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Application of Real Options in Assessing the Financial Valuation of Agricultural Investments Considering Temperature as an influencing factor

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APPLICATION OF REAL OPTIONS IN ASSESSING THE FINANCIAL VALUATION OF AGRICULTURAL INVESTMENTS CONSIDERING TEMPERATURE AS AN INFLUENCING FACTOR

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In this paper, I will present a real option analysis comparing an open-air farm and a vertical farm in relation to investment potential, focusing on temperature data. One of the critical factors which establishes the productivity and viability of agricultural systems is temperature variation. Open air farms are put through fluctuating changes in temperature, which affect crop yields and general sustainability of farming activities. On the other hand, while vertical farms are resilient against extreme temperatures, they have other cost structures and operational difficulties. In line with this, I draw upon real options theory to quantify the value of flexibility in investment choices under temperature uncertainty. This analysis will provide valuable insights for investors and policymakers on optimizing agricultural strategies in response to climate trends.

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Abstract

This thesis develops a novel framework for evaluating agricultural investments under varying environmental and economic conditions using a real options analysis (ROA) model. The model is applied to three scenarios: open-air farm considering predicted future temperatures, open air farm considering temperature increases at a steady (static) rate and thirdly, vertical farming. The analysis provides insights into the financial performance, risk profiles, and strategic considerations of each method. The findings suggest that while vertical farming offers higher yields, its viability is highly sensitive to energy costs, while open-air farming is more vulnerable to climate variability. The research contributes to a better understanding of the financial and environmental trade-offs between traditional and innovative farming practices, along with the limitations of static valuation methods in the context of global warming.

Esta tese desenvolve um novo quadro para a avaliação de investimentos agrícolas em condições ambientais e económicas variáveis, utilizando um modelo de análise de opções reais (ROA). O modelo é aplicado a três cenários: uma exploração agrícola ao ar livre considerando as temperaturas futuras previstas, uma exploração agrícola ao ar livre considerando o aumento da temperatura a uma taxa constante (estática) e, em terceiro lugar, uma exploração agrícola vertical. A análise fornece informações sobre o desempenho financeiro, os perfis de risco e as considerações estratégicas de cada método. Os resultados sugerem que, embora a agricultura vertical ofereça rendimentos mais elevados, a sua viabilidade é altamente sensível aos custos da energia, enquanto a agricultura ao ar livre é mais vulnerável à variabilidade climática. A investigação contribui para uma melhor compreensão dos compromissos financeiros e ambientais entre práticas agrícolas tradicionais e inovadoras, juntamente com as limitações dos métodos de avaliação estática no contexto do aquecimento global.

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Chapter 1

Introduction

1.1 Background and Context

Agriculture is deeply threatened by climate change; apart from the physical risks involved with extreme weather events, the transition risks—especially in terms of regulatory changes—have caused threats to traditional means of farming. One such promising alternative among these has been vertical farming, which has made a claim about lesser vulnerability to climatic variations and the possibility of achieving higher efficiency and yield. What has resulted, however, is a very tricky decision to be made by farmers: either continue conventional open-air farming, with its risks directly related to the climate, or invest in the relatively resilient technique of vertical farming at possibly much higher costs.

As global temperatures rise, the agricultural sector becomes even more vulnerable to climate risks. Vertical farming, with its potential to reduce these risks in controlled environments, is studied in relation to climate projections and electricity costs, which are critical variables in agricultural decision-making. This method offers a promising alternative to traditional open-air farming, especially in urban areas where space is limited. However, the economic and environmental sustainability of vertical farming remains a subject of debate, particularly when compared to traditional farming methods.

Vertical farming turns out to be more profitable and stable, thus being promising for sustainable agriculture, even despite the higher investment amounts in applying Binomial tree analysis, but faces additional financial vulnerability due to rising energy prices. The study spotlights the need for integrating more agriculture and climate data and expert views for the purposes of fine-tuning the model's precision and hence its applicability.

1.2 Problem Statement

This thesis seeks to meet the urgent need for a decision-making framework with demands and capabilities to accommodate these uncertainties. Traditional methods of investment appraisal usually fail in this regard and hence necessitate a more dynamic approach like real options analysis. In view of the rapidly escalating impact of climate change, there is an imperative need to incorporate climate risk assessment into farming options evaluation to ensure long-term sustainable, economically viable agriculture.

1.3 Research Objectives and Questions

The main aim of this research will be to assess the economic viability of open-air and vertical farming using real options analysis, with special regard to climate risk. Major questions being: Which factors are influencing the economic value of these methods of farming? How does climate risk change investment decisions? How is the fluctuation in electricity prices going to change the viability of vertical farming? How does the geography of the construction site affect the analysis?

1.4 Overview of the Methodology

Among the approaches to real options analysis, the binomial method is a very powerful tool for modeling investment decisions at times of uncertainty. In this research, critical variables including beta values to represent the climate risk, electricity prices, and other relevant economic factors will be used in finding the best possible strategy in farming. Real options analysis, particularly the binomial method, is used to model investment decisions under uncertainty. The binomial method provides a clear and structured framework, ideal for capturing decision points and uncertainties. Key variables include climate risk (beta values) and electricity prices. The Monte Carlo method was considered but not chosen due to its complexity and computational intensity, whereas the binomial method offers greater transparency and interpretability.

1.5 Significance of the Study

This research offers several key implications for both farmers and policymakers in regard to the risk of climate and its impact on farm productivity, thus adding weight to the literature in the area of agricultural economics. The findings will be important for farmers to make a correct decision on adopting new farming technologies and for the policymakers while guiding support for sustainable agriculture practices.

Chapter 2

Literature Review

2.1 Vertical Farming and Environmental Impact

Vertical farming is often praised for its efficient use of space and water, making it a viable option for urban agriculture. [9] highlight the development of low-cost, modular vertical farming systems designed to improve accessibility and affordability in various regions, particularly in developing economies. Similarly, [11] emphasize the potential of vertical farming to enhance food security through innovative practices.

However, these benefits are accompanied by significant environmental challenges, primarily due to the high energy demands of vertical farming. [14] provide a critical analysis of the environmental impact of vertical farms, noting that the substantial energy consumption required for artificial lighting and climate control can offset the benefits gained from reduced land and water use. [15] supports this view through a comprehensive life cycle analysis, comparing the environmental impact of vertical farming with traditional agriculture and finding that the energy demands of vertical farms are a significant drawback.

To address these concerns, [11] propose strategies to reduce energy consumption in vertical farms, such as integrating renewable energy sources and using energy-efficient LED lighting. These strategies are crucial for lowering operational costs and mitigating the environmental impact of vertical farming. Additional research by [14] further explores the role of sustainable practices in enhancing the environmental performance of vertical farming systems.

2.2 Economic Viability and Real Options Analysis

The economic feasibility of vertical farming is another critical area of concern, primarily due to the high initial capital investments and ongoing operational costs associated with these systems. [12] developed a decision-making tool for production capacity investment in the indoor vertical farming industry, providing stakeholders with a framework to evaluate the potential returns on investment by considering factors such as market demand, operational efficiency, and cost management.

Real options analysis (ROA) offers a robust framework for assessing the economic viability of vertical farms under conditions of uncertainty. [18] applied ROA to Australian wheat production under climate change scenarios, demonstrating its utility in agricultural decision-making. This approach can be similarly applied to vertical farming, where investment decisions must account for uncertainties related to energy costs, technological advancements, and market fluctuations. [11] emphasize the importance of ROA in managing the risks associated with high energy costs in vertical farming, highlighting the need for continuous innovation and adaptation to ensure economic viability.

2.3 Impact of Rising Electricity Costs

As electricity prices rise, the economic sustainability of vertical farming comes under increasing threat. [10] discuss the importance of optimizing energy efficiency in vertical farms through advanced modeling techniques, such as a multiperiodic graph-theoretical approach. These techniques are crucial for maintaining profitability in the face of rising energy costs, as they help vertical farms minimize energy consumption while maximizing productivity.

The impact of rising energy costs on vertical farming is further explored by [19], who notes that energy efficiency is a key factor in the long-term success of vertical farms. As electricity costs continue to rise, vertical farming operations may struggle to remain competitive unless they can significantly reduce their energy consumption or transition to renewable energy sources.

[11]propose a comprehensive framework for supporting decision-making in agriculture under climate-exposed conditions, which could be adapted to help vertical farms navigate the challenges posed by rising energy costs. This aligns with the work of [18], who highlight the importance of integrating climate policies with agricultural practices. Such policies may include subsidies or incentives for adopting renewable energy in vertical farming, ensuring its economic and environmental sustainability in the face of fluctuating energy markets.

2.4 Policy Implications

As vertical farming continues to develop, it is essential for policymakers to consider its environmental and economic impacts. [11] emphasize the need for policies that support the adoption of energy-efficient technologies and renewable energy sources in vertical farming. These policies could help offset the increased costs associated with rising electricity prices and promote the sustainable growth of vertical farming as a viable agricultural practice.

Future policy considerations should focus on incentivizing energy efficiency and the use of renewable energy in vertical farms. This approach would not only enhance the economic viability of vertical farming but also contribute to broader environmental sustainability goals. Integrating climate policies with agricultural practices, as suggested by [18], will be crucial in shaping the future of vertical farming, ensuring that it remains a competitive and sustainable option for food production in urban areas.

Chapter 3

Model and Methodology

3.1 Overview

This study employs a mixed-methods design to evaluate the financial viability of investments in open-air and vertical farming. The mixed-methods approach enhances the validity and reliability of the findings by integrating quantitative data analysis with established modeling techniques. The central analytical tool is a real options model based on a binomial option pricing framework, which is tailored to the specific characteristics of agricultural investments.

3.2 Model Development

The core analytical tool of this study is a real options model based on a binomial option pricing framework. Real options analysis is particularly suited for evaluating investments under uncertainty, as it allows for the consideration of various possible future scenarios and the value of flexibility in decision-making [1]. The analysis is conducted over a 30-year period, with each timestep representing one year. This structure allows for detailed analysis of long-term investment strategies in the agricultural sector.

Three different variations of the real options model were developed to reflect different investment scenarios and to compare the effectiveness of the valuation methods:

3.2.1 Open-Air Farm Model with Dynamic Temperature Forecasting

This model uses all the aforementioned parameters, including exponential triple smoothing to forecast future temperature trends. The temperature data influences yield forecasts, which are a critical component of the revenue projections. The binomial tree framework incorporates these yield variations, allowing the model to dynamically adjust for changes in climate over the 30-year period.

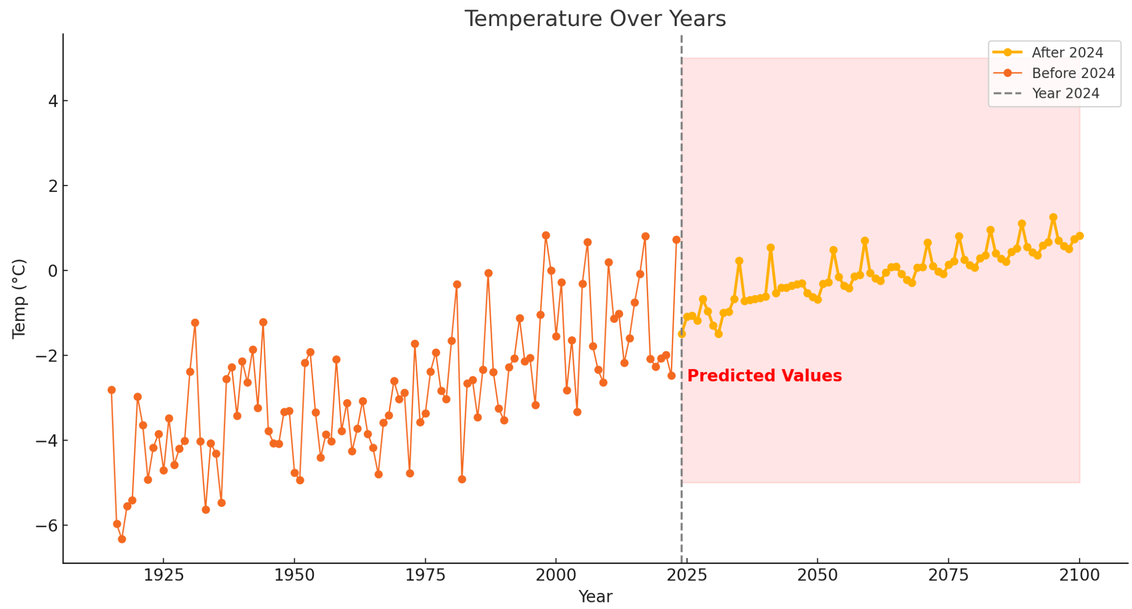

Figure 3.1: Predicted temperatures

3.2.2 Open-Air Farm Model with Static Temperature

In this variation, the temperature increase is held static rather than being forecasted using exponential triple smoothing. This approach assumes a stable climate scenario, which simplifies the yield forecasting process. The model still incorporates all other parameters, but the static temperature assumption removes one layer of uncertainty, allowing for analysis under more controlled environmental conditions.

3.2.3 Vertical Farm Model

This model disregards climate change impacts on yields, as vertical farming environments are controlled and insulated from external weather variations. Instead, it incorporates electricity costs, which are modeled using their own binomial tree of values. This tree forecasts electricity prices across the 30-year period, reflecting the potential volatility and long-term trends in energy costs. This model is particularly relevant given the energy-intensive nature of vertical farming, where electricity costs represent a significant portion of operational expenses.

3.2.4 Yield Table and Binomial Tree

The yield table is used to project future yields, which are the basis of the model. The yield table is a table of different temperatures ranging from $-n$ to $+n$, with 0 in the middle. Each value (degree Celsius) has a yield multiplier, which decreases the further away from the optimal temperature it is (assuming 0 is the optimal temperature). The data from the climate predictor is fed into this yield table to estimate the yields for the next 30 years, which are then used in the binomial real options analysis. The binomial tree is recombinant, ensuring a structured approach to calculating the option values.

3.2.5 Yield Table Data and Assumptions

The yield table presented in this section is intended to model the relationship between temperature deviations (in degrees Celsius) and the corresponding yield multipliers for lettuce. This table is an integral part of the analysis, as it impacts how changes in temperature influence crop yields over time.

Temperature Deviation (°C)	Yield Multiplier
-6.0	0.2
-5.0	0.3
-4.0	0.4
-3.0	0.5
-2.0	0.6
-1.0	0.9
0.0	1.0
1.0	0.95
2.0	0.9
3.0	0.8
4.0	0.7
5.0	0.6
6.0	0.5
Optimal Yield	165,000

Figure 3.2: Temperature Deviation and Yield Multiplier for Lettuce

The values in this yield table were not derived from empirical research or validated sources. They were selected arbitrarily to facilitate the development of the model and to demonstrate the potential impact of temperature deviations on crop yield. As such, these figures are hypothetical and should not be interpreted as accurate or reliable data.

This table serves as a conceptual tool rather than an accurate representation of real-world conditions. It is intended to illustrate the methodological approach rather than to provide definitive conclusions about the relationship between temperature and crop yield.

Given this, it is strongly recommended that future research replace these arbitrary values with data derived from empirical studies or agricultural expertise. This would significantly enhance the validity and applicability of the model.

3.3 Formula for Beta

The beta value, which measures the risk associated with the investment relative to the underlying asset, is calculated using the following formula:

$$\beta_{\text{DERIV}} = \eta\beta_{\text{UND}} = \frac{\Delta\text{UND}_0}{\text{DERIV}_0}\beta_{\text{UND}} = \frac{\text{DERIV}_{\text{up}} - \text{DERIV}_{\text{down}}}{\text{UND}_{\text{up}} - \text{UND}_{\text{down}}}\frac{\text{UND}_0}{\text{DERIV}_0}\beta_{\text{UND}}$$

This model uses this formula to calculate the project's beta at each corresponding timestep to assess how much riskier the project becomes as certain nodes are reached. Lower nodes indicate a higher beta and, therefore, higher risk.

3.4 American Option and Real Option Flexibility

The flexibility inherent in real options is similar to that in American options, where the option holder can choose the optimal time to exercise the option. The current model's "wait-exercise-abandon tree" (derived from values in the options value tree) shows that, given the current variables considered, exercising all options is the optimal decision.

The value of an American option at any node in the binomial tree is calculated as:

$$V_{i,j} = \max\left(\text{exercise value at node } (i,j), \text{hold value}\right)$$

Where: - The exercise value is the payoff if the option is exercised at that node. - The hold value is the risk-neutral probability-weighted average of the option values at the next time step, discounted at the risk-free rate.

3.4.1 Incorporation of Dynamic Model Features

To enhance the practical application of the real options analysis, the Excel model used in this thesis has been coded to automatically update as parameters change, ensuring that the binomial tree and corresponding option values reflect the most current data inputs. This dynamic model feature allows for real-time sensitivity analysis and scenario testing, making it a robust tool for decision-making under uncertainty.

Additionally, the model visually represents the decision-making process within the option value tree. Each cell in the option value tree is color-coded based on the optimal decision at that node: cells are colored green to indicate that exercising the option is the optimal decision, while cells remain white when waiting is the preferred course of action. This decision-making process is made possible by the inclusion of the American option-style formula, which accounts for the value of waiting rather than exercising immediately. This formula ensures that the model appropriately captures the flexibility inherent in real options, where the option holder can choose the optimal time to exercise the option.

This color-coding provides a clear and intuitive visualization of the model's outputs, facilitating easier interpretation of when and where the option should be exercised or deferred.

3.4.2 Incorporation of Financial Variables

To enhance the accuracy and relevance of the financial analysis, several key financial variables are incorporated into the real options model for each of the three scenarios...

3.5 3-Step Binomial Tree

A 3-step binomial tree is used here to illustrate the model's process of valuing options. This tree is a simplified version for clarity. Given the complexity of a 30-step binomial tree, it is impractical to include it in the document, but an Excel file containing the full 30-step analysis is provided in the appendix for detailed reference.

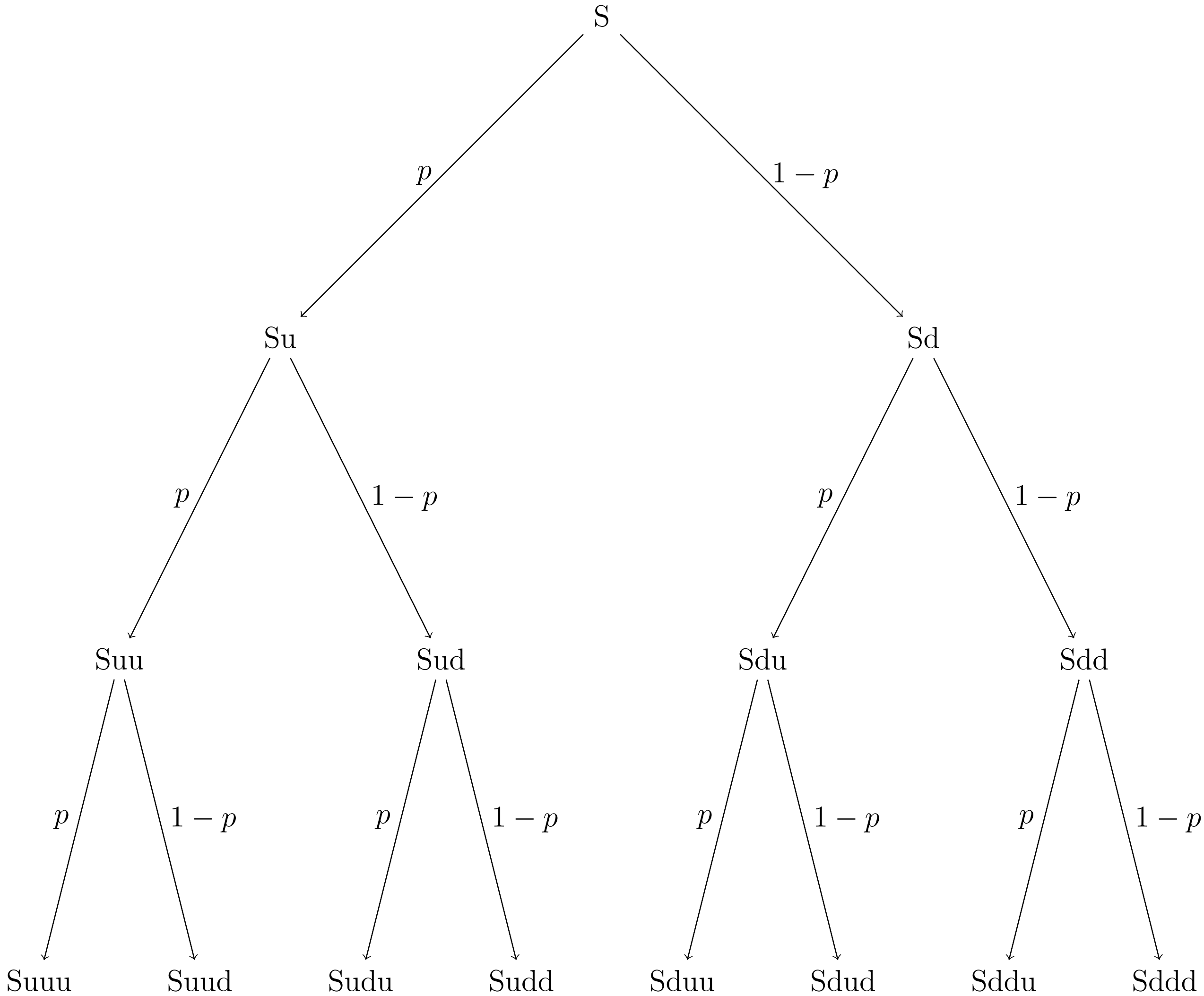

Figure 3.3: A 3-step recombinant binomial tree diagram.

3.6 Incorporation of Financial Variables

To enhance the accuracy and relevance of the financial analysis, several key financial variables are incorporated into the real options model for each of the three scenarios:

3.6.1 Risk-Adjusted Discount Rate (RADR)

The RADR is used to discount future cash flows to their present value, reflecting the time value of money and the specific risks associated with agricultural investments. The RADR is adjusted for the risk profile of each farming method, taking into account the inherent uncertainties in yield forecasts, market prices, and operational costs. By using a risk-adjusted discount rate, the model provides a more realistic valuation of future cash flows, especially in scenarios with high levels of uncertainty [2].

3.6.2 Net Convenience Yield (NCY)

The net convenience yield represents the non-monetary benefits or costs associated with holding the agricultural investment over time. In the context of farming, NCY could reflect factors such as the strategic value of land ownership, the benefits of maintaining food production capacity, or the costs associated with land degradation due to overuse. The NCY is integrated into the real options model to adjust the value of holding versus exercising the investment option at different points in time. This yields a more comprehensive understanding of the true value of agricultural investments beyond just their financial returns [3].

3.6.3 Volatility

Volatility is estimated using historical price data for crops and energy, reflecting the inherent risks and uncertainties in agricultural markets. Crop price volatility was calculated using data from sources such as Selina Wamucii and Bloomberg, while energy cost volatility was derived from historical data provided by the Canada Energy Regulator. Volatility is a critical input in the binomial tree model, as it directly influences the potential range of future outcomes and the valuation of real options [4].

3.6.4 Risk-Free Rate

The risk-free rate is derived from current and historical data provided by financial databases and reflects the minimum return on investment expected by investors. This rate is used as a benchmark for discounting future cash flows and is assumed to remain constant throughout the analysis period [4].

3.6.5 Other Variables

Additional financial variables such as labor costs, maintenance expenses, and capital expenditures are also incorporated into the model to ensure a comprehensive analysis. These variables are based on historical data and industry benchmarks, ensuring that the model accurately reflects the economic realities of both open-air and vertical farming.

Chapter 4

Results

4.1 Overview

This section presents the key findings from the real options analysis model implemented in a 30-timestep binomial tree. The detailed results and the underlying binomial tree calculations are available in the Excel file linked in the appendix. The analysis was conducted for three different farm scenarios: an open-air farm with dynamic temperature forecasting, an open-air farm with static temperature assumptions, and a vertical farm model. Detailed tables and images related to the sensitivity analysis and other results are provided in the appendix .

4.2 Financial Performance Analysis

4.2.1 Open-Air Farm with Dynamic Temperature Forecasting

The dynamic temperature model reveals that the financial performance of the open-air farm is highly sensitive to fluctuations in temperature. Yield forecasts, influenced by exponential triple smoothing of historical temperature data, show significant variability, affecting projected revenues.

- **Net Present Value (NPV):** The NPV for this scenario is $32,937,449.49. This figure reflects the substantial impact of temperature variability on the farm's profitability.

- **Real Option Value (ROV):** The real option value for this scenario is $1,105,389. This suggests that the flexibility to delay or abandon the investment is valuable, particularly given the uncertainty in future temperature trends.

4.2.2 Open-Air Farm with Static Temperature Assumptions

This scenario, where temperature is held constant, shows more stable financial outcomes, providing a control scenario to evaluate the impact of temperature variability on farm profitability.

- **Net Present Value (NPV):** The NPV for the static temperature scenario is $40,561,032.83, which is higher than the dynamic scenario, reflecting the benefits of reduced uncertainty.

- **Real Option Value (ROV):** The ROV in this scenario is $1,373,011, slightly higher than in the dynamic scenario. This indicates that even with stable temperatures, the option to delay or adjust the investment holds value.

4.2.3 Vertical Farm Model

The vertical farm scenario highlights the potential for significant profitability, influenced by factors such as yield consistency and cost structures.

- **Net Present Value (NPV):** The NPV for this scenario is \$103,042,361.60, significantly higher than both open-air scenarios. This suggests that vertical farming can achieve substantial financial performance, particularly under favorable cost conditions.

- **Real Option Value (ROV):** The ROV for the vertical farm scenario is \$1,840,031. It is important to note that this ROV was calculated assuming that all costs increase steadily, similar to other scenarios, reflecting stable long-term financial conditions. The reason electricity costs were not included in this base model is to avoid the assumption that electricity prices (modeled using a separate binomial tree) are correlated with lettuce prices (which also come from their own binomial tree and significantly influence the value of the vertical farm). This decision was made to prevent potential correlation issues that could complicate the analysis.

4.2.4 Vertical Farm Model with Separate Electricity Cost Analysis

A separate analysis was conducted where everything else remained the same as the earlier vertical farm analysis, with the one exception being that electricity costs were modeled using their own binomial tree, reflecting potential fluctuations and volatility in energy prices.

- **Real Option Value (ROV):** The ROV for this adjusted vertical farm model, incorporating the electricity cost binomial tree, was \$4,600,000. This lower ROV compared to the initial analysis (\$1,840,031) indicates that the volatility in electricity costs significantly impacts the value of maintaining flexibility in the investment decision for vertical farms.

4.3 Risk Assessment through Beta Values

Beta values were calculated using separate binomial trees for the underlying assets—temperature trends for open-air farms and uniform crop prices for all scenarios. These beta values provide insights into the relative riskiness of each investment option.

4.3.1 Beta Value for Open-Air Farm with Dynamic Temperature

The beta value at the first timestep (t1) for the dynamic temperature scenario is 1.9. This higher beta indicates that the open-air farm with dynamic temperature forecasting is more sensitive to changes in temperature trends and crop price fluctuations, reflecting a higher investment risk.

4.3.2 Beta Value for Open-Air Farm with Static Temperature

The beta value at t1 for the static temperature scenario is 1.73, which is lower than the dynamic scenario. This suggests that the investment is less risky when temperature is assumed to be stable, making it a safer but potentially less profitable option.

4.3.3 Beta Value for Vertical Farm Model

The vertical farm's beta value at t1 is 1.15, indicating its lower sensitivity to changes in crop prices compared to the open-air farms' sensitivity to temperature and price changes. This beta value suggests that vertical farming, while still risky, is less volatile relative to its primary revenue driver—crop prices.

4.4 Sensitivity Analysis

A comprehensive sensitivity analysis was conducted to assess how changes in key financial parameters impact the Real Option Value (ROV) and Beta values for the three farm scenarios. Detailed tables and images illustrating this sensitivity analysis are provided in the appendix . Separate data tables were created for each scenario, systematically varying the parameters to observe their effects.

4.4.1 Effect on Real Option Value (ROV)

The sensitivity of the ROV to changes in the following parameters was analyzed for all three farm scenarios:

- **Risk-Free Rate (rf) and Volatility of Crop Prices:**
  - **Dynamic Open-Air Farm:** Volatility directly impacts crop prices, which affects farm revenue. The ROV remains relatively stable at lower volatility levels but increases significantly as volatility rises, reflecting the value of flexibility in an environment with uncertain future crop prices. The increase in the risk-free rate further amplifies this effect, especially at higher volatility levels, where the combination of greater discounting and price uncertainty leads to a higher ROV.
  - **Static Open-Air Farm:** The static temperature scenario shows similar sensitivity to crop price volatility, though the baseline ROV is higher due to the assumption of stable temperatures. The effect of increasing risk-free rates is particularly noticeable at higher volatility levels, indicating that the value of maintaining flexibility in pricing strategies is significant even when temperature is assumed to be stable.
  - **Vertical Farm:** The ROV for the vertical farm scenario also responds to crop price volatility. As with the other scenarios, higher volatility leads

to an increased ROV, suggesting that crop price uncertainty is a critical factor in determining ROV across all farm types.

- **Risk-Adjusted Discount Rate (RADR) and Net Convenience Yield (NCY):**
  - **Dynamic Open-Air Farm:** The ROV decreases as RADR increases, particularly when NCY is low. This reflects the higher cost of capital and the diminishing value of future cash flows. However, higher NCY can offset the impact of a high RADR, preserving the ROV even under less favorable financial conditions.
  - **Static Open-Air Farm:** The static scenario mirrors the dynamic scenario in RADR sensitivity, but with higher baseline ROV values due to the stability provided by static temperatures. Higher NCY values effectively mitigate the negative impact of increased RADR, indicating the crucial role of NCY in preserving investment value.
  - **Vertical Farm:** The vertical farm scenario shows a significant decrease in ROV as RADR increases, particularly when NCY is low. This pattern reflects the critical role of NCY in maintaining the value of the vertical farm investment under various financial conditions.

4.4.2 Effect on Beta Values at t1

The sensitivity of the beta values at the first timestep (t1) to changes in the following parameters was analyzed:

- **Risk-Free Rate (rf) and Volatility of Crop Prices:**
  - **Dynamic Open-Air Farm:** The beta values indicate how sensitive the farm's returns are to fluctuations in crop prices. The table shows that beta values decrease as the risk-free rate increases, especially at higher

volatility levels. This suggests that as the expected return increases, the relative risk of the investment decreases.

  - **Static Open-Air Farm:** In the static scenario, the beta values follow a similar pattern, though the impact of volatility is less pronounced due to the stabilizing effect of temperature assumptions.
  - **Vertical Farm:** For the vertical farm, beta values similarly decrease with an increasing risk-free rate, reflecting a reduced relative risk as the expected return rises. The sensitivity to crop price volatility is consistent with the other farm types, indicating that price fluctuations influence the risk profile of the vertical farm similarly to the open-air farms.

- **Risk-Adjusted Discount Rate (RADR) and Net Convenience Yield (NCY):**
  - **Dynamic Open-Air Farm:** As RADR increases, beta values also increase, particularly when NCY is low. This suggests a higher perceived risk in environments with a high cost of capital. Conversely, higher NCY values can stabilize or even reduce beta, emphasizing the risk-mitigating effects of strategic positioning.
  - **Static Open-Air Farm:** In the static temperature scenario, beta values increase under higher RADR conditions, though the effect is moderated by stable temperatures. High NCY values further stabilize beta, highlighting the importance of these benefits in reducing perceived risk.
  - **Vertical Farm:** The vertical farm scenario shows that beta is highly sensitive to RADR, especially when NCY is low. The pattern reflects the significant role of strategic benefits in maintaining a favorable risk profile under different economic conditions.

4.5 Summary of Sensitivity Analysis

The sensitivity analysis highlights the following key insights:

- **ROV Sensitivity:** ROV across all farm scenarios is sensitive to changes in crop price volatility, with higher volatility leading to higher ROV due to the increased value of flexibility. The interaction between RADR and NCY highlights the importance of strategic benefits in maintaining investment value under varying economic conditions.

- **Beta Sensitivity:** Beta values are particularly sensitive to RADR and crop price volatility. Higher RADR leads to increased beta, reflecting greater perceived risk, while higher NCY values can significantly reduce beta, indicating a reduction in relative risk due to strategic advantages.

These findings suggest that both ROV and beta values are highly dependent on the assumptions made regarding economic conditions and strategic positioning. Investors should carefully consider these factors when evaluating agricultural investments, particularly in the context of crop price volatility and varying financial conditions.

4.6 Appendix Reference

All detailed results, including data tables and sensitivity analyses, can be found in the appendix, in the excel file.

Chapter 5

Discussion

5.1 Interpretation of Results

The real options analysis across different farm scenarios reveals critical insights into the financial performance and risk profiles of agricultural investments under varying conditions.

5.1.1 Connection to Research Objectives

The primary objective of this research was to develop a novel framework for evaluating agricultural investments, considering factors such as climate variability, technological advancements, and financial metrics. The results successfully demonstrate how this framework can be applied to real-world scenarios, providing actionable insights for investors. Each scenario analyzed—dynamic temperature open-air farm, static temperature open-air farm, and vertical farm—addresses the core research questions, particularly the trade-offs between risk and return in agricultural investments.

5.1.2 Dynamic Temperature Open-Air Farm

The dynamic temperature model quantifies the significant financial impact of climate variability, with an NPV of $32,937,449.49 and an ROV of $1,105,389. The high Beta (1.9) underscores the increased risk in dynamic environments. This quantification adds depth to the existing literature by providing a clear financial metric for the value of flexibility in responding to climate uncertainty, which is consistent with findings by [7] that emphasize the vulnerability of traditional farming to climate change.

5.1.3 Static Temperature Open-Air Farm

The static temperature scenario offers a useful comparison to the dynamic temperature scenario, demonstrating that stability in environmental conditions leads to a higher NPV of $40,561,032.83 and an ROV of $1,373,011. The lower Beta (1.73) confirms that reduced variability in temperatures leads to less investment risk. This comparison highlights the trade-offs between risk and return in agricultural investments, aligning with [6], who found that reduced environmental variability often results in more predictable financial outcomes.

5.1.4 Vertical Farm Model

The vertical farm scenario's NPV of $103,042,361.60 and ROV of $1,840,031 demonstrate the strong financial potential of isolating agricultural production from climatic variability. The lower Beta (1.15) indicates reduced risk, positioning vertical farming as a compelling investment. However, the sensitivity analysis reveals that crop price volatility remains a key risk factor, which echoes the concerns raised by [7] about the importance of market conditions in determining the success of vertical farming. Additionally, [6] has highlighted the potential of vertical farming to revolutionize urban agriculture, but this study underscores the critical role of market conditions in realizing that potential.

5.1.5 Vertical Farm with Separate Electricity Cost Analysis

Introducing volatility in electricity costs reduces the ROV to $4,600,000, highlighting the critical impact of energy prices on vertical farming. This finding emphasizes the need for strategic risk management in energy-dependent farming models, supporting the observations of [1] regarding the high operational costs associated with vertical farming. [7] also discusses the challenges of energy consumption in vertical farming, reinforcing the importance of integrating energy management into the financial planning of such projects.

5.2 Comparative Analysis Across Scenarios

When comparing all scenarios, a few key patterns emerge:

- **Risk vs. Return:** Vertical farming offers the highest potential returns with the lowest associated risk (Beta of 1.15), making it an attractive option for investors seeking stability and profitability. However, this comes with the caveat of sensitivity to energy costs, which must be carefully managed.
- **Flexibility:** The ROVs across scenarios highlight the importance of flexibility in agricultural investments. Dynamic environments require more adaptive strategies, whereas static environments allow for more predictable returns.
- **Strategic Trade-offs:** Investors must weigh the benefits of higher returns in vertical farming against the potential for increased operational costs. Similarly, open-air farming presents a trade-off between higher risks due to climate

variability and the lower costs associated with traditional farming methods.

5.3 Broader Implications

The findings of this study have several implications beyond individual investment decisions:

- **Agricultural Industry:** The demonstrated financial viability of vertical farming suggests a potential shift in agricultural practices, particularly in regions affected by climate change. As climate-related risks increase, vertical farming could become a key strategy for ensuring food security [6].
- **Policy-Making:** Policymakers should consider supporting vertical farming initiatives, particularly through subsidies or incentives for renewable energy use, to mitigate the impact of energy costs on this promising agricultural model [1].
- **Environmental Sustainability:** By reducing dependency on environmental conditions, vertical farming presents an opportunity for more sustainable agriculture. However, its reliance on energy highlights the need for integrating renewable energy sources into these operations, as suggested by recent studies [7].

5.4 Practical Recommendations

Based on the findings, several practical recommendations can be made:

- **For Investors:** Consider diversifying investments across both vertical and open-air farming to balance the potential for high returns with the need for risk management. Vertical farming, in particular, should be approached with strategies to hedge against energy cost fluctuations [7].

- **For Agricultural Managers:** Emphasize the importance of flexibility in operational planning. In dynamic environments, adaptive strategies that can respond quickly to changing conditions will be critical for maintaining profitability [8].

- **For Policymakers:** Support the agricultural sector by incentivizing the adoption of technologies that reduce exposure to climate risks, such as vertical farming, while also promoting energy efficiency to mitigate operational risks [6].

5.5 Consideration of Alternative Explanations

While the model assumptions were designed to reflect realistic conditions, alternative explanations for some findings should be considered. For instance, the lower ROV in the static temperature scenario could be influenced by factors not accounted for in the model, such as the potential for unforeseen environmental changes or technological advancements that alter the cost structures [7] Additionally, the reliance on historical data may not fully capture future trends, particularly in the context of climate change and technological innovation [6].

5.6 Limitations and Future Research

5.6.1 Model Assumptions

The study's reliance on historical data and simplified assumptions, such as steady cost increases, limits the generalizability of the results. Future research should explore more complex models that incorporate a wider range of variables and scenarios to better capture real-world complexities [8].

5.6.2 Data Limitations

The limited availability of long-term performance data for vertical farming poses challenges. Future studies should focus on gathering more comprehensive datasets to improve the accuracy of financial forecasts for this emerging technology[8].

5.6.3 Expanding the Scope of Analysis

Future research could apply this model to other types of farms, regions, or crops, providing a more comprehensive understanding of agricultural investments in diverse contexts. Specifically, examining the impact of new agricultural technologies or climate change scenarios would be a valuable extension of this work[8].

Chapter 6

Conclusion

6.1 Summary of Key Findings

This thesis developed a novel framework for evaluating agricultural investments under varying environmental and economic conditions using a real options analysis (ROA) model. Key findings include:

- **Dynamic Temperature Open-Air Farm:** Agricultural investments in high climate variability environments are risky but offer flexibility. The NPV of \$32,937,449.49 and ROV of \$1,105,389 highlight the potential for profitability despite significant risks.

- **Static Temperature Open-Air Farm:** Stability in environmental conditions leads to a more predictable investment outcome, with a higher NPV of \$40,561,032.83 and an ROV of \$1,373,011.

- **Vertical Farm:** Vertical farming demonstrated strong financial viability with an NPV of \$103,042,361.60 and ROV of \$1,840,031. However, sensitivity to crop price volatility and energy costs underscores the need for strategic risk management.

- **Vertical Farm with Separate Electricity Cost Analysis:** Modeling electricity costs with their own binomial tree reduced the ROV to $4,600,000, highlighting the impact of energy price volatility on vertical farming.

6.2 Contributions to the Field

This research introduces a novel application of the real options analysis framework to evaluate agricultural investments under uncertainty. The comparative analysis of different agricultural models provides valuable insights for investors, policymakers, and agricultural managers.

6.3 Implications for Practice and Policy

- **For Investors:** Flexibility in agricultural investments is crucial, especially in dynamic environments. Diversification strategies that include both traditional and technologically advanced farming methods can help mitigate risk and maximize returns.
- **For Policymakers:** Supporting vertical farming initiatives with subsidies or incentives for renewable energy integration could reduce operational costs and enhance sustainability.
- **For Agricultural Managers:** Developing adaptive strategies to respond to changing environmental conditions and market dynamics is essential for maintaining profitability.

6.4 Limitations of the Study

While the study provides valuable insights, it is limited by the use of historical data to forecast future trends and the uniform application of crop price volatility across all scenarios. Additionally, the availability of long-term performance data for vertical farming, a relatively new technology, posed challenges.

6.5 Directions for Future Research

Future research could explore more complex models that incorporate a broader range of variables, including technological advancements and policy changes. Longitudinal studies on vertical farming could provide valuable data for refining investment models. Expanding the scope of the analysis to include different types of farms, regions, or crops would provide a more comprehensive understanding of agricultural investments in diverse contexts.

Chapter 7

Data Sources and Appendix

Online Data Sources

1. Canada energy regulator: Cost of electricity historical data. Retrieved from https://www.cer-rec.gc.ca/en/data-analysis/
2. Selina Wamucii: Crops prices historical data. Retrieved from https://www.selinawamucii.com/insights/prices/canada/lettuce/
3. Government of Canada: Climate and temperature historical data. Retrieved from https://www.canada.ca/en.html
4. Bloomberg: Crops prices historical data. Accessed at ISEG Library. Retrieved from https://bba.bloomberg.net/?utm_source=bloomberg-menu&utm_medium=terminal
5. Federal Reserve Economic Data (FRED): Labor costs and cost of electricity historical data. Retrieved from https://fred.stlouisfed.org/
6. Paris Agreement. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement

7. Yield Calculator (lettuce). Retrieved from https://www.omnicalculator.com/biology/vegetable-yield

8. iFarm Cost calculator(vertical farm specialists). Retrieved from https://ifarm.fi/ifarm_calculators/leafy_greens_farm_calculator

9. Beta used model. Retrieved from https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html

10. Excel file with the model and other supplementary data: https://drive.google.com/file/d/1IEbb62_AOftbdp5hbqOdYJl6bRp4rbOE/view?usp=sharing

Chapter 8

Use of AI in Development of the Thesis

8.1 Overview

The development of this thesis was supported by AI assistance in various aspects. Below is a summary of the ways in which AI was utilized during the thesis preparation:

- Guidance provided in refining and expanding the content throughout the thesis.
- Assistance with organizing, formatting, and ensuring accuracy.
- Support offered in integrating visual aids and explaining complex concepts.
- Help with Overleaf formatting and structuring.
- Assistance with the general structure and flow of the thesis report.
- Help with correcting grammatical errors and simplifying sentences in certain parts of the report.

- Guidance in navigating practical errors and addressing non-viable assumptions for the model, with the intention of consulting further with a supervisor before any application.

However, I am solely responsible for the final writing, synthesis, and critical analysis. Significant contributions made by AI are acknowledged and referenced in explicit ways.

Nonetheless, I have ensured that the use of AI tools did not compromise the originality and integrity of my work. All sources of information, whether traditional or AI-assisted, have been appropriately cited in accordance with academic standards. The ethical use of AI in research and writing has been a guiding principle throughout the preparation of this thesis.

I understand the importance of maintaining academic integrity and take full responsibility for the content and originality of this work.

Zakiy Meghani

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