Coffee Futures Compliance in Colombia: A Game Theory Approach

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1 Introduction

This document aims to offer an insightful analysis of the Colombian coffee market using game theory principles. It explores the economic dynamics of coffee growing in Colombia, highlighting its significance in the national export sector and the unique challenges faced by local coffee growers. The document dives into the role of the National Federation of Coffee Growers (FNC) in stabilizing the market and assisting growers through a local futures market. A special focus is placed on the issue of non-compliance in futures contracts due to price volatility, and the resultant impact on both growers and the FNC. The project models this case study using a game theory approach, specifically sequential games. The analysis is enriched with a Monte Carlo simulation, providing deeper insights into the strategic interactions and potential outcomes in the Colombian coffee market.

2 Context

Colombia is the third biggest coffee exporter in the world. According to data provided by the ICO [5], it is surpassed only by Vietnam and Brazil. When accounting for exports in monetary values, coffee and its derivatives were 7.2% of the total exports of the country in 2022. This was the third largest group of goods exported and this value is even higher than other highly valuable commodities such as Gold and Flowers which accounted for 5.2% and 3.6% of the total exports respectively. This makes the coffee market a topic of great interest to the Colombian government.

The whole process of coffee growing and harvesting is not very industrialized when compared to other agricultural commodities such as soy and wheat. The coffee cherries are picked one by one using the hands, as opposed to for example wheat, where the use of machinery enables the harvesting of great quantities in short time and with low human labor. There is high economic inequality, reported by [1] the gini index was 51.5, which results in high land concentration in Colombia in a few individuals. Both of these facts contribute to the average Colombian coffee grower having a small parcel of land to harvest (less than 10000 square meters). The most recent report by the FNC [3] of average yield of 10000 square meters per year is 21.4 sacks, which in kilograms of unprocessed dry coffee is 2675 kg. When converting using average prices per sack and COP per EUR the annual income of a coffee grower can be around 9000 Euros. One has to take into account that this is gross income. The costs of harvesting the coffee and maintaining the crop have not been taken into account yet. The average annual costs are around 3300 Euros, so the coffee grower ends up earning roughly 5700 Euros per year. This logic applies only when the selling price of the coffee crop is favorable. There might be a season where the costs exceed the earnings and they end up in debt with different financial institutions just to get by.

Given the historic importance of coffee for Colombia, the government founded the National Federation of Coffee Growers or (**FNC** for short given by its initials in Spanish) in 1927, which aims to develop the ecosystem of coffee production in the country and deliver welfare and competitiveness to the players in the coffee supply chain. This entity helps the coffee growers by buying their coffee so they don't need

to worry about the exporting process, which is not a trivial task. The FNC has placed several buying locations throughout the country in which the coffee growers can sell dry parchment coffee whenever they have it. Then the federation handles the threshing, packaging, transportation, and selling to a coffee roaster, which is usually an international buyer. The federation has established a pricing system that is based on two main components: the price of coffee in the Intercontinental Exchange and the price of the Colombian Peso against the US Dollar. There are some costs and premiums associated with the final internal price of coffee at which the federation buys coffee.

3 Local Market

The local coffee market in Colombia is atomized, meaning that it has several buyers and sellers. Nevertheless, there are some players on the buyers side with high market concentration. By data provided by the research team of th FNC [4], they were the main buyer, making roughly 16% of the market(as of 2022 as total share of colombian coffee exports). The second and third largest buyers had 9.8% and 8.5% respectively. And the top five buyers make up to 50% of the total market. This is a big percentage, and the market might be considered an Oligopoly, but this document does not pretend to argue around this topic. Just note that the buyers have a lot or market share, while the sellers are more atomized. There are some big players willing to buy coffee from coffee growers, that are private companies operating for profit (except for the FNC), which affects their relationship with the growers differently than that of the FNC.

On the selling side there are the coffee growers. Most coffee growers are "small" farmers. Meaning they have crops that are not considerable enough to go through trouble of selling to international clients. So it makes sense to sell to a local buyer such as the FNC, that has already establish a country-wide infrastructure to buy at any time of the year.

With contribution from the national government, the FNC establishes a best available pricing system that maximizes the profit of the coffee growers. As presented in the website of the FNC [2], the formula for the price of a sack of coffee in the national market is as follows:

$$P = (KC + premium - tax - costs) * USD/COP * k \tag{1}$$

where:

- P: is the coffee price expressed in COP per 125 kg sacks of dry parchment coffee.
- KC: is the price of the most liquid coffee futures in the Intercontinental Exchange (ISE) expressed in USD cents per lb of green coffee.
- $premium$: is the quality premium that is normally associated with the higher quality coffee with respect to standard arabica. This usually goes from 10 to 35 cents per lb of green coffee.
- tax: is the contribution made by the coffee growers when they sell their coffee to the federation, in which the price has a discount of 6 USD cents per lb of green coffee.
- $costs$: are the costs that the FNC incurs when buying coffee. Here the main activities that stand out are the threshing, packaging, transportation. These costs are hidden for the coffee grower and only the federation knows them.
- k: is a normalization factor of quality. As seen all the prices on the right hand on the equation are expressed on USD cents per lb of green coffee. But the left-hand side of the equation is expressed on COP per 125 kg of dry parchment coffee. The FNC has outlined some quality conversion factors for threshing dry parchment coffee and getting green coffee. The default factor is 88. The conversion is as follows. 88 is the number of dry parchment coffee kilograms you need to thresh to obtain 70 kg of green coffee. So, if we normalize, by the units of 125 kg sacks we get that by every 125 kg sacks of dry parchment coffee we obtain 99.43 kg of green coffee.

This price is offered by the FNC, but there is no legal binding to it. Meaning that other coffee exporter

can take this price as reference and offer a higher or lower price to the coffee growers. The coffee price calculated by the FNC is taken as a reference price for all the other buyers, since it incorporates all the elements of the supply chain of coffee, but in many cases other big buyers prefer to outbid the FNC to win market share.

4 Coffee crop

To gain deeper understanding of the problem it is crucial to understand the coffee growing business.

Coffee growing begins with the planting of trees. The coffee trees begin their productive phase from two to four years after being planted. So at first the coffee grower has nothing to do but wait. After the coffee trees begin being productive one can harvest the fruits. The tree blossoms approximately every six to eight months. In Colombia, given the historic meteorological conditions, the harvests are not equal. One of the crops is the main one and the other is called the fly crop. Of the total crop per year the first one is between 60 to 70% while the second is the remaining.

So in summary, coffee crops are seasonal and depend on meteorological conditions. This opens the door to market volatility in prices, specially in the recent years where meteorological conditions have been extreme and unpredictable.

To give a sense of the an actual crop calendar we can say that the fly-crop in most coffee farms in Colombia takes place in the months of July and August while the main crop takes place in November and December. In the subsequent months (January and February), the coffee growers have to plan their year, buy fertilizers, take out loans to cover their costs, and decide whether to make an effort or not to exploit the trees for the given year. If they decide to buy fertilizers, agricultural equipment and harvest their trees, they will have to hope that the prices are better when the time to sell comes than at their current time.

5 Standard Futures

Given the volatility of prices and the uncertainty associated to the final income of the coffee growers, the FNC has opted to develop a local futures market. Each coffee grower in the database of the FNC can sell them up to 50% of their crop via futures contracts. The contract works as follows: both parties agree on the quantity and quality of coffee to be delivered in the future. The price is also settled at the sign of the contract, legally biding the coffee grower to deliver the coffee according to the agreed conditions. The contracts are due to deliver on a specific date, that matches with the expected harvesting date. At the expiracy of the contract, the coffee grower is supposed to deliver the agreed quantity of coffee to the FNC and the FNC is supposed to pay the agreed price to the seller. If they do not deliver the coffee, they would be on breach of contract. To offset a possible force majeure event, the limit of 50% of the total crop is placed, so that if a grower has problems due to climate variability or other conditions out of their control they can still deliver the agreed quantity of coffee.

With this futures mechanism the FNC expects that the coffee growers can take better financial planing decisions. For example if the growers see that the coffee price is high, they might want to sign a futures contract to secure profits for the year, because there is the possibility that the prices will be lower when they have the physical coffee and it is time to sell on the spot market.

6 Compliance

"Due to the high price volatility and upward price trend in recent years, there was a wave of non-compliance in the local futures market. Non-compliance in this case is referred to the non-delivery the physical coffee to the buyer at the end of the contract. Some coffee growers have seen the opportunity to make higher profits by selling their coffee at the spot price, which was higher than the agreed price. This non-compliance wave caused buyers to suffer significant losses, because they were already facing a fu-

tures contract themselves with a foreign buyer. This situation forced the buyers to buy the non-delivered coffee from other coffee growers at a higher spot price and cover the price difference.

The previous situation is of particular interest for the FNC, because they established the futures contracts with the coffee growers in first place to grant them financial stability, but this backfired and resulted in large financial losses for the FNC. The futures contracts have mechanisms to make the delivery enforceable, meaning that if not delivered there can be fines or even seize of assets to cover the price difference incurred by the buyer.

Under this scenario the FNC faces trade-off: enforce the compliance by fining or seizing assets of the coffee growers, or just take the losses in their balance-sheet knowing that the coffee growers are better off thanks to the greater returns on their crop. This decision, along with the decision of the coffee grower of whether to deliver the coffee when they have the opportunity to take a profit by selling to a third party or not, risking consequences, can be modeled by a game theory approach.

7 Game Modelling

The base game is a sequential game, in which there is the interference of randomness before the players make their move. The game is described as follows:

The coffee grower (player 1) and the FNC (player 2) sign a futures contract for one year. The coffee grower makes a commitment to deliver some quantity of coffee at a certain price. For example lets say 100 for simplicity after 365 days of the sign of the contract. They both agree that the price (100) that will be payed for the coffee is the price observed on day t=0.

Natures move: coffee price in this game is modelled with a discretized GBM (Geometric Brownian Motion).

After 365 days the price will be determined by the equation:

$$S_{t+\Delta t} = S_t \exp\left(\left(\mu - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t}Z\right) \quad (2)$$

where:

- $S_{t+\Delta t}$: The coffee price at time $t + \Delta t$.
- S_t: The coffee price at time t.
- μ: The drift coefficient of the coffee.
- σ: The volatility of the coffee.
- Δt: A small time increment.
- Z: A random variable drawn from the standard normal distribution.

In our specific case, we take $S_0 = 100$, representing the P from equation (1) at t=0.

After 365 days the coffee grower has gathered the coffee. He/she observes the spot price S_{365}, that is price at t=365, and faces the decision of: deliver the coffee to the FNC at the agreed price **(D)**, or fail to comply **(F)**, meaning don't deliver and sell at a higher bidder.

If the price went up $S_{365} > S_0$, the coffee grower has the incentive to fail to comply **(F)** and sell their coffee on the spot market gaining the price difference $\Delta S = S_{365} - S_0$. In all cases that the coffee grower chooses **(F)** they will see a payoff of ΔS in their Utility function. It does not matter if ΔS is positive or negative, they will have this difference by selling the coffee at a different price than the one agreed in the futures contract. Based on the move of the coffee grower, the FNC makes now their move. If the coffee grower failed to comply **(F)**, the FNC has to choose if they let this pass and do nothing about it **(N)**. Or if they want to enforce the futures contract via a fine, or size the assets of the coffee grower to cover the expenses of finding coffee at the spot price **(E)**. Note that a "rational" coffee grower will optimize their utility function, so they do not have monetary incentive to fail compliance **(F)** under a negative ΔS.

Also note that a "rational" FNC has no incentive to play **(E)** when the coffee grower plays **(D)**, since they do not have any price difference to cover.

Now let us discuss the payoffs of the FNC under each price scenario. If the coffee grower plays **(F)** the FNC will have to cover ΔS to be able to comply with

their own counterparty. Given that the coffee grower failed to deliver, the FNC has the possibility to play **(E)** to cover the losses. This will not automatically cover the losses, just a part of the financial losses, because they have to pay for lawyers to enforce the contract via fines or asset seizing. So they only get a fraction of the ΔS, lets say $\alpha < 1$. Besides, they are deteriorating the welfare of the coffee grower, which is against FNCs mission. This last can be quantified by a reputational loss of say ρ. In the case the FNC chooses to do nothing when the coffee grower fails to deliver, they sense a gain of welfare to the coffee growers. This can be quantified as the opposite of the case of the reputational loss so lets say that ρ is added to the utility function in the case when the FNC plays **(N)** and subtracted for when they play **(E)**. Finally if the FNC chooses to play **(E)** the coffee grower will have to pay Φ as a fine for not complying with the futures contract. Φ might be up to ΔS.

Now that we have our game, we can represent it in extensive form:

8 Analytical Solution

To solve this game analytically we can apply backward induction beginning from the last nodes, where FNC makes their move.

Price goes up: If the price goes up we are in the left part of the tree. There the FNC decides between **(N)** and **(E)**. For the most left subgame, the FNC chooses **(N)**, because ρ takes positive values and it is better to have positive ρ than negative ρ.

In the next subgame the FNC must decide between $-\Delta S+\rho$ and $-\Delta S-\rho+\alpha\Delta S$. Clearly the move **(E)** gives out a higher payout, so FNC plays **(E)**.

Then there is a subgame that the Coffee grower plays. He must choose between **(D)** where he/she gets a payout of 0 or **(F)**, where the payout is $\Delta S-\Phi$. Here the value of Φ turns out to be key to solve this subgame. If it exceeds the ΔS, then the coffee grower plays **(D)**, while if it is lower than ΔS then the coffee grower plays **(F)**, because after failing to deliver and paying the fines, they will still make a profit.

Now let us solve the subgames for when the price goes down

The solution for the first subgame is the same as before: FNC plays **(N)** because $+\rho > -\rho$. This logic applies to the other subgame to the right, because the FNC faces a the same values separarated by $+\rho$ and $-\rho$, sho FNC plays always **(N)**.

For the Coffee grower the choice is now between 0 and ΔS, and because this is the scenario where ΔS is negative, the coffee grower will choose **(D)**.

SPE NE: If price goes up: Coffee grower plays **(F)** as long as $\Delta S - \Phi > 0$ and FNC plays **(E)**

If price goes down: Coffee grower plays **(D)** and FNC plays **(N)**.

We have easily found the SPE NE, where the FNC and the coffee growers do not regret their choice if they had the opportunity to change moves. However, the assumptions in this game are somewhat simplistic. More specifically the value of ρ is not so straight forward always, it depends on other outside factors such as overall price inflation, political frictions between the current government and the rural population, and the price of the coffee itself. Under a high price scenario, the FNC must take great losses, so maybe the reputational damage of enforcing the contracts is not as large as the "welfare" they are giving by letting the coffee growers default on their futures contract.

To fine tune this assumption we can say that the welfare/reputational-damage ρ can be split into two independent random variables that can take different values depending on the social and economic conditions of the country. We define ω as welfare and ρ as reputation. We won't focus too much on the underlying phenomena behind what affects the welfare given and the reputational damage perceived but we can say that both ω and ρ are:

$\rho = abs(X * \Delta S)$ where $X \sim \mathcal{N}(0,1)$ and $\omega = abs(Y * \Delta S)$ where X, $Y \sim \mathcal{N}(0,1)$

For the case of the price going down, we force ρ to be negative so that there is no incentive for the FNC to play **(E)** when the coffee grower delivered the coffee.

We can also update the process thinking of the coffee grower. They are not just infinitely selfish and take every opportunity to fail to deliver and make a profit from the price difference. They are motivated to not comply when the see extreme price dif-

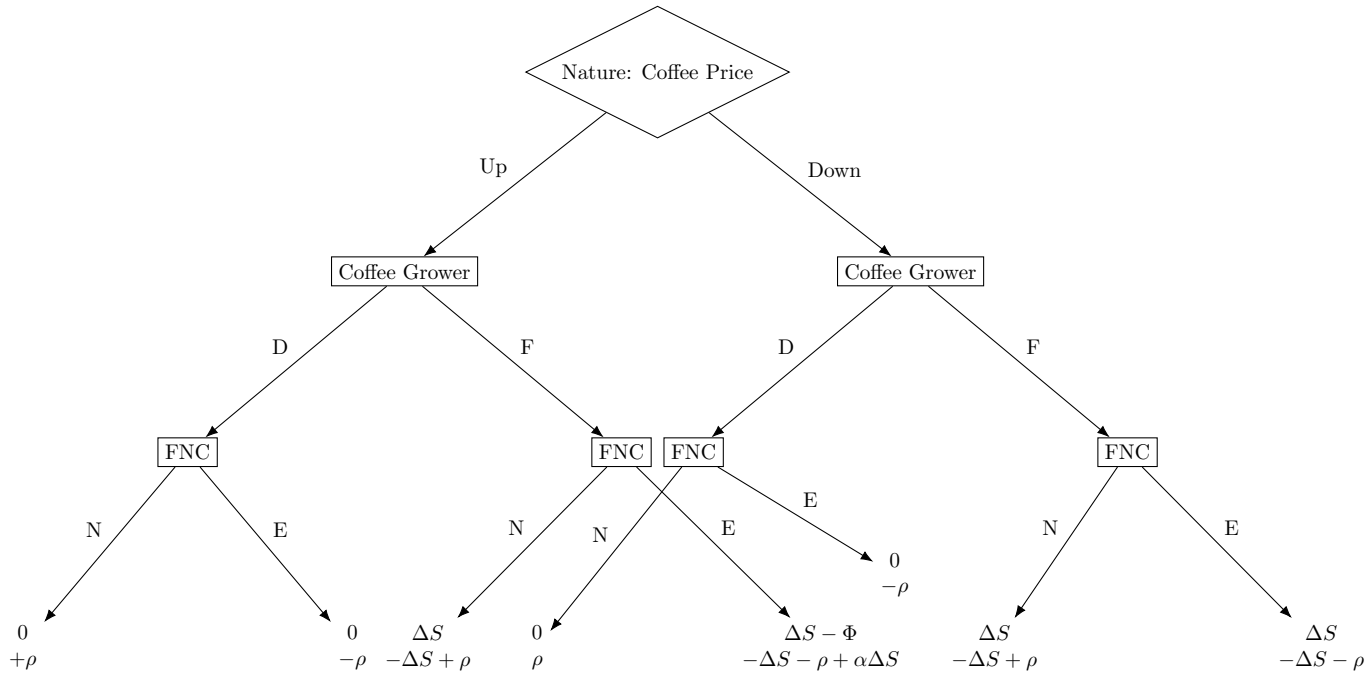

Figure 1: Extensive form representation

ferences of the spot market versus their agreed price. Given the daily series time of coffee prices in Colombia since January of 2012, we set a threshold of "abnormal" price differences in periods of one year. That is, $\frac{S_{365}}{S_0} - 1$. After analyzing the distribution of price returns a a threshold is defined for "abnormal" yearly returns in the 70th percentile. That is 26.10%. Given that this will be used in a hypothetical simulation we can arbitrarily round down to 25% without loosing much of the information. This can be seen in figure 2.

We now define the new decision making of the coffee grower by defining a function that creates the incentive to fail delivery. First define as $Z = \frac{S_{365}}{S_0} - 1$ then the utility function of the coffee grower will be updated by:

$$\mathbb{1}_{\mathcal{F}}(Z) = \begin{cases} 1 & \text{if } Z \geq 0.25 \\ 0 & \text{otherwise} \end{cases}$$

The updated version of the game is presented in Figure 3.

9 Game Simulation

Now to solve the new game we perform a montecarlo simulation to see how are the payouts of the moves distributed. They will obviously depend on the values that Z, ρ and ω take, but they will give us insights of under which scenario that the FCN faces, which outcome can we observe.

We perform 10.000 iterations. Each iteration simulates a random path for the coffee price using the historic data of the price to adjust the parameters of equation 3. Inside each iteration there is a random number generated for both X and Y to simulate the economic and political conditions of the country. We compute the payouts and choose the ones that maximize the utility of FNC and the Coffee grower via backward induction. We solve first for the FNC and second for the coffee grower. The results are dis-

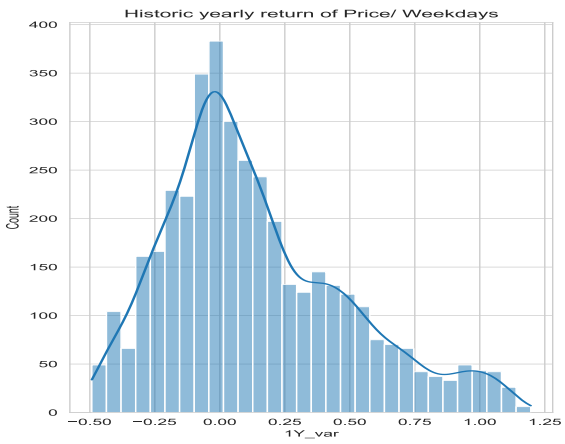

Figure 2: Price return over 1 year

played in Figure 4.

10 Results

We see that for the case when the price goes down there is only a SPE NE, which is **DN**. The coffee grower delivers the coffee and the FNC does nothing else. But for the scenarios of the price going up, which is of more interest for the conclussions, we see that the most frequent outcome of the game is **FE**, this means that the coffee grower fails to deliver the coffee and the FNC enforces the contract to cover some of their financial losses. Still there are some cases when they see that the coffee grower delivers the coffee even when they could see a profit, and in some cases, the reputational damage out-weights the financial losses so the outcome is **FN**.

This study focuses more on the decision taken by the FNC, which ultimately rests on the values of ρ and ω, which are defined by natures chance. Nevertheless the outcome given by Z is also fundamental for the FNC to make a decision. This result is useful in the scope of policy implementation. Because nowadays the reputation and welfare are not measured rigorously, so the decision of playing **(E)** or **(N)** is taken out of instinct rather than evaluating if the welfare given to the coffee growers outweighs the reputational damage that the FNC is incurring when they seize assets and fine the coffee growers for not complying to deliver the coffee when the price moves up and they prefer to sell it in the spot market.

11 Conclusions

In this project we solved a sequential game with the interference of randomness. The parametrization of the game is crucial to find the SPE NE. This parametrization can help in the policy-making process. Identifying the variables in more depth can maximize the utility function of the FNC and help bring welfare to the coffee growers in Colombia.

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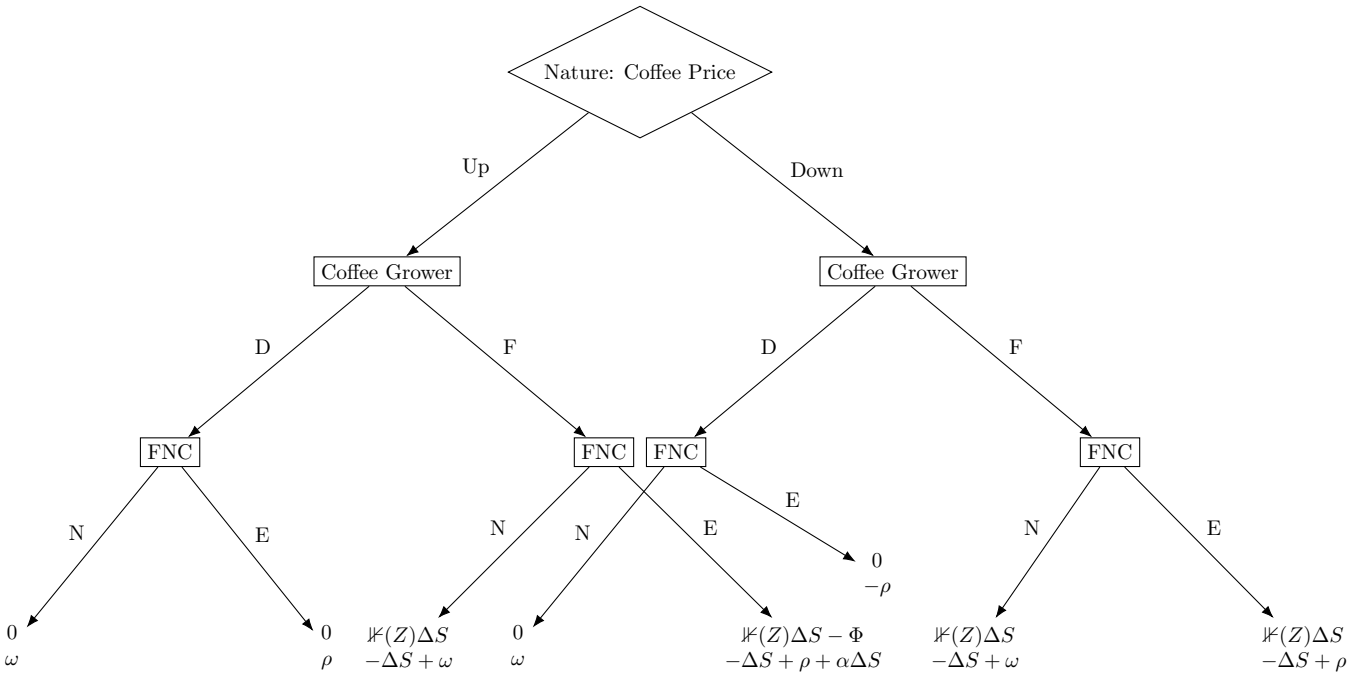

Figure 3: Extensive form representation with random outcomes

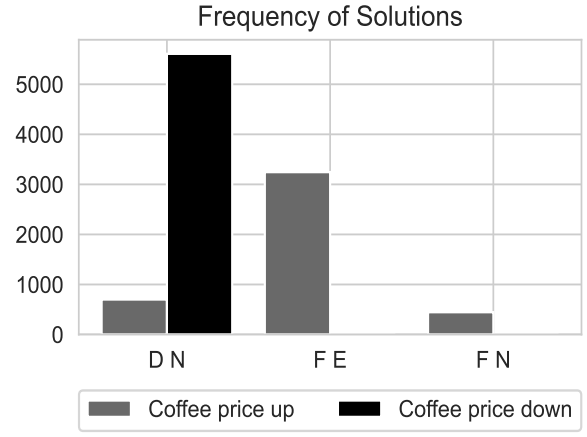

Figure 4: Distribution of outcomes