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Article

Game of Chains: Unravelling Uncertainty and Trading Behaviour in Horticultural Supply Chains

Marinus van Haaften [1,2,*], Iulia Lefter [1], Jessy Lee Kemmers [1], Olaf van Kooten [2,3] and Frances Brazier [1]

1 Department Multi-Actor Systems, Technology, Policy and Management, TU-Delft, P.O. Box 5015, 2600 GA Delft, The Netherlands; f.m.brazier@tudelft.nl (F.B.)
2 Horticulture & Agribusiness, Domain Agri, Food & Life Sciences, Inholland University of Applied Sciences, P.O. Box 3190, 2601 DD Delft, The Netherlands
3 Horticultural Supply Chains, Plant Sciences Group, Wageningen University, P.O. Box 16, 6700 AP Wageningen, The Netherlands
* Correspondence: m.a.vanhaaften@tudelft.nl

Abstract

The Dutch horticultural supply chain is characterised by substantial uncertainty resulting from ongoing organisational changes, such as the transformation from an auction-cooperative system to a sales organisation-based structure. This uncertainty causes strategic behaviour among all supply-chain members (including producers), which often disadvantages primary producers. This study investigates how uncertainty shapes trading behaviour and decision-making using Transaction Cost Theory as a theoretical framework. Specifically, it examines the relationship between environmental and behavioural uncertainty, trading behaviour and strategic responses. Employing a multimethod approach involving interviews, simulation sessions and debriefings to collect data, this study integrates a qualitative and quantitative analysis. The findings reveal: (1) how uncertainty influences trader behaviour and strategic decision-making, and demonstrates the need for more effective coordination mechanisms and strategies to reduce opportunism and inefficiencies in horticultural trade, (2) the diversity of strategic responses to uncertainty and (3) the factors that influence uncertainty and their relationship. Thes factors, include the current supply-chain structure that upholds uncertainty and strategic behaviour such as the deliberate exploitation of the absence or lack of information (asymmetric information). By combining methodological triangulation with theoretical insight, this study provides a foundational understanding of strategic behaviour under uncertainty in agri-food supply chains.

Keywords: uncertainty; strategies; trading behaviour; supply-chain structure; gaming simulation; horticulture

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1. Introduction

The structures governing transactions in the horticultural supply chain in the Netherlands have changed significantly in recent decades. The coordination of the supply chain has shifted away from centralised market mechanisms, such as Dutch auctions and the Commodity Board, which offered high levels of transaction transparency [1]. This situation was characterised by perfect market information, in which relatively small producers of homogeneous products, were seen as price-takers [2,3]. The Dutch Commodity Board of Horticulture facilitated the coordinated exchange of knowledge and legislation between companies, society and government at a platform level [4]. The market is currently moving towards a decentralised, market-driven system in which uncertainty of supply and demand are considered to be of equal importance [5,6]. The abolition of the Commodity Board in 2014, coupled with accelerated market liberalisation, has led to the dismantling of platforms for trusted and transparent market information [1,7]. This has a detrimental effect on the efficient exchange of transactions and the flow of greenhouse vegetables at all levels of the Dutch horticultural supply chain. Consequently, all companies within the supply chain rely on informal and frequently asymmetric sources of trade information. A review of the existing literature indicates a lack of research addressing this issue and a dearth of discussion regarding the factors influencing trade information.

Meanwhile, market conditions have become increasingly volatile due to the perishability of horticultural produce, climate variability, and changing consumer demand [8]. The number of enterprises has decreased at every part of the supply chain, with retailers gaining dominance [9]. Mergers and acquisitions have concentrated the retail sector and increased its international reach [10], resulting in 25 different supermarket formulas joining forces in five purchasing offices [11]. This has created a retail-owned supply-chain bottleneck. Growers joined cooperatives to obtain more (reliable) information and compensate for the lack of comprehensive, asymmetric trading information. At the time of this study, the majority of greenhouse vegetable growers were members of six different cooperatives, two of which had merged by 2020. This has led to an increase in uncertainty for supply-chain participants, ranging from producers to retailers. Unlike the previous auction-based system, today's supply chain is characterised by fragmentation, heightened competition, and power imbalances, primarily due to the growth of retail-owned purchasing alliances. These alliances have consolidated demand among a few dominant actors. These dynamics create a supply-chain bottleneck, thereby exacerbating uncertainty and undermining trust.

Despite the evident impact of these structural and market changes, there remains a significant lack of understanding of how uncertainty, particularly environmental and behavioural uncertainty, affects trading behaviour and strategy. Most existing studies [6], have focused on either logistical optimisation or general market trends, neglecting the empirical realities of day-to-day decision-making by traders, growers, cooperatives, and wholesalers.

This study addresses this gap by investigating the strategic behaviours that emerge in response to uncertainty in the Dutch greenhouse horticulture sector. Horticulture is an informative Several supply-chain studies have shown that supply uncertainty is more important due to exogenous factors, such as climatic change, which affect production [12]. However, the effects of these recent changes on uncertainty, trading behaviour and, in addition, related strategies are not well understood. These circumstances have given rise to a state of uncertainty at multiple levels within the supply chain [5]. Production uncertainty has ramifications for quantity, quality and financial management (return on investment), whilst markets are subject to uncertainty with regard to prices, supply and demand [5]. Furthermore, business relations have the potential to become a source of risk, placing pressure on human and personal skills and welfare [5]. Complicating matters further, horticultural supply-chain organisations exhibit a complex interplay of traditional solidarity, social and business cooperation, trust and community awareness, that goes hand in hand with various forms of competition [13]. This complexity is supported by the fact that supply organisations in Dutch horticulture are largely family-run businesses [14]. These circumstances highlight the importance of this study's research objective of addressing the lacky of literature on the understanding of the relationship between uncertainty, trading behaviour, and the subsequent trading strategies employed by actors within the horticultural supply chain.

This study captures motivations and strategic behaviour that influence trading decisions, investigating the impact of uncertainties such as changing market structures and loss of institutional coordination on trade and power in supply chains. This study aims to understand how uncertainty influences trading behaviour and trading strategies, focusing on horticulture. Specifically, it explores the factors that actors consider when faced with disrupted information flows, and the strategies employed to adapt to price and volume volatility. This includes leveraging relationships or asymmetries to gain a competitive advantage. Incorporating behavioural uncertainty and power dynamics within the framework of Transaction Cost Theory diverges from conventional supply-chain models, which frequently neglect human factors and informal mechanisms of trade.

2. Literature Review

Uncertainty affects trading behaviour and trading strategies. In turn, trading behaviour in general, and trading strategies specifically, are used to reduce uncertainty and optimise the exchange of supply and demand. This exchange of supply and demand is established through transactions between members of a supply chain. Literature characterises transactional relations as actions that meet the business performance expectations of other actors [15]. This section discusses the current literature on uncertainty (2.1), trading behaviour (2.2), and its relationship with Transaction Cost Theory (2.3).

2.1. Uncertainty

Uncertainty influences decision-making within the supply chain due to unclear objectives, insufficient information, limited predictive capabilities, and ineffective control measures [8]. Uncertainty in supply chains can be categorised as operational, environmental or behavioural. As operational uncertainty refers to the internal, process-driven aspects of individual supply-chain entities (e.g., equipment failure, labour availability or production efficiency), it has been excluded from this study. Incorporating operational uncertainty would distract from the behavioural and strategic elements central to understanding the impact of uncertainty on the trade behaviour of supply-chain actors. In contrast, this study focuses on external supply-chain aspects, namely uncertainties associated with trade behaviour and trade strategies. These external uncertainties include environmental and behavioural factors, that potentially influence market dynamics, trade decisions and inter-organisational relationships. Environmental uncertainty is caused by a lack of information about environmental factors [16], and can result from market circumstances, such as volatility, competition and market turbulence [16], institutional environments [17], and/or socio-cultural dimensions [18]. Behavioural uncertainty in supply chains can rise from risk avoidance [19], decision biases [20], over- or underreaction to potential supply-chain disruptions [21], strategic responses to the bullwhip effect [22], and/or to lead time variability [23].

Environmental and behavioural uncertainty converge in horticultural supply chains, where members perceive demand and competitive behaviour as factors giving rise to a high level of uncertainty [24]. Environmental and behavioural uncertainty affect the unpredictability of the volume supplied or demanded. In some studies, this is referred to as demand and supply uncertainty [25]. The primary factor that contributes to uncertainty in the supply chain is demand amplification, mostly known as the Bullwhip Effect [26]. More recently, attention has been given to supply amplification, known as the Reversed Bullwhip Effect [27]. This phenomenon has been observed in the context of delays to inbound logistics and uncertainty in outbound logistics flows. Cachon et al. observed the presence of both the Bullwhip Effect and Reversed Bullwhip Effect across a range of industries in the US [28]. The Reversed Bullwhip Effect has been scarcely addressed in the literature [29]. It is more frequently discussed in the context of pricing than product flow within the supply chain [30]. In terms of product flow, the Reversed Bullwhip Effect has been identified as a consequence of inaccurate forecasting of demand, inefficient internal operational processes, too long order lead times, sales price promotions, a low levels of information sharing and a lack of coordination within the supply chain [31]. Variance in supply amplification is often ignored as potential cause of the (Reversed) Bullwhip Effect [30], particularly in combination with the Bullwhip Effect [32].

2.2. Trading Behaviour

Uncertainty is caused by the behavioural responses of traders to the Bullwhip Effect [22]. Croson and Donohue [33], discuss the persistence of the Bullwhip Effect as a consequence of individual cognitive limitations and collective behaviour within an industry. They argue that information sharing mitigates the effect for upstream members. Conversely, there are also behavioural responses to uncertainty, including: (1) risk- and loss aversion; (2) herding behaviour; and (3) cognitive biases and information processing.

First, pricing strategies are used to compensate for risk- and loss aversion. A risk-averse supply-chain structure leads to lower trading prices [34]. To avoid potential losses, traders tend to generate higher returns, in a phenomenon commonly referred to as the "flight to quality" or the "flight to liquidity" [35]. Risk and loss aversion can also occur through holding high levels of safety stocks or reducing orders to decrease dependency. This results in deteriorating supply-chain performance at all levels [36]. Diversifying suppliers leads to more flexible short-term contracts with multiple suppliers, making companies more resilient to disruptions [37]. However, diversification can also increase trading volume variability, operational complexity and trading cost [38].

Second, when exposed to uncertainty supply-chain members exhibit herding behaviour [39,40]. Herding behaviour, which involves following others' actions, is often shown in the presence of uncertain market conditions or when traders lack confidence in their own assessments [39]. In times of uncertainty, traders mimic the actions of others if they perceive their decisions to be more informed [41]. Herding behaviour can lead to market bubbles or market crashes [42]. Some studies suggest that, when faced with high levels of uncertainty, traders rely on social or public information. This affects market prices and leads to collective market behaviour [43].

Third, uncertainty affects information processing and cognitive biases [44]. Uncertainty affects how traders process information asymmetrically, causing them to place excessive importance on recent events or personal beliefs [45]. Traders may also selectively interpret information to confirm their existing beliefs (confirmation bias) [46]. These biases can result in sub-optimal trading decisions or patterns.

To overcome asymmetric information supply-chain members implement various practices. Companies' behavioural responses to uncertainty affect supply-chain performance with actions such as stockpiling or hastily switching suppliers [47]. Flexible quantity contracts [48], and joint forecasting and/or shared management [49], improve predictability of supply or demand. Vertical integration, reduces the number of echelons and uses long-term contracts to reduce downstream dependence on suppliers and increases stability in trading behaviour [50]. More recently, data analytics and forecasting models have been used to anticipate unforeseen fluctuations in supply and demand, reducing inventory levels and creating reliable transactions [51]. In a systematic review Yang et al. conclude that more attention is needed in empirical studies on strategies and individual characteristics associated with decision-making [22].

2.3. Transaction Cost Theory

Transactions are coordinated within supply-chain structures ranging from individual companies and markets to vertically integrated supply chains and hybrid structures in between [52,53]. When these supply-chain structures lack the capacity to respond effectively to disturbances around transactions, uncertainty and asymmetric information (i.e., a lack of transparency) increase [50,54]. Uncertainty can arise ex ante and ex post from environmental and behavioural factors, associated with market exchange, thereby increasing the scope for opportunistic behaviour and governance failure [50,55]. Categorising uncertainty as environmental and behavioural uncertainty is one of the cornerstones of Transaction Cost Theory [50]. This categorisation is rarely found in supply-chain research. Environmental uncertainty is inherent in the transaction of horticultural products due to uncontrollable external influences from nature or society, such as weather patterns, market dynamics, disease prevalence and similar factors. These factors affect the yield, perishability and overall quality of horticultural products. Behavioural uncertainty can arise from a lack of communication [56], but also from undisclosed strategic behaviour that can contribute to opportunism and intended, limited rationality when conducting transactions, a concept that is known as 'bounded rationality' [50].

Transaction Cost Theory also describes the transaction costs of exchanging goods between buyers and suppliers in supply chains. Williamson [50] distinguishes three dimensions along which transactions differ: asset specificity, frequency, and uncertainty [50]. 'Asset specificity' refers to investments that are specific to a given transaction. 'Frequency' refers to the interactions between the parties involved in the transaction. 'Uncertainty' pertains to the behaviour of the parties involved in a transaction in relation to market developments. While most literature examines horticultural supply chains from the perspective of asset specificity [57], this study takes uncertainty as its starting point. This approach is consistent with the finding that uncertainty is the main factor influencing organisational structures within horticultural supply chains [57].

2.4. Syntheses of Uncertainty, Trading Behaviour and Trading Strategies

The horticultural sector is a particularly revealing setting to study uncertainty and strategic behaviour in supply chains. Horticultural products are highly perishable and frequently traded in decentralised spot and auction markets. They are produced by a heterogeneous population of small and large growers who interact via cooperatives, sales organisations and auctions. These features intensify the costs of delays, amplify the consequences of asymmetric information, and create frequent trade-offs between spot market flexibility and governance stability. Consequently, horticulture amplifies the mechanisms predicted by Transaction Cost Economics, providing an effective laboratory in which to observe how environmental uncertainty translates into opportunistic behaviour and governance responses. However, mechanisms such as information asymmetry and governance choices that mitigate or amplify opportunism are not unique to horticulture: they also apply to other perishable commodity markets such as fresh produce, seafood and cut flowers, and to production networks where short lead times, quality heterogeneity, and fragmented supplier structures create similar coordination challenges. Therefore, a focus on horticulture offers both domain-specific insight and broader lessons for supply-chain design under uncertainty.

This study investigates how uncertainty affects trading behaviour and subsequently the specific forms of behaviour, such as trading strategies. The relationships between uncertainty and trading behaviour and trading strategies, as described in the above literature, are shown in the conceptual model in Figure 1. By testing this conceptual model in the horticultural domain, this study contributes to a more complete and detailed overview of strategic behaviour and trading strategies and the factors influencing uncertainty.

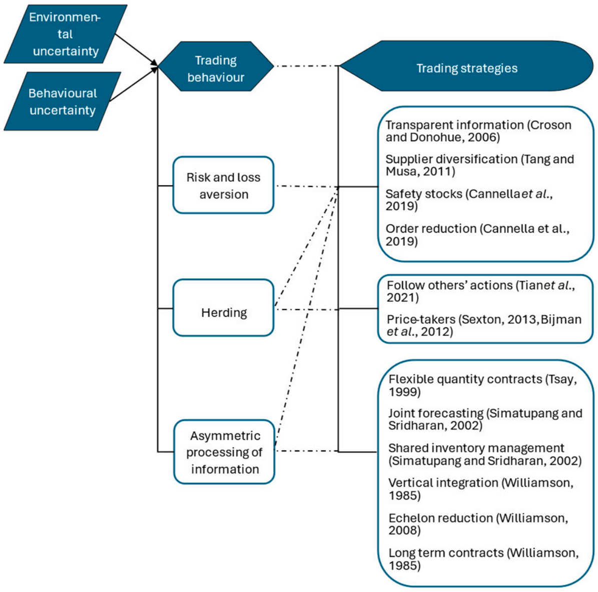

Figure 1. Conceptual model of relations between uncertainty, trading behaviour and trading strategies [2,3,33,36,37,39,48–50,54]. Dashed lines indicate relations between behavioural uncertainty and trading strategies.

3. Materials and Methods

This study deployed multiple methods with different data sources (triangulation), combining semi-structured interviews, simulated trading sessions, and post-session debriefings. To increase the validity and reliability, triangulation of data collection methods (in-depth interviews, simulation sessions and debriefings) and data analysis techniques (qualitative, quantitative) was used [58]. This triangulation is purposeful: interviews capture actors' motivations and perceived constraints, simulations expose behaviour under controlled information conditions where strategic choices can be observed, and debriefings provide narrative accounts of reflections that link perceived motives with observed actions. Together these methods improve construct validity (by linking theory with measured behaviour), internal validity (by observing behaviour in repeated simulated environments), and external validity (by sampling real market participants and using realistic simulation scenarios). Triangulation of researchers was employed for the qualitative processing and analysis of the data. An overview of the triangulation of methods is presented in Table 1.

Table 1. Triangulation of data collection and analysis methods.

Data Collection Method	In-Depth Interviews	Simulation Sessions	Debriefings
Function	Topic list	Participation in gaming simulation	Reflecting on behaviour
Data collection (Section 3.1)	In-depth interviews with professionals in the field	Participation of professionals in simulation	Reflection and discussion of participants
Subjects (Section 3.2)	Interviewees: Growers (self-trading) (n = 3) Traders cooperatives (n = 4, all male) Traders wholesalers (n = 3, all male)	Participants: Traders cooperatives (n = 10, all male) Traders wholesalers (n = 8, 7 male, 1 female)	Participants: Traders cooperatives (n = 10, all male) Traders wholesalers (n = 8, 7 male, 1 female)
Data analysis (Section 3.3)	Transcription of recordings in Elan [59] Coded text (open and axial coding, categorization) in Atlas.ti [60] Statistical analysis of co-occurrences in SPSS 26.0 [61]		

3.1. Data Collection

In-depth, semi-structured one-to-one interviews were conducted to explore trading behaviour in detail. The term "in-depth" refers to open-ended, conversational interviews, that were guided by a flexible topic list covering six thematic areas [62], see File S1. These thematic areas include market organisation, decision-making processes, information asymmetry, cooperation and governance mechanisms, price formation and future market developments. The interviewer followed these themes while allowing participants to elaborate freely and provide examples from their daily trade practices, consistent with qualitative inquire standards [63,64]. Interviews continued until the point of data saturation, defined as the stage at which no new codes or themes emerged from subsequent interviews [64]. These in-depth interviews were conducted for two reasons: (1) strategic information, associated motives and uncertainty were perceived as sensitive; and (2) explicit information relating to individual supply-chain members could influence competitive relationships. As participants were mostly unable to answer directly which uncertainties affected their trading behaviour, they mainly shared their experiences indirectly through storytelling/narratives. Coding the transcripts provided insight into participants' motivations, strategies and contextual factors that influenced their behaviour towards other supply-chain members. The structure of the in-depth interviews is shown in File S1.

A gaming simulation session on the trading process was conducted as part of four separate framed field experiments [65]. Gaming simulations are commonly used to extract and collect empirical data on human behaviour [66]. In our study, the gaming simulation provided a controlled environment to observe actual trading behaviour under uncertainty of supply and demand. Details of the simulation design can be found in File S1. Previous research has demonstrated the importance of mirroring real trade circumstances, as well as the fact that trading processes are tacitly performed in reality [67,68]. During the simulation sessions, each participant played the role of either a cooperative or a wholesaler when selling and buying tomatoes. Conversations between participants during the simulation sessions were recorded. Participation in the game simulation sessions enabled reflection on behaviour during subsequent debriefings.

Debriefings, conducted between October 2015 and July 2018, were held after simulation sessions. Debriefing after a qualitative experience in a gaming simulation session is essential for empirical data collection [69]. The debriefings allowed participants to transform their experiences into explicit knowledge [70]. During the debriefings, participants shared their personal experiences of their participation and reflected chronologically and collectively on their actions and experiences (see File S1). The facilitators of the debriefing used three core questions to structure each debriefing [71]: (1) How did you experience the simulation session? (2) What happened?, (3) How will you now proceed? The first question enabled participants to express their actions, feelings and experiences. The second question encouraged participants to engage in conversation about the actions taken, as well as the perceptions and thoughts about these actions. The third question addressed the knowledge and insights that participants had gained as a result of their participation. The debriefing recordings show participants' behaviour, thoughts and rationalisations for their transactions carried out amid uncertainty regarding supply and demand.

3.2. Participants

This study was approved by the Human Research Ethics Committee of TU Delft (reference number #5185). All participants were professional traders who had acquired their skills through extensive personal experience in the Dutch horticultural sector. Their expertise was largely tacit and developed through practice rather than formal training.

In-depth interviews

To gain an in-depth understanding of trade under uncertainty, semi-structured, in-depth interviews were conducted with ten professional traders between 2015 and 2019. A total of 26 traders were initially contacted through peer-to-peer nomination to ensure credibility and trust within the trading community. Of these, 10 participants (all male, reflecting the demographic composition of the field) completed interviews. All ten traders were specialised in tomatoes, peppers and cucumbers. Reasons for non-participation included time constraints and scheduling conflicts. Recruitment continued until data saturation was reached, indicated by the ninth and tenth interview in which no new codes or insights emerged during analysis of the final two interviews. Following accepted standards in data saturation [64,72]. Thematic convergence across participant categories confirmed that the sample size was sufficient to capture the variations in trading behaviour and perceptions of uncertainty. The sample comprised three traders employed by different growers (4 June 2015; 7 June 2015; 5 October 2016), four traders, each from a different cooperative at (19 May 2015; 4 April 2016; 5 July 2017; 25 November 2019), and three traders working for different wholesalers (19 January 2017; 30 January 2017, 5 March 2018). Each interview lasted between 60 and 90 minutes and followed a flexible interview guide (see File S1) covering four main themes:

1. Market organisation and trading routines (how transactions are structured and governed);
2. Information flows and uncertainty (sources of and ways of managing incomplete or asymmetric information);
3. Strategic behaviour and opportunism (e.g., withholding, signalling, or timing strategies);
4. Coordination and governance mechanisms (e.g., the use of contracts, cooperatives, auctions, or informal agreements).

Simulation sessions

To complement the self-reported data with observed behaviour, four simulation sessions were organised: two with cooperatives and two with wholesalers on 19 December 2016, 5 and 6 January 2017, 14 September 2017. In total, 18 professional traders (17 male, 1 female) participated on a voluntary basis. Participants were selected through the same peer-nomination process to maintain confidentiality and ensure realistic interaction patterns. Retail traders were invited but declined participation. During the simulation sessions participants engaged in a simulated trading process focused solely on sequential transactions for the exchange of supply based on a predefined demand at a chosen price on a specific date. Participants took part in the simulation sessions in the everyday environment in which trading takes place. All participants participated voluntarily.

Debriefing sessions

Structured debriefing sessions were conducted with the same participants immediately following each simulation session to capture their reflections on decision-making processes, motivations, and perceived constraints. These discussions provided qualitative explanations for the strategic behaviours observed during the simulations and enabled triangulation with the interview data.

Potential participants were contacted by telephone, to be informed about the project and invited to participate in the study. Those who expressed interest were given an information leaflet about the study. They were then contacted again to arrange an appointment to confirm their participation in a simulation session. Inclusion criteria for the interviewees and participants required respondents to: (a) possess professional knowledge of trading greenhouse vegetables (tomatoes, peppers and cucumbers); (b) have at least five years of trading experience (nine participants had ≥ 10 years); and (c) have been informed twice about the project and the purpose of the study: once before participating and once before a meeting or simulation session was scheduled. The exclusion criteria were limited to (a) unavailability and (b) being under 18 years of age.

3.3. Data Analysis

Two independent transcribers transcribed the audio recordings of the interviews, which were then reviewed a second time by the first author. The simulation session and debriefing recordings were transcribed and verbatim by the first and third authors and reviewed a second time by the author who did not undertake the initial transcription. The transcriptions were created using Elan version 6.1 [59].

Atlas.ti was used to analyse the transcripts and to manage the data [60]. The thematic structure of the interviews was developed inductively using open and axial coding. The data were initially subjected to open coding, to generate a list of codes related to trading behaviour, extracted from the transcripts. Codes were compared across interviews until conceptual saturation was achieved and then linked to behavioural patterns observed in the transcribed simulations. This analytic process ensured methodological transparency and replicability of the qualitative component [73]. The interview guide is provided in File S1 for data transparency purposes. To avoid selectivity, this process was carried out independently by the first and third author, who then discussed their interpretations of the transcripts and related audio files, their explanations of the codes, and additional areas for exploration of trading behaviour. This resulted in three categories of codes: (a) Functioning of the market, (b) Motivations to trade, (c) Trading strategies. The codes were then compared, resulting in an 82% agreement rate between the two coders. Inter-rater reliability was determined to be 0.781 (p-value 0.000) using Cohen's Kappa. By comparing codes and using deviant case analysis to explore possible differences in views [64,72,74], the data were interpreted for validity and agreement was reached on the remaining 18%. Secondly, axial coding was performed to identify the interrelationships between strategic trading behaviour, occupations (e.g., cooperative, wholesaler) and roles (e.g., seller, buyer). Thirdly, the properties of open and axial coding were categorised, in order to identify behavioural anomalies and to explore possible theoretical relationships among the codes. This process continued until no further insights were derived from the dataset [64,72,74].

Statistical analysis was performed in SPSS [61]. Contingency tables, Chi-square tests for independence and Fisher's Exact tests, were used to investigate potential associations between participants' occupations or roles played in the simulation sessions and their self-appointed strategies. Chi-square tests of homogeneity were executed to test whether the distributions of the variables differed significantly between the various roles played or between participants' occupations. Data were considered significant if the p-value was less than 0.05.

4. Results

The findings of this study provide an overview of trade relations in the horticultural supply chain for greenhouse vegetables, as well as with the factors influencing uncertainty and strategic behaviour.

4.1. Uncertainty as Motivation

The results of the coded transcripts, from both the interviews and the game simulation debriefings, revealed the uncertainties participants experienced. Figure 2 shows these uncertainties, experienced in trade by different supply-chain members. Note that the thickness of the beams indicates the frequency of coding. Participants assigned uncertainties to cooperatives, wholesalers, and retailers within the supply chain. The overview of uncertainties suggests that, contrary to retailers, most cooperatives and wholesalers are aware of most environmental and behavioural uncertainties.

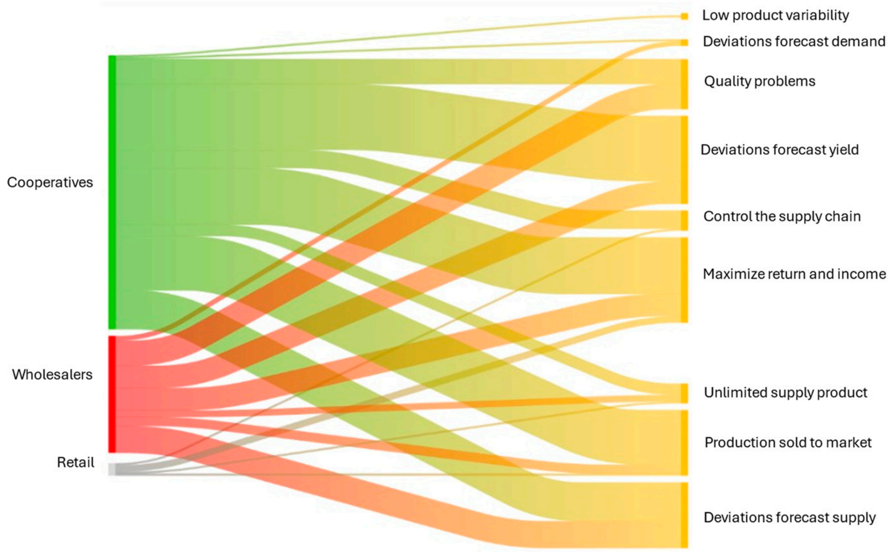

Figure 2. Overview of experienced uncertainties per supply-chain member.

These uncertainties can be categorised into behavioural or environmental uncertainties and were used by participants to inform their trading decisions. Figure 3 provides an overview of these uncertainties, which are partially expressed in trading behaviour. Following Transaction Cost Theory, the figure distinguishes between environmental uncertainties (left) and behavioural uncertainties (right). Environmental uncertainties include demand-related factors such as (a) low product variability and (b) forecast demand deviations, as well as production-related factors such as (c) quality problems, and (d) forecast yield deviations. Behavioural uncertainties reflect actors' strategic responses to these conditions: These include (e) controlling the supply chain, (f) maximising returns and income, (g) ensuring continuous product supply, (h) selling output directly to the market, and (i) managing deviations in the supply forecast.

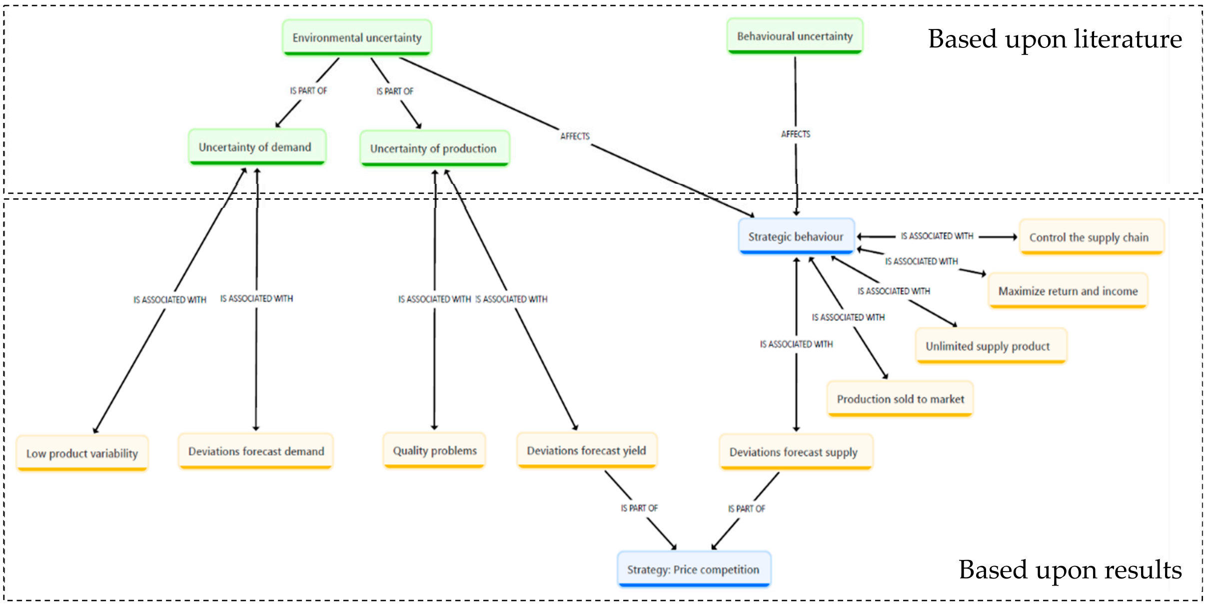

Figure 3. Categorization of uncertainties and corresponding trading motivations.

Together, these categories link the theoretical constructs of uncertainty and opportunism to the empirical motivations observed in interview and simulation session recordings. These findings were visualised in the form of a conceptual framework connecting environmental and behavioural uncertainties to the types of strategic motivations observed in trading behaviour (see Figure 3). This figure illustrates how each uncertainty dimension derived from Transaction Cost Theory relates to the empirical examples provided by participants. It also shows how these categories informed the development of subsequent hypotheses on opportunistic behaviour and coordination outcomes.

Members of the supply chain employed by a cooperative or wholesaler mentioned these motives at different frequencies (see Table 2). All participating wholesalers and cooperatives cited profit maximisation as one of their main motives, although cooperatives (n = 27) mentioned it much more often than wholesalers (n = 4). Deviations in the yield forecast (n = 33) and production sold to the market (n = 26) were cited as main reasons for strategic behaviour, followed by deviations in the supply forecast (n = 19) and quality problems (n = 11). For wholesalers, the main reason for strategic behaviour was deviations in the supply forecast (n = 14) and demand forecast (n = 10). Significant differences were found when cooperatives and wholesalers switched roles in the gaming simulation. It became clear that both cooperators and wholesalers found it difficult to empathise with each other's position when describing motives. The strength of associations showed a strong relationship between cooperatives and wholesalers in both roles.

Table 2. Analysis of independence between roles in the supply chain.

		Occupation Cooperative		Occupation Wholesaler		Adjusted Residuals	χ^2-Test	Strength Association	
	Role	C [a]	W [b]	C [a]	W [b]		Sign.	Phi (ϕ)	Sign.
	Motivations to act								
E	Low product variability	1	1	0	0	-	-	-	-
E	Deviations forecast demand	1	0	1	10	2.335	χ^2 = 5.455 (0.020)	0.674	0.020
E	Quality problems	11	3	0	9	3.682	χ^2 = 13.554 (0.001)	0.768	0.000
E	Deviations forecast yield	33	1	0	2	4.826	χ^2 = 23.294 (0.000)	0.804	0.000
B	Control the supply chain	8	0	1	0	-	-	-	-
B	Maximise return and income	27	7	0	4	3.313	χ^2 = 10.973 (0.001)	0.537	0.001
B	Unlimited supply product	5	1	0	2	2.108	χ^2 = 4.444 (0.035)	0.745	0.035
B	Production sold to market	26	1	1	3	3.970	χ^2 = 15.758 (0.000)	0.713	0.000
B	Deviations forecast supply	19	3	4	14	4.083	χ^2 = 16.667 (0.000)	0.646	0.000

Legend: E = Environmental uncertainty, B = Behavioural uncertainty, C = cooperative, W = wholesaler, [a,b] = Column proportions compared with adjusted *p*-value (Bonferroni method) differed with a 2-sided significance < 0.05.

4.2. Supply-Chain Structure

The empirical findings on market participation, coordination structures, and uncertainty sources across growers, cooperatives, wholesalers, and retailers are integrated in Figure 4. This figure illustrates how environmental and behavioural uncertainties are distributed within the current Dutch greenhouse horticulture supply chain, and how these variations give rise to strategic behaviour. In line with Transaction Cost Theory, actors facing greater production uncertainty, such as growers and cooperatives, are more susceptible to information asymmetry and opportunistic risks. In contrast, intermediaries operating under lower uncertainty, such as wholesalers and retailers, utilise contractual mechanisms or selective market participation to mitigate transaction costs. The figure therefore visualises the structural relationships among supply-chain actors, as well as the mechanisms through which uncertainty and strategy interact.

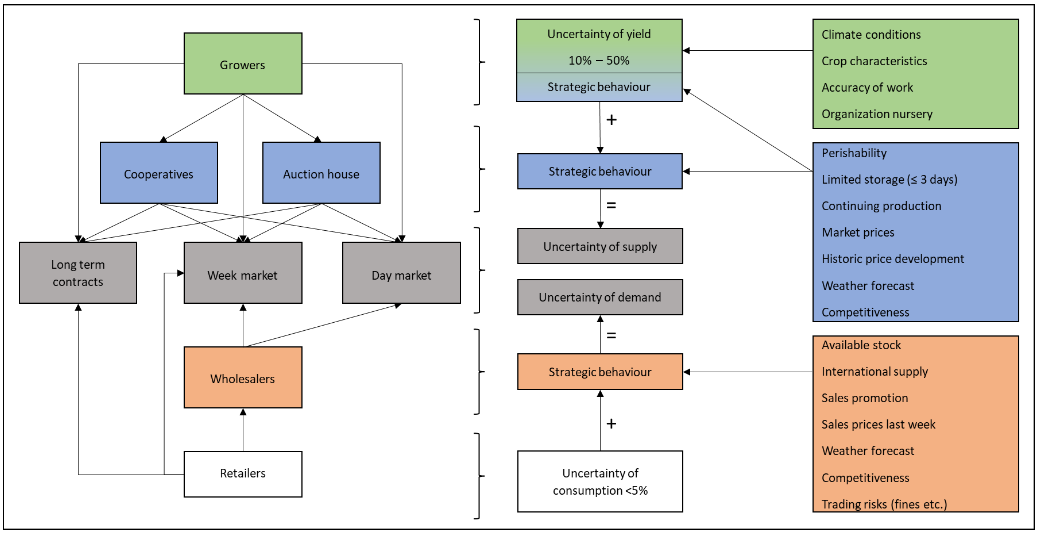

Figure 4. Structure of trade relations and distribution of uncertainty in the Dutch greenhouse horticultural supply chain.

The figure illustrates the key trading relationships between growers, cooperatives, wholesalers and retailers, showing how each party is involved in the three main market types: long-term contracts, week markets and day markets (the latter of which functions as a spot market). Wholesalers participating in the market did not trade in long-term contracts, while retailers did not operate on the day market. Growers sell their produce to cooperatives at auctions, but also trade directly with wholesalers or retailers, particularly on week and day markets. Cooperatives, which are owned by growers, trade with wholesalers and retailers on all three markets. Wholesalers purchase produce from cooperatives and sell it to retailers. Retailers trade on long-term contracts and in week markets. These trading relationships are visualised in Figure 4. All participants indicated that prices on week markets determine prices on day markets and prices in long-term contracts. These three market mechanisms (long-term contracts, week market, day market) are used both internationally and nationally, providing growers with multiple trading opportunities. However, by taking advantage of these opportunities, growers increase competition with other growers and their own cooperative (as each grower is a cooperative member). When growers act as cooperatives and wholesalers by dealing directly with retailers, all the factors associated with strategic behaviour apply to them too.

Environmental uncertainty primarily arises from production variability (e.g., forecast-to-realised yield deviations of 10–50%) and demand fluctuations (typically < 5%), factors that cannot be regulated. These factors lead to short-term adjustments in traded volumes, particularly on the day market.

Behavioural uncertainty manifests through strategic behaviour aimed at managing or exploiting these conditions. This includes altering supply volumes, timing sales, and negotiating prices in order to maximise returns or reduce risk.

All participants exhibit strategic behaviour in an attempt to alter the volume supplied or demanded, trading prices, or both, with the aim of maximising profits or reducing risk. Differences in uncertainty influence each actor's choice of governance. Rather than through open market exchanges, cooperatives organise trading activities within a collective governance structure. By coordinating sales, logistics and information sharing among member growers, they reduce the coordination costs and transaction risks that would otherwise arise from market uncertainty and opportunistic behaviour. Conversely, wholesalers and retailers rely on contracts and market signals to minimise exposure. Figure 4 thus connects the empirical structure of the Dutch horticultural market with the theoretical mechanism that links uncertainty, opportunism, and coordination efficiency, forming the contextual basis for assessing strategic trading behaviour.

4.3. Strategic Trading Behaviour

Participating growers, cooperatives and wholesalers evaluated the trading behaviour of members within the supply chain. While these results overlap with the conceptual model described in Section 2.4, they also differ in some respects (see the grey areas in Figure 5).

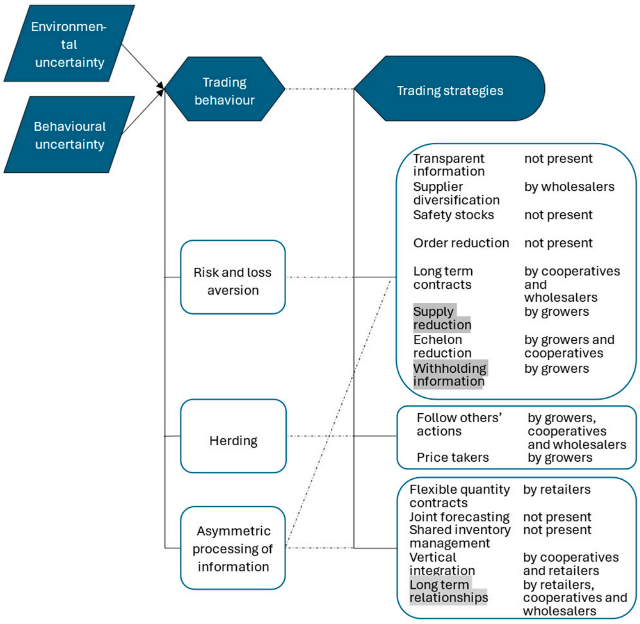

Figure 5. Results from transcriptions of interviews, simulation session and debriefings (grey areas differ from Figure 1).

Growers own the shares of cooperatives, but exhibit strategic behaviour towards their own cooperatives when they view market prices as unfavourable. In some cases, growers use production uncertainty as an excuse to supply a lower volume to cooperatives, while expecting a higher market price. Meanwhile, cooperatives use the same reasoning towards wholesalers. Greenhouses are often used by growers for storage. At low prices, yields can be stored or harvesting can be delayed by three to five days. When market prices are high, the harvest can be brought in a few days earlier than usual. In this case, growers perform the functions of cooperatives and wholesalers by selling directly to wholesalers or retailers, resulting in echelon reduction. Retailers experience uncertainty in demand and therefore need to buy additional supplies at the day market or directly from growers and/or cooperatives. To fulfil this uncertain demand, retailers can run sales promotions, paying growers and cooperatives slightly more than the day/week market price. Growers and cooperatives sometimes sell produce at auction because it can provide accurate trading prices. However, auctions often make trade information available only after payment, by which time it is no longer accurate. All supply-chain members complained about the lack of visibility of accurate and reliable information on trade volumes and prices.

Cooperatives and wholesalers named two categories of strategic behaviour applied by cooperatives and wholesalers: commercial traders and pass-throughs (see Table S1, File S2). Commercial traders focus on direct trade with the buyer who offers the highest price, not regardless of, but in spite of, previous trading relationships. Participating wholesalers described failed attempts to establish long-term relationships with commercial traders due to higher prices elsewhere in the market. According to these participants, when market prices became more favourable elsewhere, growers terminated their contracts with cooperatives or wholesalers, which, in turn, leads to supplier diversification. This leads to the complaint from cooperatives and wholesalers that batch trading is inexplicably rejected. Organisations and traders known as 'pass-throughs' have established relationships with retailers and cooperatives of growers. Retailers most often divide their demand between these wholesalers. Consequently, cooperatives and growers receive multiple offers for the same demand. Trading takes place within fixed margins, but accurate trade information is not shared with growers, who act as price-takers. Large cooperatives and growers often deal with the same wholesalers. This reduces supply risks and lowers the market price for retailers.

Retail was categorised as either discounters or quality-focused supermarkets (see Table S2 in File S2). Retailers enter into fixed-term contracts with wholesalers, cooperatives and large growers. Under these contracts, retailers are free to decide how much and when to buy. Participants reported that German supermarket discounters were the first to issue a market price, followed by other German and Dutch retailers. Dutch and German retailers are supplied through long-term, established trading relationships with cooperatives or wholesalers. Participants reported that 60% of the exported volume was sold to the German market. Retailers in the UK and France had a more diverse sales focus. Growers create asymmetric information when they deliberately communicate inaccurate supply information to cooperatives or wholesalers. Growers also experience the consequences of asymmetric information when they receive incomplete contractual trade information from wholesalers or retailers.

Apart from efforts to increase the price by reducing the flow of goods or limiting the distribution of information, participants mentioned strategies to mitigate risk and avoid loss. Each participant mentioned a different combination of trading strategies to mitigate risk or avoid loss. Generally, large growers who applied economies of scale as their business strategy also focused on reducing the number of intermediaries (through acquisition, joint ventures or long-term partnerships) and selling directly to retailers. However, some retailers split their demand volume among different wholesalers and growers to minimise supply and dependency risks. According to participants, responses to the Reversed Bullwhip Effect of supply are based on three aspects: price expectations, historic figures and factors related to the organisation of work and processes in the company itself. These aspects influence the decision to sell or buy volume.

Herding behaviour is a widespread phenomenon according to all participants. Due to the absence of transparency on market prices, prices and volumes supplied are compared with competitors at all horizontal levels of the supply chain on a daily basis or more frequently.

Asymmetric levels of information arise across the supply chain due to a lack of information exchange between retailers and growers regarding demand and supply specifications. Sometimes, information is deliberately misreported or withheld to gain a better bargaining position, both horizontally (e.g., from grower to cooperative) and vertically (e.g., between wholesalers) within the supply chain.

4.4. Trading Strategies

Participants described six different strategies for trading behaviour by cooperatives, wholesalers and retailers: price competition; economies of scale; supply-chain shortening; differentiation; customer/supplier satisfaction; information asymmetry; and laissez-faire. See Figure 6 for an overview, where the thickness of the lines indicates the frequency of coding.

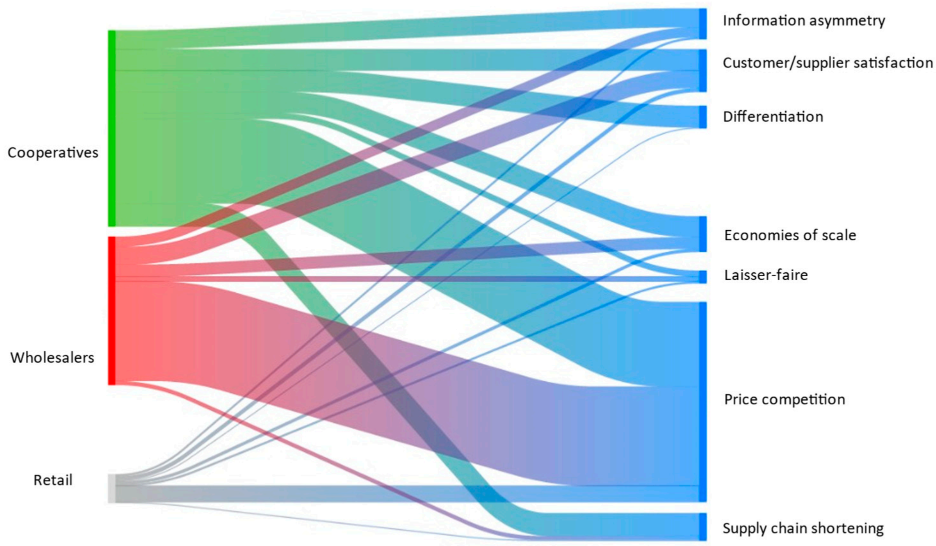

Figure 6. Trading strategies of participants.

Price competition was the most frequently cited strategy among all supply-chain members (see Table 3). Both growers and cooperatives stated that they pursue competition for the lowest market price through economies of scale and technological leadership. The second most frequently cited strategies were economies of scale and shortening the supply chain, which are commonly used to reduce costs and achieve better prices, respectively. Third place went to differentiation, customer/supplier satisfaction and information asymmetry. Cooperatives predominantly apply differentiation of products, packaging and markets, and a laissez-faire strategy. Information asymmetry refers to the withholding of information, whether intentional or not.

Table 3. Analysis of independence between roles in the supply chain and occupation for strategies.

	Occupied as Cooperative			Occupied as Wholesaler			Fisher's Exact Test	Strength Association	
Supply-chain member	C	W	R	C	W	R	Sign.	Phi (ϕ)	Sign.
Strategies									
Information asymmetry	37	9	3	3	13	1	0.000	0.547	0.000
Customer supplier satisfaction	40	11	3	1	29	5	0.000	0.700	0.000
Differentiation	42	0	2	1	0	0	1.000	−0.033	0.827
Economies of scale	49	13	6	0	11	1	0.000	0.576	0.000
Laissez-faire	12	8	3	0	1	0	0.500	0.269	0.419
Price competition	175	91	27	63	181	28	0.000	0.381	0.000
Supply-chain shortening	50	3	1	1	4	1	0.000	0.639	0.000

Legend: C = cooperative, W = wholesaler, R = retailer, Sign. = significance, where 0.05 (α) is used as a cut-off point for the significance level.

In contrast, exchanging information on opportunities to match quantities with appropriate packaging is central to customer and supplier satisfaction. Wholesalers most frequently use customer/supplier satisfaction following price competition, followed by information asymmetry and economies of scale. For retailers, strategies other than price competition were mentioned almost equally frequently. The least frequently used strategy was 'laissez-faire', which is associated with accepting a price without negotiating it or asking critical questions. This strategy was attributed to cooperatives, wholesalers, and retailers.

To ascertain whether the coded strategies occurred with equal frequency among participants engaged in cooperative and wholesaler roles and in fulfilling the occupations of a cooperative and a wholesaler, tests for homogeneity were conducted. The statistical results, as detailed in Table 4, demonstrate that the proportion of occurrences for cooperatives and wholesalers was identical with regard to the strategy price competition. This was evident for both roles (χ^2 = 2.267, p = 0.132) and occupations (χ^2 = 0.949, p = 0.330). However, when participants' occupations were considered, five of the six strategies were significantly more frequently attributed to cooperatives operating as wholesalers. No significant difference was observed between the roles of cooperative and wholesaler with regard to the strategies of customer/supplier satisfaction (χ^2 = 0.012, p = 0.912) and laissez-faire (χ^2 = 0.429, p = 0.513). The strategies of information asymmetry (χ^2 = 5.226, p = 0.022), differentiation (χ^2 = 39.093, p = 0.000), economies of scale (χ^2 = 8.562, p = 0.003) and supply-chain shortening (χ^2 = 33.379, p = 0.000), occurred significantly more frequently when participants fulfilled the role of cooperative rather than wholesaler. The results indicate that cooperatives employ more and a greater variety of strategies and use them more frequently than wholesalers.

Table 4. Chi-square test for homogeneity in roles and occupations.

	Homogeneity Between Roles				**Homogeneity Between Occupations**			
	n_c	n_w	χ^2	Sign.	n_c	n_w	χ^2	Sign.
Strategies								
Information asymmetry	40	22	5.226	0.022	46	16	14.516	0.000
Customer/supplier satisfaction	41	40	0.012	0.912	51	30	5.444	0.020
Differentiation	42	1	39.093	0.000	42	1	39.093	0.000
Economies of scale	49	24	8.562	0.003	62	11	35.630	0.000
Laissez-faire	12	9	0.429	0.513	20	1	17.190	0.000
Price competition	238	272	2.267	0.132	266	244	0.949	0.330
Supply-chain shortening	51	7	33.379	0.000	53	5	39.724	0.000

Legend: n_c = frequency cooperatives, n_w = frequency wholesaler, Sign. = significance, where 0.05 (α) is used as a cut-off point for the significance level.

The occurrence of coded uncertainties and strategies showed a significant relationship (χ^2 = 117.851, p = 0.000), indicating that the two are related. The frequency table with the corresponding statistical outcomes is presented in Table S3, File S2. Further tests for homogeneity showed that cooperatives mentioned a much greater variety of strategies in response to each form of uncertainty than other groups did (see Table S4, File S2).

5. Discussion

This study demonstrates how environmental and behavioural uncertainty can lead to inefficiencies in supply chains, by identifying the key strategies that affect supply-chain stability such as vertical integration and transparency, and strategic trading behaviour. The results clarify: (1) how behavioural and environmental uncertainty play a role in the supply chain and affect trading behaviour; (2) the strategies pursued by supply-chain members; and (3) that the current functioning of uncertainty and trading behaviour shapes competitive trading behaviour. The discussion concludes by examining the implications for research and practice.

5.1. Uncertainty and Associated Factors

Deviations of up to 50% in yields and up to 5% in consumption disrupt the balance between supply and demand. The factors identified as influencing strategic behaviour among participants, relate to (1) environmental uncertainty and (2) behavioural uncertainty.

Factors of behavioural uncertainty are related to company-level decisions, market dynamics and environmental factors (e.g., climate), which affect the volume traded between supply-chain members [75]. The climate-related factor 'weather forecast' relates to the seasonal supply of greenhouse vegetables. Furthermore, temperature directly impacts consumer demand in the short term (within a week) and yield in the longer term (three to eight weeks), which gives rise to fluctuations in market prices. Ultimately, weather forecasts are accurate five days in advance, which complicates accurate yield forecasting beyond a week [76]. Current models predict horticultural production with about 70% accuracy three weeks in advance [77]. Along with the unpredictability of pests and diseases, this means that transparency is not currently a solution to environmental uncertainty. Due to climatic conditions and the perishable nature of the products, there is a latent discrepancy between the predicted yield and the quantity actually delivered to market.

The discrepancy between the predicted yield and the volume delivered and traded increased due to strategic behaviour intended to influence the traded volume and market price. Growers forecast their yield and communicate this to cooperatives as the volume to be marketed. Growers, cooperatives, wholesalers and retailers then adjust the traded volume based on the weather forecast to influence the price. All supply-chain members frequently use the factors 'current market prices' and 'historical market or sales prices' as reference points to assess accurate trade terms. All supply-chain members use these factors to decide the volume to be traded or the desired market price. No literature was found on the use of these trading factors to influence volume or price in a supply chain.

Other factors related to behavioural uncertainty include storage (available inventory and storage space), perishability, sales promotion and contractual conditions (penalties and trade risks). Having storage space available or stock on hand gives each member of the supply chain a competitive advantage in price negotiations. Cold storage can be used to create a short-term surplus or deficit in trade volume [78]. This can have negative consequences for growers and consumers [79]. In the absence of cold storage, the harvested volume is supplied within three days to avoid quality loss. Two other important factors for postharvest quality are harvest time and ripeness [80]. Growers delay harvesting in anticipation of more favourable market prices, which brings these two factors into play. Perishability affects quality deterioration, which becomes more significant further down the supply chain, creating marketing uncertainty [75]. This can lead to supply backlogs at a later date and is also caused by rapid changes in weather conditions.

Promotions are a tool that all supply-chain members use to reduce uncertainty by supplying or marketing large volumes [75]. This study's results suggests that if promotions are not communicated in a timely manner, they can lead to oversupply from growers or cooperatives, or excess demand from retailers. The results also show that cooperatives, wholesalers and retailers enter into supply contracts to reduce opportunistic behaviour, which leads to supply fluctuations, and to manage price risks. These contracts often include fines or penalties, which are used to offset risks if the volume delivered falls below a threshold. Cooperatives also use other systems, such as entrance fees that growers must pay when they join, to increase commitment, participation, and shared responsibility. However, while these clauses are widespread in the horticultural sector [81], their effectiveness is questionable given the latent environmental uncertainty. Clarity about how much a farm will produce would also indicate its short-term competitiveness. These findings confirm that behavioural uncertainty contributes to opportunistic behaviour [50].

5.2. Competition in Trading Behaviour

The presence of environmental and behavioural uncertainty among supply-chain members creates opportunities for opportunistic behaviour. Opportunistic behaviour is enabled by the market mix and international context of the supply-chain structure, which offers a variety of trading opportunities involving short-, medium- and long-term contracts at national and international levels. Within this mix of market types, the day market acts as a vessel for absorbing fluctuations in supply and demand. These fluctuations are latent due to environmental uncertainty and exacerbated by trading behaviours such as flow reduction and the asymmetric processing of information. The international context increases the number of trading relationships and actors in the supply chain. This increases uncertainty, compounded by the choice of trade and the risk of noncompliance. Some studies indicate that, in horticultural trade transactions, uncertainty plays a more important role in determining market structure organisation than other factors [82]. The results of this study demonstrate that uncertainty, trading behaviour, and supply-chain organisational structure are mutually reinforcing.

In the horticultural supply chain, small and medium-sized enterprises (SMEs) join forces in cooperatives. These cooperatives countervail market power on the demand side of the market [1]. Previous research suggests that producers perceive cooperative and peer interests as a barrier to sales cooperation [83]. However, the structure of the supply chain provides opportunities for trade outside the cooperatives, a practice employed by all participants. Other contributing factors include the imbalance of market power on the retail side [84], and the increased intensity of competition between growers/cooperatives and wholesalers. This is characterised by more frequent transactions, limited growth opportunities, and larger companies expanding their market share at the expense of smaller companies.

5.3. Balancing Competition, Information and Risk

This study's findings show that, in the horticultural supply chain, growers and cooperatives and, to a lesser extent, wholesalers use a combination of strategies to protect themselves against uncertainty and to mitigate the effects. The emphasis on price competition can be attributed to the fact that greenhouse vegetables are traded as a commodity in an international market. The trade of horticultural produce as a commodity is facilitated by the industry-wide strategy of achieving economies of scale [85]. Research shows that growers experience lower market prices, as well as lower transaction and overhead costs, as a result of economies of scale [83]. Growers also assert that larger volumes generally provide better market access [83].

Dependence on climatic and growing conditions, as well as vulnerability to pests and diseases, creates a latent level of uncertainty within the supply chain that fosters information asymmetry. However, deliberately using information asymmetry as a strategy increases uncertainty. Several studies on the introduction of electronic markets in the ornamental horticulture sector indicate that the absence of information asymmetry lowers market prices for traded horticultural products [86]. This explains the deliberate use of information asymmetry as a strategy by growers, cooperatives and wholesalers, such as withholding or providing inaccurate information, to offset the risks of volume and price fluctuations. In line with this, it has been found that full transparency in the supply chain reduces the tendency of supply-chain members to engage in opportunistic behaviour [78].

Changes to the structure of the supply chain in recent decades have led to information asymmetries and the fragmentation of information relating to trade and transactions. In a fiercely competitive market characterised by low prices, cooperatives and growers depend on wholesalers to provide information about the upstream supply chain. This highlights the importance of transparency and effective supply-chain organisation in coordinating trade transactions [87].

Participants mentioned strategies such as differentiation, shortening the supply chain, and focusing on customer and supplier satisfaction, as well as a laissez-faire approach. A review of case studies suggested that differentiation is primarily a company-level strategy, which is not supported by retailers, who primarily want fresh products for their own brands [88]. Participants cite the elimination or skipping of intermediary links in the supply chain as a way of shortening it, with transactions taking place directly between growers and small retailers. Some studies indicate that there are limited market opportunities for a local-for-local market, where buyers in the Netherlands would pay a higher price [89]. This suggests that the cost of setting up a new distribution channel to market products is not covered. Therefore, this strategy may be of limited use for the time being. Some wholesalers stated that a local-for-local market is not in their interest as it limits their product sales. The range of strategies employed by growers and cooperatives contradicts the prevailing view in the literature that they are price-takers, unable to influence the market price [2]. The results of this study show that only a minority of growers and cooperatives accept market prices, adopting a laissez-faire strategy. The selection of the best deal is still mainly driven by price and quantity. In a competitive and uncertain trading environment, supply-chain members focus primarily on minimising price risk and the risk of non-compliance between companies.

5.4. Limitations and Implications for Research and Practice

The results of this study show that growers and cooperatives employ a wide range of strategies to mitigate uncertainty and risk relating to volume and price. These are both primary determinants of trade decisions. A validation study could reveal the extent of these strategies and explore potential solutions to challenges arising from environmental and behavioural uncertainty [12]. Effective supply-chain management can reduce uncertainty and information asymmetry by facilitating continuous exchange of information on expected returns and consumption. Future research should focus on trade information exchange in decentralised markets to promote awareness and understanding among supply-chain members of each other's trade risks. This has implications for the negotiation process, long-term cooperation among supply-chain members and contract selection. The findings also apply to industries beyond horticulture, such as fisheries, the pharmaceutical industry, and high-tech manufacturing, where production and market conditions are uncertain. This is especially pertinent given that environmental uncertainty and asymmetric information increase the incentive for opportunistic behaviour, which can lead to coordination failure unless governance adapts. These developments are also relevant to other decentralised manufacturing supply networks where information is fragmented and to contractual agricultural markets that face short lead times and heterogeneous producers. The findings offer general insights into governance choices in production networks facing high uncertainty.

Effective supply-chain management requires a transition from managing the interests of individual companies and processes to a vertically integrated approach [90]. This can be achieved by acquiring ownership of producers (i.e., growers) and processors (i.e., cooperatives and wholesalers), or through vertical transactions to solve the problem of transaction costs for perishable products [1]. The current fragmentation of the supply chain, coupled with the large number of small-to-medium enterprises, has resulted in an absence of a unified supply-chain strategy. Additionally, there is a significant divergence in the time horizon of decisions made by different supply-chain members, as well as an imbalance in the size and number of companies in successive links. Future research on this imbalance could explain why the ornamental fruit and vegetable sector tends to concentrate supply by participating in online auctions, especially those where growers can set a minimum price. The results highlight the effects of supply-chain fragmentation that is a concern for globalised trade networks and cross-border supply chains.

This study's findings are based on an analysis of interviews, as well as participants' involvement and reflections during game simulation sessions. Participants had to have previous experience in the field of commerce to take part. It is worth noting that not all supply exchanges are strictly commercial in nature. In horticulture, for example, it is common for buyers and sellers to have pre-existing long-term relationships and to connect and move within the same social networks. This is reflected in the peer-to-peer nomination of participants for each simulation session, which takes place within the companies' comfort zones. Further research should focus on clarifying the beliefs, mental models, skills, practical intelligence and know-how underlying the strategic behaviours presented in this study. Although retailers declined to participate in the simulations and interviews due to confidentiality constraints, their influence was captured indirectly through wholesalers' and cooperatives' accounts. Future studies should include the perspectives of retailers to improve our understanding of retail power and uncertainty.

Although significant technological advancements have emerged during and after the study period, including digital trading platforms, blockchain and online auction systems, the findings presented here offer a valuable baseline for understanding the underlying dynamics of horticultural trade. These results provide a basis for evaluating how new technologies build upon existing behaviours and market structures.

Despite the historical nature of the data used in this study predating post-COVID-19 developments, the study's insights into trader motivations and information asymmetries remain highly relevant. The present results provide a foundational perspective through which the effects of digitalisation on the dynamics of the supply chain may be studied. Recent research has indicated a reciprocal relationship between the increasing scale of greenhouse operations and the adoption of digital technologies [91]. Many large growers are affiliated with major Dutch horticultural cooperatives, such as Harvest House, Growers United, Prominent Tomaten and the Dutch Flower Group. These cooperatives and their sales organisations benefit from economies of scale and efficient supply chains, creating a network of growers and connecting them directly with major retailers [91]. Clearly, the trade of greenhouse vegetables continues to rely on conventional structures, such as cooperative-auction-based trade systems. These have evolved into sales organisations in response to dynamic shifts in market conditions [92]. Flowers and plants are still traded physically via auctions by smaller growers [91,93], while larger companies increasingly use online auction systems [94,95]. The relevance of auctions lies in their potential to reduce information asymmetry and opportunistic trading through real-time transparency of supply, demand and pricing. Furthermore, the horticultural supply chain exhibits a notable absence of intra-chain trade systems, which has been shown to perpetuate deficiencies in information quality [93]. Consequently, the uncertainties and strategies identified in this study continue to reflect the current state of the sector. Future research incorporating more recent data is needed to explore how digital technologies may have altered the structure, behaviour and information flows within horticultural trade.

Industry and cooperative reports indicate that over 80% of greenhouse vegetables are still marketed through cooperatives and wholesalers, with online auction functionalities being increasingly being integrated into trade processes [96,97]. Secondary data from the Dutch greenhouse industry indicate that digital trading platforms and blockchain-based traceability systems remain embedded within the existing supply-chain trade structure rather than replacing them [98–100]. Government market analyses report a similar situation for cut flowers and ornamental plants, where physical auctions continue to handle the majority (currently 73%) of trade [101,102]. Royal FloraHolland, the Dutch flower auction, has expanded its digital trading platform, integrating the traditional auction clock with an online environment that facilitates direct trade while maintaining cooperative governance [96,103]. Sector-level initiatives have been proposed to address this issue by establishing a layered digital infrastructure connecting growers, buyers, and logistics partners in floriculture. However, the implementation of such systems in other greenhouse sectors, such as vegetables, remain limited or fragmented, with digital tools primarily being adopted at the company level [104]. Wageningen University & Research underscores the potential of blockchain and associated technologies to enhance transparency and traceability of transactions [105,106]. However, the institution acknowledges that their implementation does not substitute existing trade structures but provides supplementary trade options [106]. It is further noted that the adoption of these technologies remains incremental and necessitates further reinforcement through supply-chain structures [105,106]. In a similar vein, industry reports emphasise the gradual digital adoption through robotics and AI, thereby enhancing efficiency and coordination without altering the governance structure of the supply chain [107]. The findings of complementary evidence from the Dutch statistical office [108,109], and industrial trade reports [110], indicate the persistence of productivity growth, such as higher incomes and increased productivity. This suggests that technological and digital efficiencies are not isolated developments, but rather coexist within established trading structures. Collectively, these data substantiate the study's conclusion that the underlying uncertainties, coordination mechanisms, and strategic behaviours identified in preceding periods persist in today's more digitalised market environment.

6. Conclusions

This study contributes to the existing literature by providing data relating uncertainty to the strategic behaviour of growers, cooperatives, wholesalers, retailers, and trading strategies. The findings reveal a fragmented supply chain, in which both environmental and behavioural uncertainty influence strategic behaviour, thereby inhibiting supply-chain integration. Transaction Cost Theory provides a valuable framework for understanding the effect of uncertainty on supply-chain interactions in trade, emphasising the need for better coordination mechanisms and strategies to reduce opportunistic behaviour and inefficiencies in horticultural trade.

Despite experiencing negative consequences (see Section 4.3), supply-chain members deliberately exploit the absence or lack of information (asymmetric information). The horticultural supply chain always faces some degree of information asymmetry, as environmental uncertainty affects production and makes accurate forecasting difficult. While weather conditions can have an immediate impact on consumer demand, it takes weeks for this impact to become apparent to growers. The strategic behaviour of supply-chain members exacerbates latent information asymmetry.

The current supply-chain structure allows suppliers to choose when and where they supply their produce, which promotes competition and provides incentives for opportunistic behaviour. This seems advantageous for the large number of suppliers (1200 Dutch suppliers in 2018). However, the bottleneck at the five retail buying offices creates a market situation in which supply-side competition increases, benefiting only the retail sector. Reorganising the supply side could address the current imbalance in market power and improve the position of individual growers. Cooperation within the supply chain could mitigate price and market risks through contracts or hedging price risks in futures markets. Creating a supply-side bottleneck (for example, by setting up an online vegetable auction) could be an effective strategy.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture15222327/s1.

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