
- Just looking at the tree can be instructive
  - You can see the range of outcomes
- Using the tree to identify classic decision-making strategies
  - Start at end, with the outcomes, and work backward to the root
  - At event nodes calculate the min/max/expected value
  - At decision nodes, cut decisions that do not maximize value
- The procedure identifies a range of risk-sensitive strategies
  - Risk averse, gain seeking, risk neutral

When using decision trees, keep the following in mind

- You can have big trees, many layers of decisions and events
- Cash flows that stream in over time should be discounted
- Where do the cash flows and probabilities come from?
  - In IDEA's case, may be past data; sometimes "expert judgment"
  - That's another form of "predictive" analytics
- You can do sensitivity analysis to address shaky data
  - Find "break-even" probabilities, cash flows for decisions
  - E.g., probability of a strong market needed so that P maximizes expected value
- Easiest to use events that have juust a few discrete scenarios
  - But the reality can be more complex
  - We'll look at this in Session 2

Decision trees in practice

- IDEA is a small example designed to convey the essential ideas
- In practice, decision trees are used to evaluate a wide range of complex problems. You can find examples in articles published in *Interfaces*
  - R&D licensing

    Phytopharm

    Research and Development Project Valuation and Licensing Negotiations at Phytopharm plc.
    Pascale Crama, Bert De Reyck, Zeger Degraeve, Wang Chong.
    Interfaces 2007, 37:5, 472-487.
  - Credit Scoring

    CHASE

    Managing Credit Lines and Prices for Bank One Credit Cards.
    Margaret S. Trench, Shane P. Pederson, Edward T. Lau, Lizhi Ma, Hui Wang, Suresh K. Nair.
    Interfaces 2003, 33:5, 4-21.
  - Polio Eradication

    CDC

    Polio Eradicators Use Integrated Analytical Models to Make Better Decisions.
    Kimberly M. Thompson, Radboud J. Duintjer Tebbens, Mark A. Pallansch, Steven G.F. Wassilak, Stephen L. Cochi.
    Interfaces 2015, 45:1, 5-25.
- There exists software to help manage and analyze large decision trees
  - core-feature, single user, products: e.g., TreePlan (free trial)
  - massive-feature, enterprise-use products: DecisionTools, Logical Decisions