

A Systems Approach to Business Strategy:
The Case of Chocolate Production

Tatiana Boyarskaya

Evgenia Ushakova

Markus Schwaninger (Supervision)

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Abstract

In this contribution, we explore the logic of systemic strategy making. Our aim is to demonstrate the strengths of dynamic modeling and simulation in crafting business strategies. As a case study we have chosen a company from the chocolate-processing industry. The respective enterprises are exposed to a context which entails high complexity of decision-making. International chocolate-processing companies have been increasing their market footprint through capacity expansion into cocoa producing countries, where unstable economic and climatic situations lead to cocoa price fluctuations. These in turn affect the pricing and investment decisions of producers, who seek to avoid demand shortfalls and idle capacities. A system dynamics approach is applied to help chocolate companies manage capacity and price-risk hedging decisions. Based on simulation results we suggest an optimal range for annual capital expenditure and efficient risk-mitigation policies. The modeling and simulation approach chosen shows substantial benefits which exceed those of conventional, merely qualitative strategy making.

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Introduction

The purpose of this paper is to explore the logic of systemic strategy-making. Our aim is to demonstrate the strengths of dynamic modeling and simulation in designing business strategies. This exercise will be achieved by means of a System Dynamics model, which represents the business system of a chocolate producing company. This kind of enterprise features fragile sourcing conditions and stable consumption in capital-intensive, high-risk commodity markets. If capacity investment and cocoa price risk policies are tackled properly in such a company, the economic benefits can be high. Accordingly, dynamic modeling is a tool with high potential leverage.

We use a single case setting, which is the appropriate research design if the character of the case is revelatory: we expect to draw insightful conclusions on the basis of a longitudinal study (Yin, 2009). In the case under study the focus will be on modeling (1) supply and demand, and (2) the capacity extension cycle. The resulting behavior patterns and scenario analysis should help understand the issues of investment and pricing policies, and provide effective policy recommendations to processors of cocoa beans and manufacturers of industrial chocolate.

The paper consists of five parts. It begins with an overview of the industry, which is today dominated by four international companies, introduces the reference company Barry Callebaut, its strategy, and the major strategic challenges.

In the second section, we develop conceptual foundations of the simulation model to anticipate the future behavior of four key variables: consumption, price, production (grinding) capacity and sales revenue of the target company. We assume that all these variables will demonstrate growth during the chosen simulation period of 18 years. We then formalize the model according to the System Dynamics methodology and with the help of computer simulation software.

The third section looks at the simulation results for different capacity investment and cocoa risk hedging strategies, expressed as rates. Assuming no changes to the model structure, we first apply a default model setup ('Base case') and then compare it to the marginal cases and, based on the findings, select the most appropriate strategies.

The fourth part is concerned with the assurance of model quality. We provide results of the selected validation tests of the model structure and behavior. Once the model and the simulation results are proven to be valid, recommendations can be made.

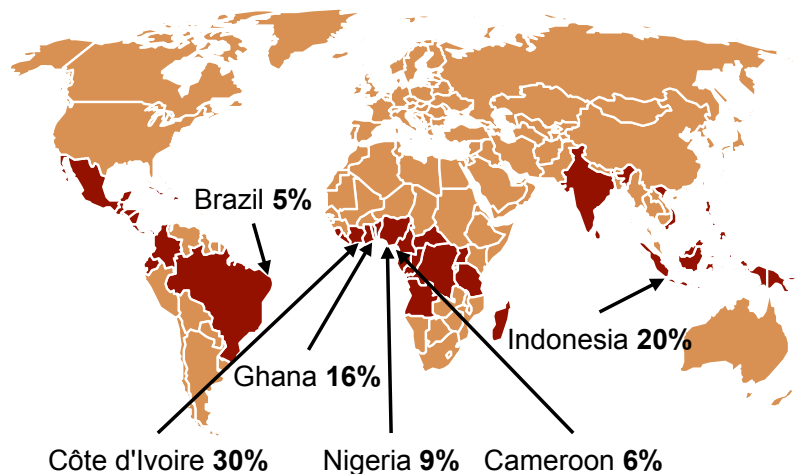
The major policy suggestions and directions for further research are outlined in the fifth part. The report is then finalized with brief conclusions.

1. Business Model Description

1.1 Cocoa-Chocolate Supply Chain

Chocolates and chocolate confectionery are the final products of a processing and manufacturing sequence that begins with cocoa beans, the seeds of a tree whose cultivation is confined to limited areas and climatic conditions of the Equator region (UNCTAD, 2008). Currently, six countries generate 86 percent of the world's cocoa output (see Figure 1).

Figure 1: Main areas of cocoa cultivation

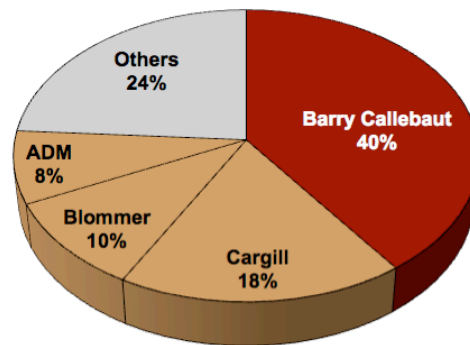


Source: based on Faostat data (FAO, 2012)

The supply chain begins with cocoa cultivation and ends with consumer goods, so-called chocolate confectionery¹. Chocolate-based products have by now been produced in the developing countries to satisfy the demand of the industrialized world. As a result, the processing of cocoa into chocolate is carried out in both the cultivation areas and the factory settings in consumer countries, to which full or semi-processed beans are delivered by international traders.

The boundaries between cocoa processing and chocolate manufacturing are blurry because the processing is nowadays closely related to the making of *couverture* or *industrial chocolate*, an intermediate product and the main input for manufacturing of chocolate confectionery: chocolate makers do not themselves manufacture *couverture*, but they only rework it into various chocolate products. The *couverture* market is dominated by four so-called *industrial chocolate processors*: Barry Callebaut, Cargill, Blommer, and ADM (see Figure 2).

¹ Glossary of terms related to the chocolate industry can be found in Appendix A.

Figure 2: Shares of major processors in total annual output

Note: in annual output terms (tonnes)
Source: UNCTAD (2008)

The unsophisticated cocoa processing technology makes couverture pricing rather transparent. The main raw materials for couverture (cocoa-based products, milk, and sugar) are actively traded in the commodity markets². Unlike those of milk, cocoa prices are highly volatile and depend on fluctuating economic health of OECD countries, disinvestment in the cocoa trade and processing industry, cyclical pattern of cocoa production, and ever-growing speculation in the markets. In fact, the volume of cocoa traded in futures contracts is ten times that of actual world production. Current high prices are strongly affected by production deficits (2006 – 2010) and disruption of cocoa exports (Fairtrade Foundation, 2011).

1.2 Barry Callebaut Company Profile

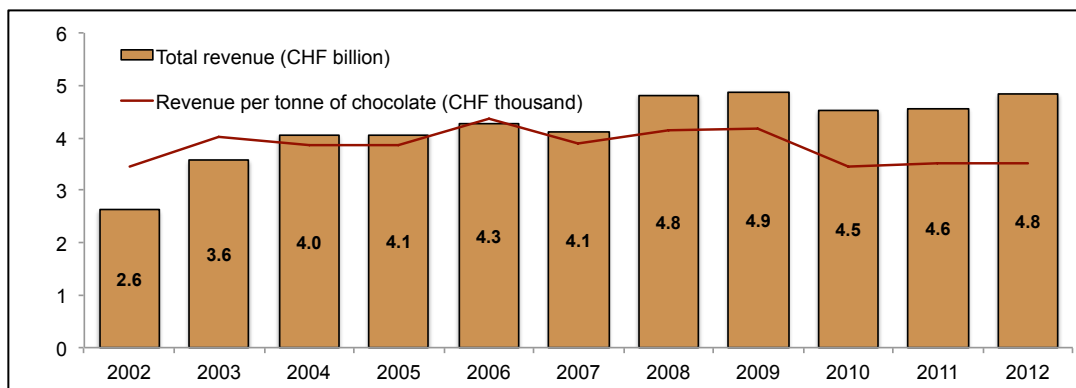
Barry Callebaut is a Swiss industrial chocolate processor that operates in the business-to-business environment. Barry Callebaut is a successor of a chocolate company Callebaut, which was founded in Belgium in the 19th century and later became part of the Swiss-based food company Jacob Suchard. Callebaut's principal activity was production of industrial chocolate for sale to chocolate-makers³. In 1990, all Jacobs Suchard businesses except for Callebaut were sold to Kraft Foods, an American food conglomerate. In 1996, Callebaut and the smaller French company Cacao Barry merged into a new entity called Barry Callebaut.

Today, Barry Callebaut is the world's leading manufacturer of high-quality cocoa and chocolate products. The company has evolved from a supplier of industry and specialty chocolates for industrial and artisanal customers into a provider of integrated solutions, from cocoa bean to packaged couverture.

Since the early years, the Company revenues have been growing at an average annual rate of 6 percent. Over 10 years, Barry Callebaut managed to almost double its turnover (see Figure 3). At the same time, revenues per tonne of chocolate have slightly diminished over the past years due to overall price decrease in the market.

² Monopolies and Mergers Commission (1997)

³ Ibid.

Figure 3: Barry Callebaut revenue highlights

Source: Barry Callebaut (2012)

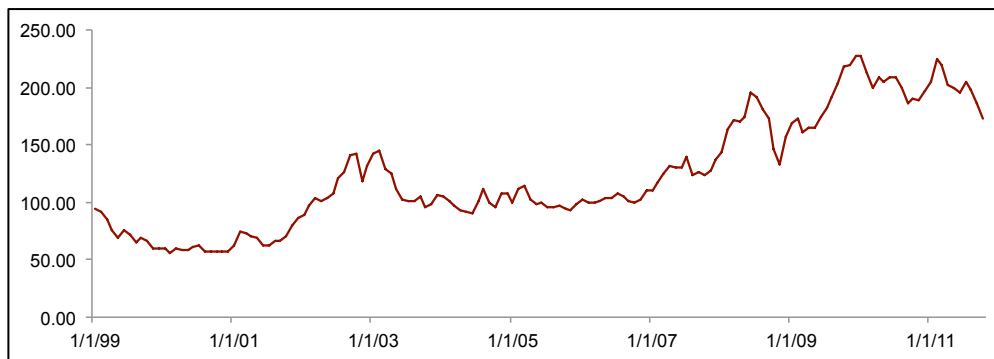
About 80 percent of Barry Callebaut's production costs lie in raw materials, which the company either supplies from its own sources or purchases in the commodity markets. By selling all its couverture on a cost-plus basis, the company transfers the risk for cocoa price shocks to the customer and maintains high working capital levels to both secure its day-to-day operations and support capital-intensive geographic expansion, which includes diversification of initial cocoa sourcing and production increase in consuming countries.

Despite attempts to diversify sourcing, Barry Callebaut mostly collects cocoa in the unstable Western-African region: Five major grinding facilities, which amount to eleven percent of the company's workforce, are located in Ghana, Côte d'Ivoire and Cameroon (Barry Callebaut, 2012).

1.3 Strategic Challenges

Industrial chocolate processors face two strategic challenges, which are connected to each other but should be tackled separately.

Dealing with volatile prices is the first challenge. During the first 12 years of its existence, Barry Callebaut saw the two cocoa price extremes when prices first reached a 27-year low (USD 714 per tonne) at New York Mercantile Exchange in November 2000 and a 32-year high (USD 3,775 per tonne) in March 2011 (see Figure 4).

Figure 4: Historical cocoa price development trend

Note: 1999 is the base year. Source: ICCO (2012)

Local obstacles in the cocoa-growing countries lead to higher prices, both at source and in the open commodity markets, and subsequently low demand for chocolate.

When crop output shrinks in response to processing capacity growth, cocoa processing companies either have to pay more for the beans or leave the capacity idle (BF&T, 2010). Thus, the second challenge is the capacity investment tradeoff: Investment decisions have to be made in order to keep supply of chocolate stable and cope with the competition. This being said, industrial chocolate processors keep investing in new capacities, usually when demand for chocolate is growing. However, once demand shortage occurs capacity investment policy should be adjusted so as to stimulate the market on one hand, and to avoid idle capacities on the other hand. Moreover, capacity extension is needed to geographically diversify sourcing of cocoa. This would mitigate the risk of cocoa price fluctuations that are subject, among other reasons, to weather conditions and political instability in the Ivory Coast, the world's largest area of cocoa cultivation. It is easy to exemplify the expansion strategy: in 2012, Barry Callebaut invested CHF 178.2 million to extend and maintain its factory footprint (Barry Callebaut, 2012).

2. Modeling with System Dynamics: Structure

2.1 Goal and Questions

The *capacity tradeoff* and the *cocoa price challenge* have so far been the main concerns of the industrial chocolate processors and the former will most likely continue to jeopardize the cocoa-chocolate business in the future.

The goal of this modeling project is to make a quantitative forecast of sales revenues of a big industrial chocolate processor for distinctive capacity investment rates at different degrees of cocoa price risk mitigation.

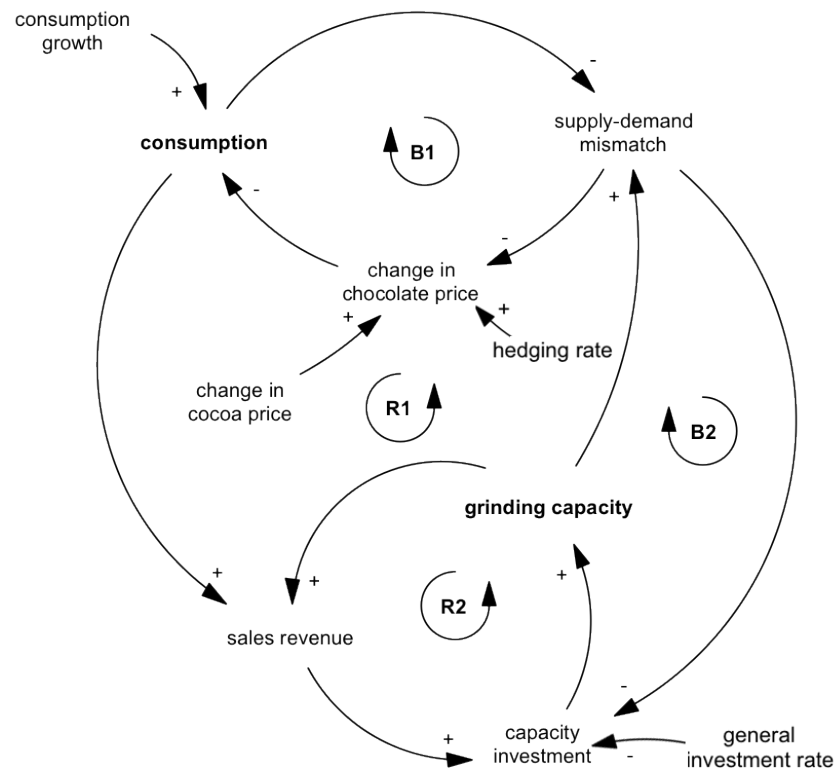
The case of Barry Callebaut was chosen because the company is the ultimate market leader and innovator and only engages in the cocoa-chocolate business with active presence in almost all cocoa-producing countries and major chocolate markets. Unlike some of its competitors, Barry Callebaut is a publicly traded company, and therefore it officially publishes all the necessary financial and strategy-related information.

Once the goal is reached, the forecast should help the company management (i.e. potential users of the model) answer the following questions: (1) Should industrial processors like Barry Callebaut pass on the risk of cocoa to the consumers of chocolate confectionery or rather employ risk-mitigation (hedging) strategies? (2) How intense should the capital expenditures be in order to ensure sales growth with no destructive effect on consumption and prices?

2.2 Key Variables and Causal Loops

We shall build a dynamic model and look at the in-time behavior of the chocolate price (CHF), consumption demand (tonnes) and grinding capacity (tonnes) to further translate them into Barry Callebaut's sales revenue (CHF).

We started with a conceptual framework and mapped the underlying feedback logic in form of a causal loop diagram (see Figure 5). There are four key loops, documented in analytically in Appendix B, which have either positive (reinforcing – “R”) or negative (balancing – “B”) feedback (Sterman, 2000). The diagram includes consumption growth, which constantly disrupts the stable state of the model. In stable state, for a given price, producers' output capacity (supply) should equal consumption (demand). However market growth and price fluctuations constantly disrupt this equilibrium causing supply-demand mismatch. The latter, in turn, changes the chocolate price. When price increases, chocolate becomes less affordable and consumption falls, and vice versa.

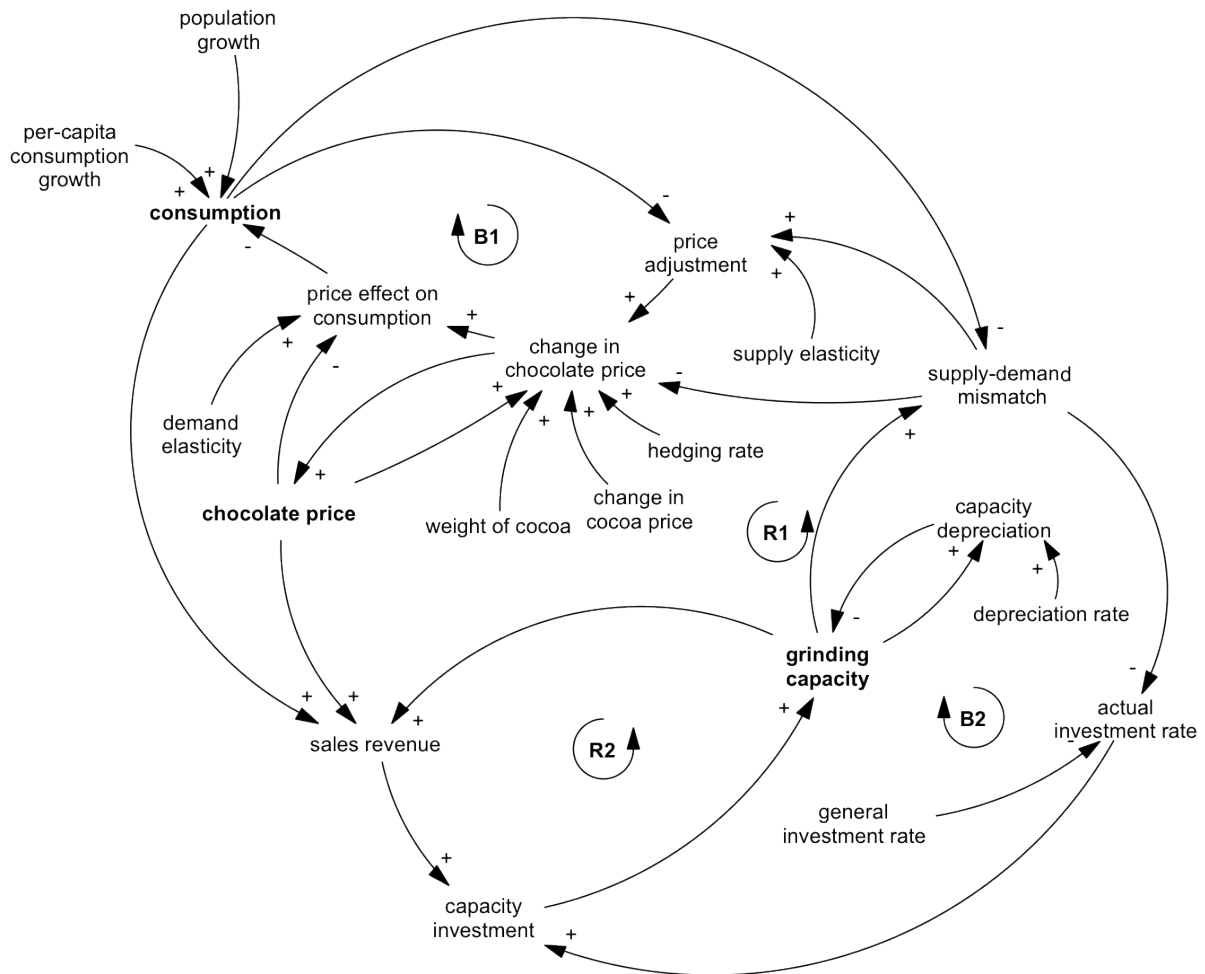
Figure 5: Primary causal loop diagram

The behavior of the market is well illustrated by loops R1 and B1. As long as consumption and chocolate price change, the reinforcing loop R1 attempts to match supply with increasing consumption through capacity increase and price adjustment. In the end, the reinforcing loop leads to sales revenue growth. The balancing loop B1 draws on the classic price-setting logic for different supply and demand combinations, pulling consumption down at higher, and hence less affordable, price levels.

The producer's internal capacity expansion policy is depicted by loops R2 and B2. Reinforcing loop R2 explains the internal capacity expansion policy, according to which the producer invests a certain fraction of sales into capacity growth. At the same time, there is a balancing loop B2 that restrains the capacity expansion cycle when the supply level is too high.

Even though the four loops frame the model (Appendix B provides a complete illustration of these loops), they still do not embrace all variables, which are necessary to describe the nature of the cocoa-chocolate business in a quantitative way; therefore, additional variables are needed (see Figure 6).

Figure 6: Complete causal loop diagram



In the complete diagram consumption growth is explained by the world population growth and simultaneous increase in per-capita consumption of chocolate due to higher incomes and changing preferences (Euromonitor International, 2012). Price elasticity is added to the model to express the strength of the price effect on consumption.

The complete diagram does not include some of the third-party variables like capacity growth limits, profit, expenses, and price behavior of other commodities such as milk and sugar.

2.3 Assumptions and Reference Mode

Being a simplified replication of reality, the model builds upon certain generalizations and assumptions, which are summarized below.

- Market. We assume that the growth rate of population and per-capita chocolate consumption will be decreasing in the future, and the United Nations (2004) projection is our main reference. Since the final product (chocolate) is homogeneous and sold on a long-term contractual basis, we also assume that there are no stocks

of finished goods and virtually no competition in the short and medium run. Thus, Barry Callebaut constantly has 40 percent of the market in terms of output.

- Production capacity. We estimate the share of cocoa as 55 percent of the weight of final cocoa-based products⁴, to measure the extent to which cocoa price fluctuations affect the price of chocolate. There is also a time lag of two years between the decision to invest into a new capacity and the actual capacity increase, with no limits to growth for at least 200 years. The capacity investment and depreciation rates are held constant.
- Cocoa supply. We assume homogeneity of cocoa supply and apply the historical oscillating price growth pattern based on ICCO⁵ (2012) data. There are no supply-side shocks (e.g. crop failures) in addition to those reflected in the fluctuating cocoa prices. Finally, fluctuations of milk and sugar prices are taken as negligible.

The time frame of the model is set to 200 years for the tryout phase, but only 18 years (from 2012 until 2030) are needed for the strategy analysis. The time step is set to 0.03125 years to avoid integration error.

As a next step, we will apply quantitative simulation techniques and employ the Vensim⁶ software to build the quantitative model as well as to test and explore its behavior.

2.4 Stocks, Flows and Model Quantification

After drawing the causal loop diagrams (Figures 5 and 6) we proceed to design of a stock-and-flow diagram as the structure for the simulation model. In this phase, consumption, chocolate price and grinding capacity are defined as stock variables, as depicted in

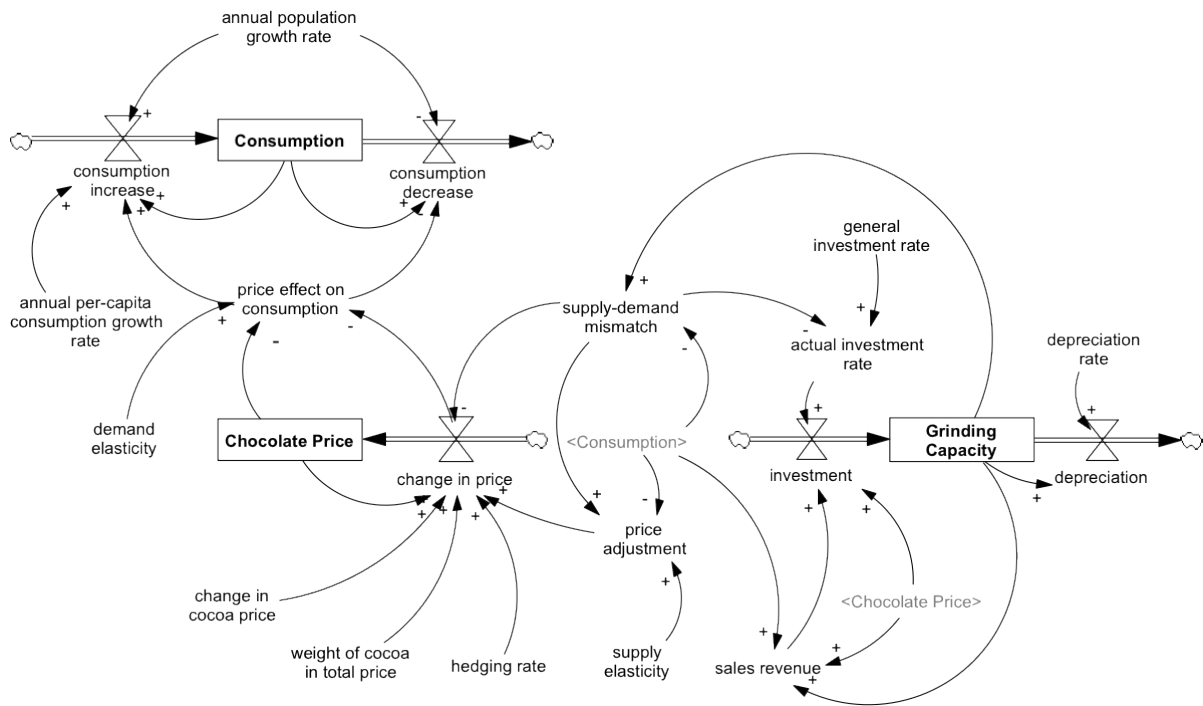
Figure 7. In the stock-and-flow diagram, all causal relationships are programmed in a quantitative way, and all respective equations are documented in Appendix C.

⁴ We take the average cocoa content of min. 25% and max. 85 % (Haas, 2011; Barry Callebaut, 2012).

⁵ International Cocoa Organization: www.icco.org.

⁶ Vensim is a System Dynamics simulation software developed by Ventana Systems (www.vensim.com).

Figure 7: Stock-and-flow diagram



In mathematical terms, the three stock values accumulate or downgrade with each iteration through respective inflows and outflows.

```

Consumption = INTEG(consumption increase - consumption decrease)
Chocolate Price = INTEG(change in price)
Grinding Capacity = INTEG(investment-depreciation)
    
```

The sales revenue is left as a standard variable that can be simply calculated as the product of current price and consumption if supply is higher than demand and vice versa.

```

sales revenue = MIN(Consumption, Grinding Capacity) * Chocolate Price
    
```

The model is built in a way that it follows the “floating goal” principle (Sterman, 2000, p. 533) because there are no external reference points to determine the equilibrium price, optimal capacity or target sales. In order to approach these floating goals, the model recalculates the supply-demand mismatch, producer price adjustment as well as the adjusted price effect on consumption.

```

supply-demand mismatch = Grinding capacity - Consumption
price adjustment = -"supply-demand mismatch" / Consumption*supply elasticity
price effect on consumption = demand elasticity * change in price / Chocolate Price
    
```

Exogenous variables such as price elasticity of supply and demand, general investment rate, and depreciation rate are held constant throughout each simulation run. The patterns of population growth and per-capita consumption growth are also external to the model, but since their behavior is not linear, their values change for each point in time (please refer to Appendix C for respective equations).

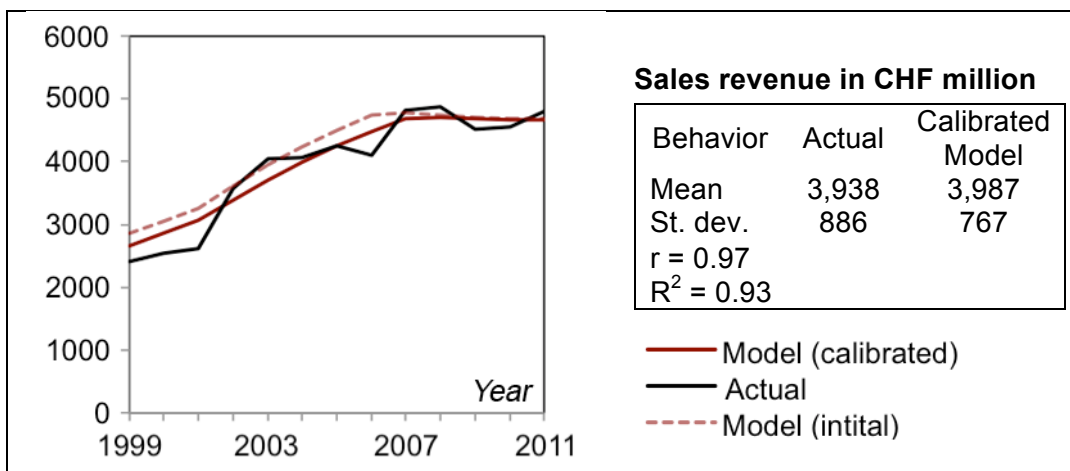
2.5 Historical Fit and Dynamic Hypothesis

While most of the variables' values are set outside of the model or follow predefined paths, two rates can be managed through management policies. These are (1) the rate of actual investment to sales (marked as "general investment rate" in Figure 7) and (2) the cocoa price risk-hedging coefficient ("hedging rate"). We aim to vary these rates to test the outcomes of alternative courses of action, while keeping all parameters and equations unchangeable for all simulation runs.

In a first step we look for the closest-to-actual values of the two rates above. Therefore, we set consumption, grinding capacity and chocolate price for the end of year 1999 at actual values and run the model for 12 consecutive periods, until the end of year 2011. We apply the Vensim optimization tool to compare the payoff (sales revenue) to the actual sales of Barry Callebaut for the period from years 1999 to 2011 (see Appendix D). This operation is called calibration. It is a quantitative way to optimize the model so that it makes a better historical fit, in other words, it enhances the precision of the model's replication of the real behavior of the system under study. The methodology aims at minimizing deviations of the target variable from its historical evidence, by varying parameters of the model (Sterman, 2000).

The optimization parameters in our case are general investment rate and hedging rate. The investment rate is allowed to fluctuate between 0.1 percent and 30 percent of sales revenue per period, whereas hedging strategies can vary between naught and 99 percent risk mitigation. The result of this calibration exercise shows a 97 percent correlation between modeled and actual sales revenues for the period with most of the error concentrated in the correlations between the two datasets according to Theil statistical error breakdown (see more detail in section 4 on model validity and testing). The optimal parameter values amount to 5 percent for the general investment rate and 95 percent for the hedging rate. The visual result for sales revenue is shown in Figure 9.

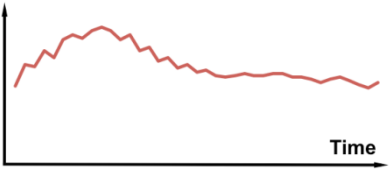
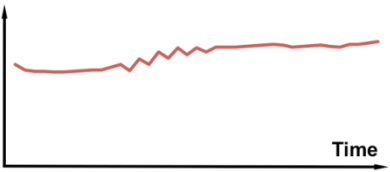
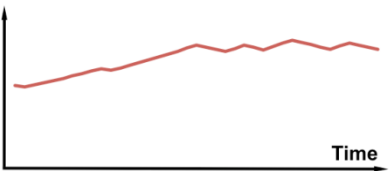
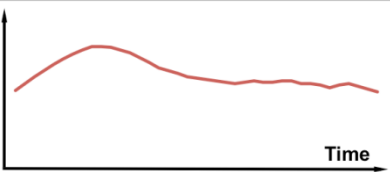
Figure 9: Sales revenue reproduction



An initially strong historic sales growth pattern reverts into a slower momentum and almost turns to decline by 2011. Based on model structure, we expect that such sales behavior will unfold into an overshoot and decline pattern. This implication also finds support in the forecasted behaviors of other key variables, as shown in Table 1.

Consumption, which also denotes the demand for chocolate, grows steadily over the forecasting period. Growing consumption requires more output, and temporary shortage of capacity catalyzes further price growth. However, as soon as capacity adjusts to demand over several periods, chocolate price will start to fall. Falling prices will partially restrain natural consumption growth.

Table 1: Reference mode

Modeled variable	Expected behavior	Illustration
Chocolate Price	Overshoot and decline	
Consumption	Steady slow growth	
Grinding Capacity	Steady slow growth with lags	
Sales Revenue	Overshoot and slow decline	

The overall structure of the model and its setup are sufficient to reach the initial goal: The model should be able to quantitatively ascertain the future behavior of the four key variables, based on different inputs for investment and hedging rates. The simulation results can therefore have practical significance for managers who determine appropriate risk hedging and capacity investment strategies.

3. Model Behavior

3.1 Base Case Simulation Output

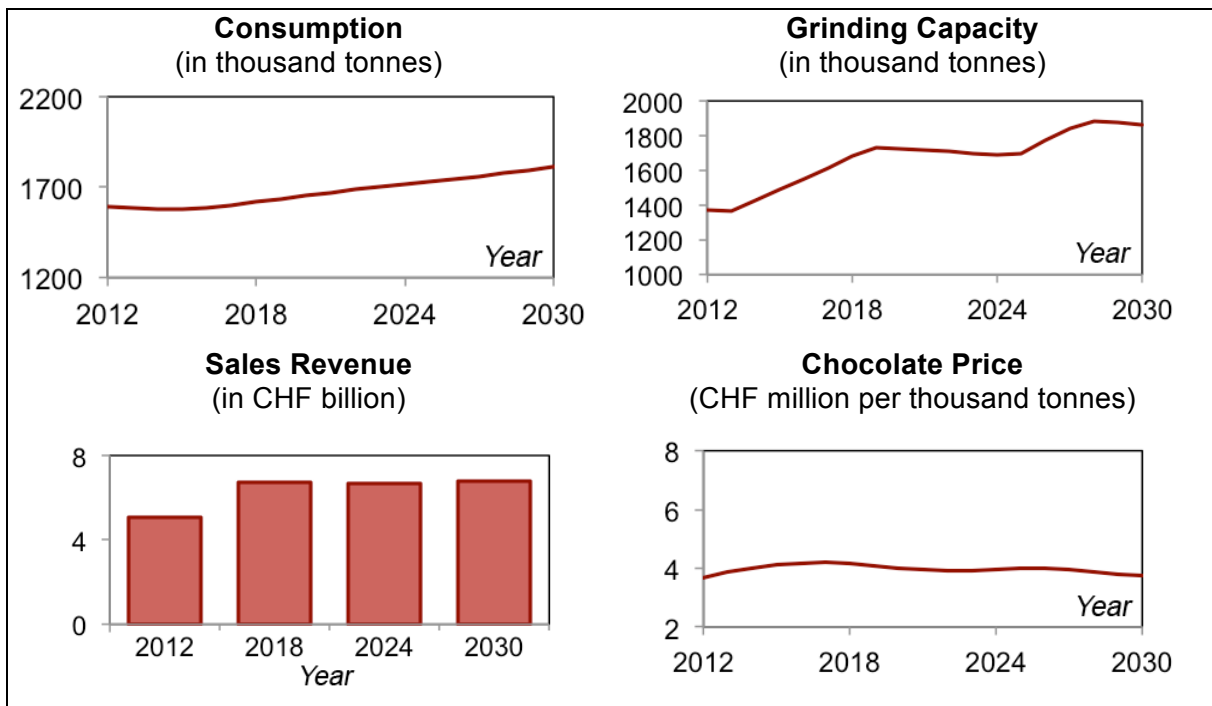
The first simulation run is labeled as Base case as it assumes the closest-to-actual initial values: The yearly investment rate equals 5 percent in cases of undersupply and most of the cocoa price risk is passed on to the market in form of various hedging products. The Base-case simulation over the period of 18 years generates the results depicted in Figure 10.

Chocolate price is the main driver of sales revenue growth and after a short period of growth its path reverses into slow decline. Such behavior of this stock variable is similar to the pattern we used for the reference mode although the decline does not seem as pronounced and the compound annual growth rate (hereinafter CAGR) remains positive at 0,4 percent over the forecast period.

Former projection was based on a slow consumption growth based on the assumption that the demand would be relatively inelastic to price shifts. However, the simulation results show that consumption is more likely to rise more sharply from 2012 until 2030 at a compound annual rate of 0.7 percent. Despite the fact that this pattern is not in line with the reference mode, it still seems sensible given the maturity of the market in question and negative price dynamics.

The grinding capacity behaves similarly to consumption, albeit its growth pattern has a larger amplitude and amounts to 1.6 percent per year on average. This pattern corresponds to the reference mode, though the latter expected a more moderate growth dynamics.

Figure 10: Base case results



Sales revenue grows by 1.8 percent per year with a decelerating pattern starting in the middle of the forecast period. Albeit no collapse is visible over the forecast period, growth is only observed during the first three years of the simulation period with no hint of further cyclicity. This result is more optimistic than the initial expectations but still in line with the reference mode for sales revenue.

3.2 Scenario Analysis

Scenario building involves parameter adjustments to replicate various exogenous situations or managerial decisions without structural changes to the model. As noted earlier, Barry Callebaut may influence the market equilibrium either by investment in capacity (i.e. increasing supply) or by changing pricing policy (i.e. limiting or stimulating demand). In the latter case, the industrial chocolate processor can on one hand employ a ‘cost-plus’ strategy, where contractual prices are linked to three-month cocoa beans futures, passing therefore the raw material price shock risks on to final consumers. On the other hand, hedging strategies can be applied and consumer contracts would then be agreed upon through negotiations and altered every six months or once a year.

This common policy became the basis for other plausible scenarios. Taking the Base case with the actual investment rate of 5 percent of sales revenue, a four-percentage-point span was employed to create two additional scenarios. Then the hedging ratio was changed from 95 percent, as in Base case, down to 50 percent and 0 percent. This is how, we decided upon the two marginal scenarios for closer consideration (see Table 2).

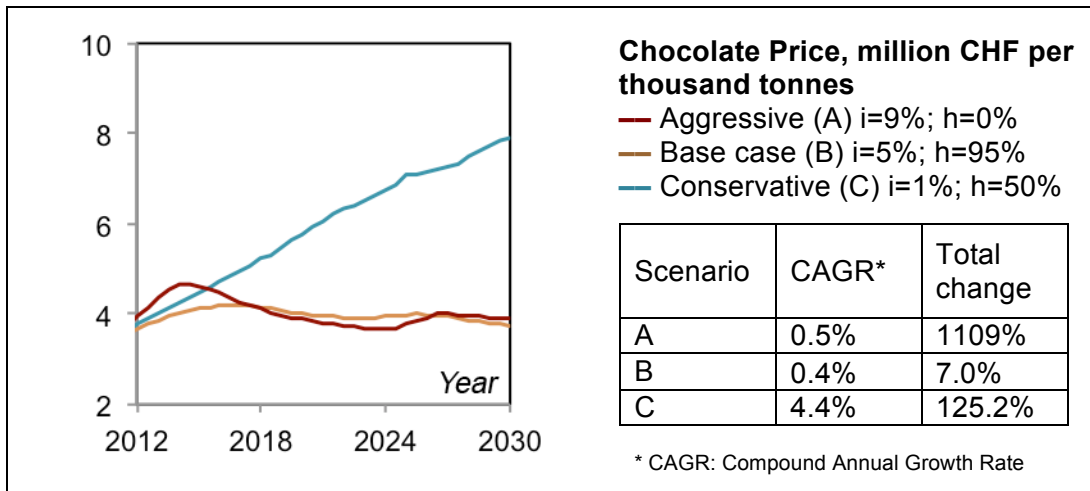
Table 2: Three selected scenarios

Hedging rate Investment rate	0%	50%	95%
1%		(C) Conservative	
5%			(B) Base case
9%	(A) Aggressive		

The Conservative scenario assumes the least intensive investment effort and moderate hedging strategy with about half the risk taken by the producer and the other half passed on to the consumers, whereas the Aggressive one is characterized by a more active investment attitude and zero hedging. The simulation output for all three stocks in various scenarios is provided in Appendix E.

Chocolate price is the first to respond to supply shortages and raw material growth. In comparison to the Base results, the Aggressive strategy may help stabilize prices in the long run, whereas the Conservative strategy even leads to doubling of prices in 18 years, which is well depicted by Figure 12.

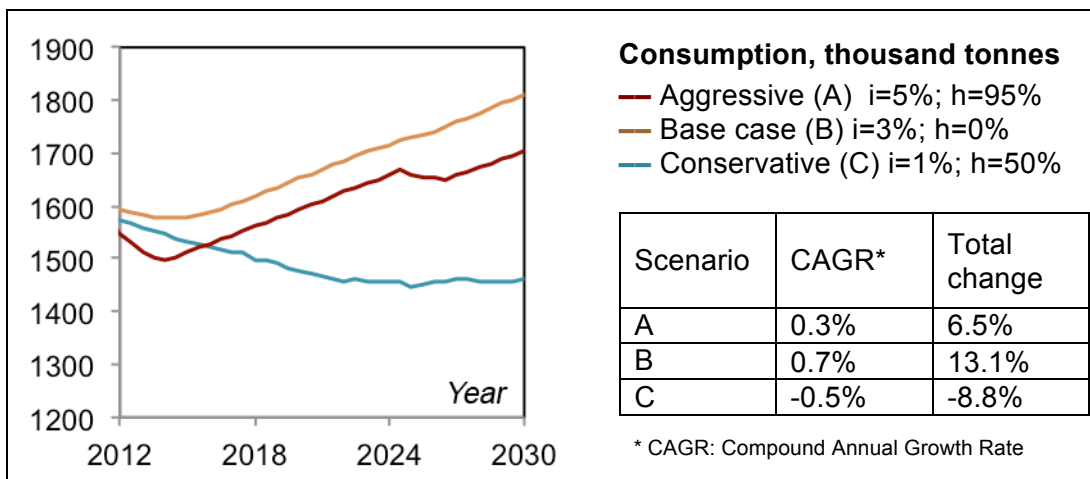
Figure 12: Price growth pattern in three scenarios



Obviously, the observed price patterns differ from one another and therefore must have a vast impact on the market itself.

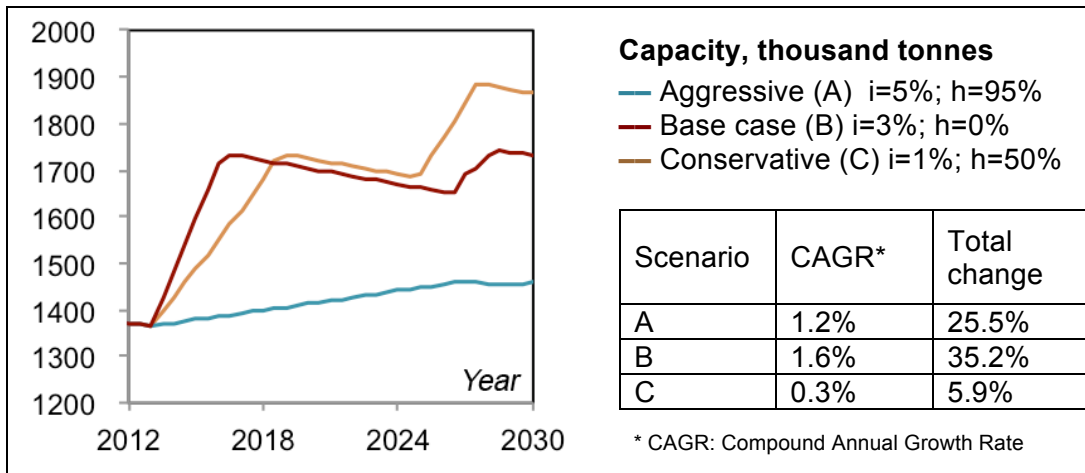
Though consumption prediction of steady growth in the Base case does not match the reference mode, its growth slows if the company chooses the Aggressive strategy and reverts into decline if the company chooses the Conservative one (see Figure 13). This means that consumption can be manipulated by means of combinations of investment and price risk hedging measures. In fact, in the ‘secured’ and ‘moderate’ Base case, consumption rises but once investment is constrained and more price risk is passed to the market, or the market is overflowed, demand levels and shrinks according to supply and price dynamics.

Figure 13: Consumption change pattern in three scenarios



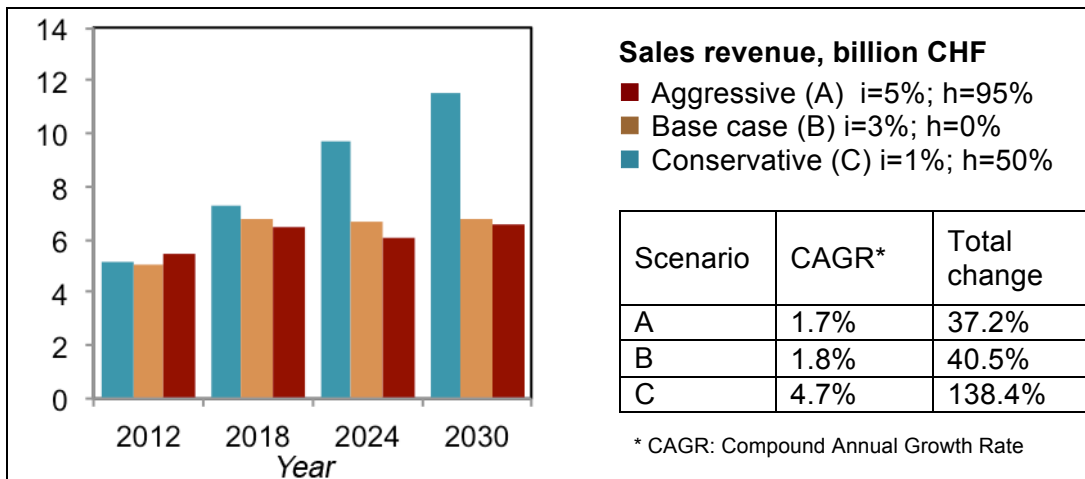
The “floating goal” principle makes grinding capacity (shown in Figure 14) approach the established consumption level. With a certain delay these variables show similar patterns.

Figure 14: Grinding capacity growth pattern in three scenarios



The financial forecast for all three scenarios finally draws our special attention, and is illustrated by the histogram in Figure 15. Quite unexpectedly, choosing the Base case means higher growth in sales during the first 8 years, whereas the Conservative strategy promises sales revenue doubling in longer term. Aggressive strategy does not ensure strong growth even though the pattern is still in line with our reference mode expectations. One should not forget that this option involves higher cash outflows due to more intensive capital expenditures. Therefore, high consumption and stable prices are probably not what chocolate manufacturer should aim at.

Figure 15: Sales revenue development in three scenarios



To summarize the findings, it can be concluded that the Conservative investment strategy leads to higher sales driven by higher prices. This is justified by supply limits that stir consumers to pay more for the same quantity of chocolate. Therefore, consumption shrinks in quantity but producers' income rises more sharply than in the Base case. On the contrary, in the Aggressive scenario, the market grows in quantity, but sales underperform and prices remain more stable.

4. Model Validity and Testing

4.1 Overview

All validation procedures are meant to establish confidence that the selected model represents the reality under study appropriately, and therefore provides accurate answers to the questions posed. The two possible approaches to validation, structural and behavioral, are interconnected; as according to Forrester and Senge (1980, p. 217), the structure of the model generates its behavior.

Structural tests assess the inner logic of a model. Behavioral tests make sure that the model generates adequate and convincing behavioral patterns, namely that it replicates the behavior of the real-world system under study adequately.

In order to test the cocoa-chocolate model, we selected the total of nine validation techniques derived from the literature in System Dynamics. These techniques are summarized in Table 3.

Table 3: Selected validation techniques

No .	Technique name	Domain	Forrester & Senge (1980)	Sterman (2000)	Schwanger & Groesser (2009)
1	Boundary adequacy	Structure	X	X	X
2	Dimensional consistency	Structure	X	X	X
3	Parameter check	Structure	X	X	X
4	Extreme conditions	Structure	X	X	X
5	Behavior reproduction	Behavior	X	X	X
6	Behavior sensitivity	Behavior	X		X
7	Extreme policy	Behavior	X	X	
8	Integration error test	Behavior		X	X
9	Theil inequality statistics	Behavior		X	

Four tests help examine the structure of the model, while the other five tests deal with the behavior generated by computer simulation.

4.2 Structural Tests

First of all, it is important to revise the conceptual boundaries of the model, as its depiction of the real life is simplified along several dimensions. On one hand, cocoa beans are

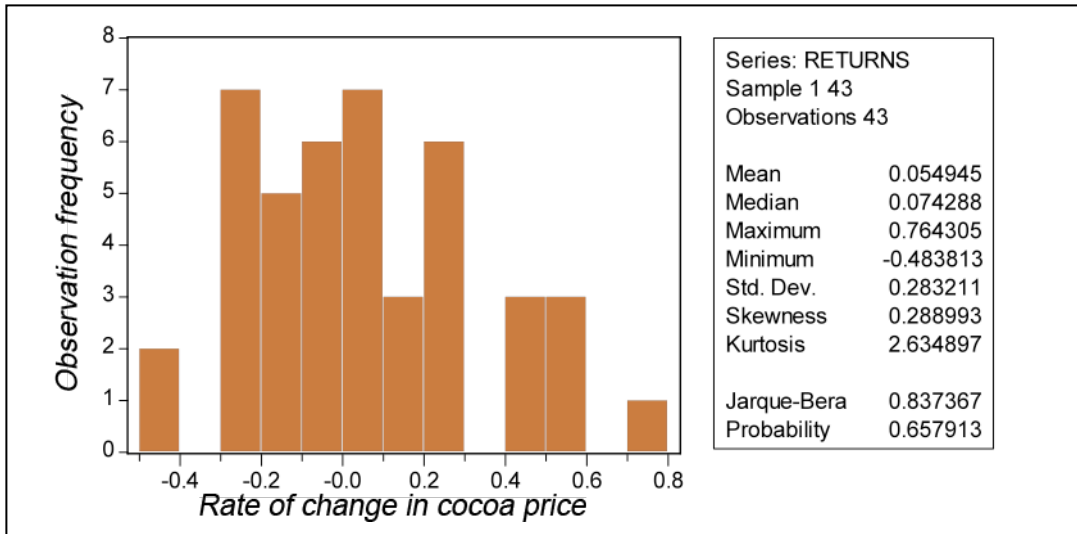
considered homogenous, whereas in reality the quality can vary significantly depending on the origin, breed and weather conditions. However, as couverture producers always use mixed cocoa bean sorts, the differences are negligible when it comes to the modeled output volumes. Next, we exclude competition. This can be justified by the fact that there are only a handful of big couverture producers who operate in an oligopoly rather than a purely competitive environment, and three out of the four largest producers do not have a significant footprint in Europe and Asia. Given such a market structure, along with high industry entry barriers, the assumption that constrained competition empowers market change is deemed reasonable. Another strong limitation of the model lies in scope of stock management: the model assumes that every tonne of couverture produced is sold immediately given the contractual nature of operations, where present production depends on prearranged future sales. Finally, the model excludes profits assessment and focuses on sales growth as the main reference point for strategies oriented towards market power.

Dimensional-consistency test reveals whether the measurement units of variables included in the model are consistent. In order to pass this test alone, it is often required to include the so-called “scaling” parameters (Forrester & Senge, 1980). Thus, one additional variable (“current year” = 1) had to be added in equations for stock-dependent variables. Vensim also has a built-in unit consistency test, which the current model has successfully passed.

When it comes to parameter check, the focus shifts to constants and exogenous influence factors used in the model. These should be plausible given real life structures, and must represent reality well, both logically and numerically. There are several external parameters considered in the present model. On the demand side, annual consumption growth rate and population growth rate structurally contribute to consumption growth. World per-capita consumption growth is approximated on the basis of the Euromonitor International (2012) data for the last five years. Population growth conforms to a long-term population prognosis by United Nations (2004): it equals to 1.03 percent until 2025 and comes close to null within the next 75 years. The parameter is plugged in as a horizontal zero-approaching hyperbola.

On the supply side, the exogenous parameter is depreciation rate. In Barry Callebaut’s (2012) financial statements, this value equals 0.5 percent of fixed assets. Finally, on the chocolate price side, we assume that the share of cocoa cost in the overall chocolate price is about 55 percent, and we express cocoa bean price fluctuations as a rate of change in time. For modelling purposes we assessed cocoa bean price change based on historical yearly commodity prices for the past 40 years published by ICCO (2012). We supposed that this time process could follow a normal distribution, which is confirmed in the statistical summary in Figure 16.

Figure 16: Cocoa beans price fluctuation pattern



4.3 Behavioral Tests

One way to assess the modeled behavior is to conduct behavior replication tests. However, in the present exercise we employed a behavior reproduction test directly after model calibration in order to set up the model in the best way possible and not only to check it for errors after the forecasts have been made. Such decision was made due to the nature and availability of historical data that can significantly influence the quality of forward looking statements regarding the problem. Please refer to the replication results in section 2.

Replication results can be confirmed by means of Theil inequality statistics. It is a quantitative way to test for the precision of historical fit of the model. It technically represents a breakdown of the minimum squared error (MSE) rule (Sterman, 1984). The decomposition reveals errors contributed by difference in observed and estimated means U_m and standard deviations U_s , as well as the correlation between historical and modeled datasets U_c :

$$MSE = (U_m + U_s + U_c) \times MSE$$

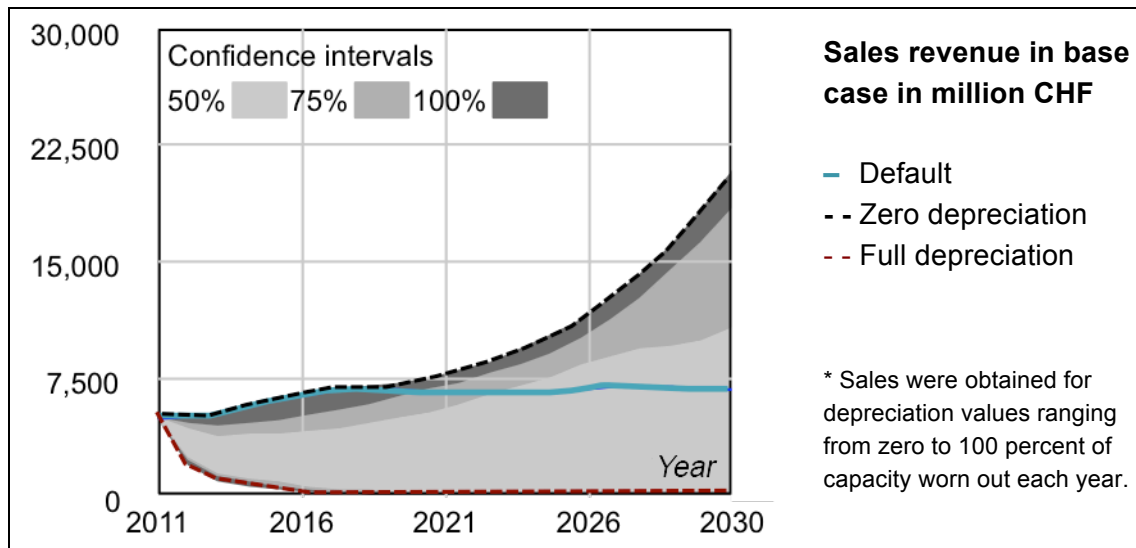
Computation of the statistic for sales revenue, the target variable, shows no evidence of systematic error because the mean and the standard deviation errors are close to zero (see Table 4). Errors occur largely due to the impact of correlations between historical and simulated behaviors, which leads to the conclusion that the model should not be failing to capture the scale and trend of the actual dynamics.

Table 4: Theil test of modeled and actual behavior

Indicator	Model vs. Actual
R	0.97
MSE	57,605
U_m	0.04
U_s	0.24
U_c	0.80

We tested the sensitivity of sales revenue behavior to adjustments of depreciation. Figure 17 shows that the revenues have greater downside potential once depreciation rate augments and the revenues eventually collapse at full capacity depreciation. This pattern is in line with economic fundamentals because the supply side pulls revenues down straight after the first iteration.

Figure 17: Test of sales revenue sensitivity to all depreciation values*

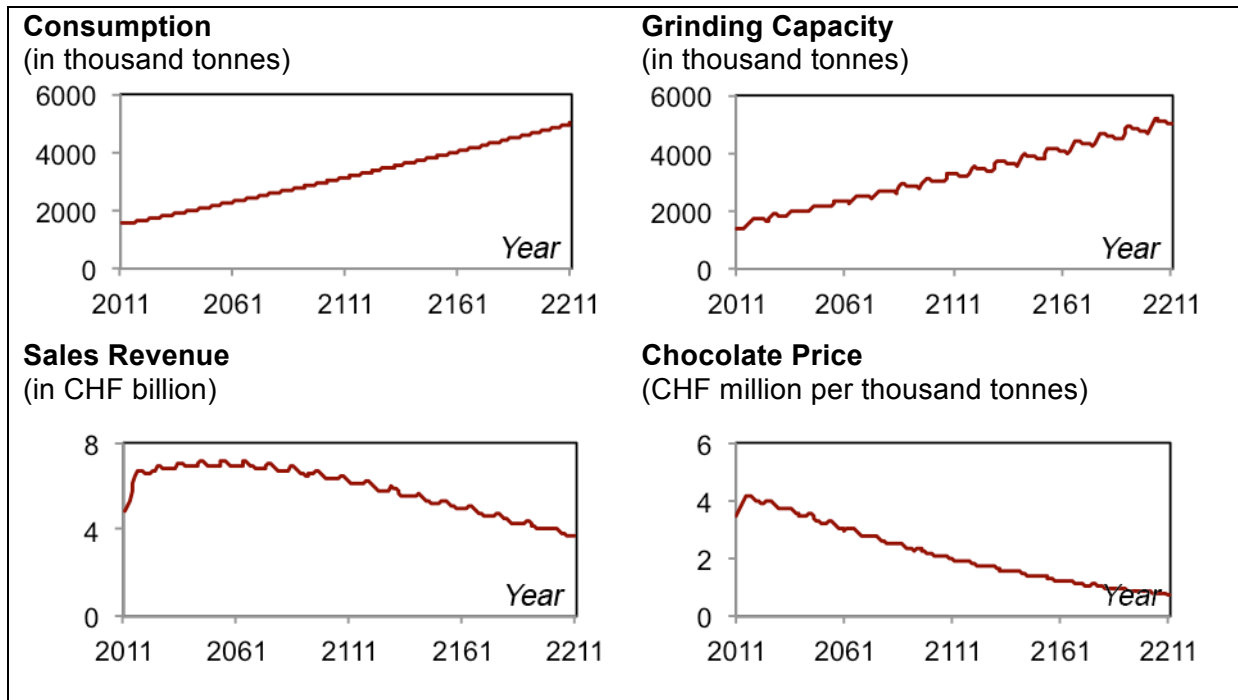


After we tested the structure against extreme shocks of depreciation, we apply another extreme condition to check the forecast quality.

Extreme policy tests operate with both radical parameter changes and a great extension of the model's time horizon, in order to control for pattern stability. Having tested the behavior generated over 200 years, we find that the resulting curves are in line with the reference mode for each of the four variables (see Figure 16).

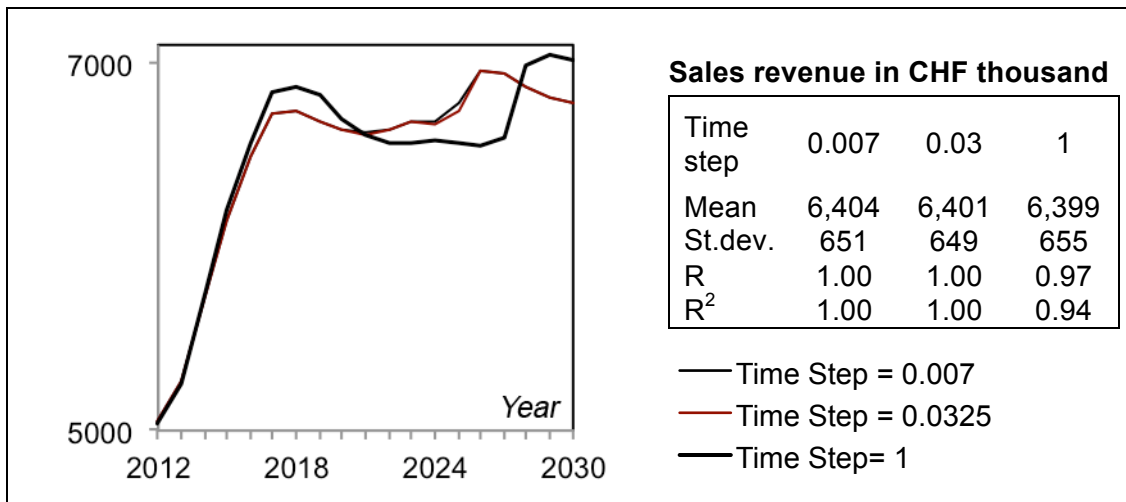
Even though the selected time horizon of two centuries is strategically irrelevant, the test underpins the model's forecasting stability and alignment to the reference mode. This approach helped us eliminate some flaws and make the forecast consistent during the model design phase.

Figure 18: Extreme policy base case forecast for 200 years



Finally, integration error test needs to be performed. The model is set to time step of 0.03125 years. For confidence reasons, it was downgraded to 0.007 and upgraded to one full year. As a result, there is little evidence of impact in the downgrade case and far larger deviations of the goal variable once the time step is increased (see Figure 17).⁷

Figure 19: Integration error test in base case



Overall, both the model structure and its behavior have passed the presented number of validation tests and proven to be robust, consistent and adequate for the stated goal.

⁷ The output values for this test can be found in Appendix F to this paper.

5. Discussion and Policy Recommendation

5.1 Key Findings

Different scenarios have been analyzed and the simulation results have been tested for adequacy and robustness. Based on this, three key findings can be derived:

- (1) Unevenly growing cocoa prices make chocolate more expensive and pull the long-run consumption down. This is visible from the causal relationships within the model (see Section 2.2).
- (2) Rapid consumption growth alone does not promise higher sales, due to stagnating prices. This is visible from the Aggressive scenario (for details see Section 3.2 and Figure 11).
- (3) Supply has to be constrained in order to boost sales; therefore, lower capital investment rates lead to higher revenues. This is shown in the Conservative strategy explained above (see Section 3.2 and Figure 13 for more detail).

Mitigation of the cocoa-price effect may strengthen control over consumption and prices. Investment rate may be less important, but it should be considered as the means to control for risk management, which will be discussed in line with the measures that are further recommended.

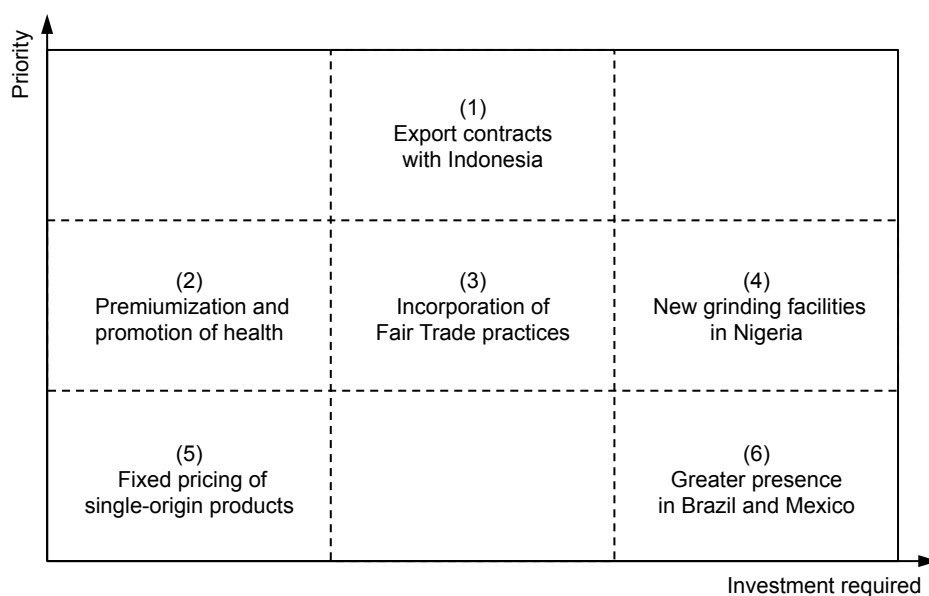
5.2 Policy Recommendations for Barry Callebaut

Based on the findings, we believe that the optimal strategies that Barry Callebaut should pursue in the future lie between Base case and Conservative scenario. The future strategy path should involve diversification of cocoa sourcing and a gradual minimization of the operations in the volatile open market. Thus, the two main managerial devices to create impact would be: (1) strategic and operative levers employed by the management team and the sourcing division, and (2) financial tools to hedge the commodity risks for the open market operations.

The second measure purely deals with hedging instruments for the open-market operations. This obviously requires involvement of traders and the controlling department to decide upon such instruments as swaps and options or search for trustworthy trade intermediaries.

The first strategy not only requires certain tools but also involves expansion decisions, looking into the future and dealing with both capacity and cocoa price challenges that we identified at the beginning of the project.

Reducing capacity investment levels in the future is practical to balance growing demand and rising prices for the benefit of the company. At the same time, sufficient facility expansion is required to boost the consumption level, which tends to decline in the long run, according to our projections. Based on this, six measures, grouped in Figure 20, are recommended.

Figure 20: Key strategic measures

Focus on high-priority measures assumes mitigation of the cocoa price risk at lower investment rates. Export contracts with Indonesia would stabilize cocoa supply without requiring any investment in new capacity. Owning no factories in Indonesia, one has to search for the most reliable partners and constantly monitor the quality of supplies. Other measures are briefly summarized in Table 5.

Table 5: Impact and potential challenges of the selected measures

No.	Measure	Impact	Potential challenge
1	Establish export contracts with Indonesia	Safeguards high scale supply of lower quality beans in case of cocoa shortage in Africa	Requires special quality control actions
2	“Premiumize” product offering and promote health	Boosts per-capita consumption growth, stressing the health benefits of chocolate	Can only promise a temporary short-term effect
3	Promote Fairtrade ⁸ practices in Western Africa	Improves on-site operations in Western Africa, providing workers with fair reward	Leads to higher and more stable chocolate prices
4	Build facilities in Nigeria	Ensures stable cocoa supply from politically and economically stable Nigeria	Requires high-scale investment in an ‘unexplored’ economy
5	Apply fixed pricing to single-source products	Ensures steady cash inflow from premium products	May rather incur more costs than benefits
6	Increase presence in Brazil and Mexico	Reaches out to the growing Latin American market with local cocoa supply	Deals with higher construction and labor costs than in Africa or Asia

⁸ Fairtrade is a movement that promotes better trading conditions for help producers in developing. The Fairtrade certification indicates the payment of a higher price to exporters as well as higher social and environmental standards. For details, visit www.fairtrade.net.

All outlined measures are selected because they should to some extent stabilize long-term prices, maintain steady consumption level and gradually increase production output.

5.3 Suggestions for Further Investigation

Since the model is designed and tested in an academic setting, it is still rather condensed and oversimplified in comparison to real market systems. Therefore, two types of improvements to the model are suggested, with or without structural changes.

The current model structure allows for adding new dependent variables without creation of new causal loops. From the financial perspective, the application of the model is not limited to sales forecasting. Adding fixed and variable costs would enable the users to predict profitability and calculate margins though these indicators do not play a crucial role in the decision-making process. It would also make sense to look at operating and investing cash flows and net present values of capacity investment.

By adding new causal variables, loops and stocks, the structure of the model can be further enhanced and generate behavior, which is closer to reality, or even answer additional questions. To make predictions more accurate, milk and sugar price growth patterns as well as labor cost dynamics could be added. The new research question would be to analyze, whether the modeling would give similar results if competitive behavior as well as external shocks and disasters were added to the structure.

Conclusion

To finalize, we can present two sets of conclusions, substantive and methodological.

Several insights have been gained that lead to a number of substantive conclusions. The study of industrial chocolate market formation, with its sales dynamics and applicable strategic policies, shows that market equilibrium can be achieved through consumption growth on the demand side in parallel with constant production capacity adjustment on the supply side. Producers like Barry Callebaut use levers to influence market equilibrium: either capital investment levers or cost-plus pricing that reflects fluctuating raw material costs.

An industrial chocolate processor's present day policy of a 3 percent annual capacity investment and no hedging employed will lead the market to an equilibrium situation with growing sales revenue, but contracting chocolate tonnage released and consumed.

Optimal policies on the supply side lie between the current case of moderate investment and full pricing risk transfer to customers on the one hand and more conservative strategies on the other. For Barry Callebaut it would therefore be recommendable to invest in grinding capacity at one to five percent of sales revenue per year in case of strong market demand for chocolate. In addition, moderate hedging activities should be initiated, which could involve diversification of sourcing into new countries as well as financial tools for the open market operations. Implementation could be achieved through sourcing expansion to Indonesia, Brazil, Mexico, Nigeria, financial markets hedging and marketing effort.

Caution should be taken when constraining capacity investment, as this may greatly offset price-driven sales growth: Once chocolate becomes virtually unaffordable, the consumption might drift to a niche market. In this case, overcapacity might become a burden. At the same time, companies like Barry Callebaut should maintain stability in consumption volumes. For this reason they are recommended to restrain from passing all the risk of cocoa price fluctuations to their consumers.

We have also come to methodological conclusions. The modeling and simulation methodology chosen for this case study offers substantial benefits, which exceed those of conventional, merely qualitative strategy making. First of all, strategies can be corroborated or refuted on solid grounds. Not only are the assumptions made explicit, but also the whole set of variables under study is made transparent with its relationships. The formal modeling process requires a flawless logic underlying a decision. Finally, the capability of setting up scenarios enables the exploration of the decision space, and the policy simulations help to ascertain the implications of policies and to find the best decisions. The modeling and simulation approach as used here does not show any grave disadvantages, except the danger of drawing premature conclusions on the basis of low-quality models.

More research would benefit practitioners and could involve both structural and qualitative model extensions. For instance, the model could be adjusted to analyze chocolate producers' profits dynamics or even to reformulate research questions and include competition in the analysis.

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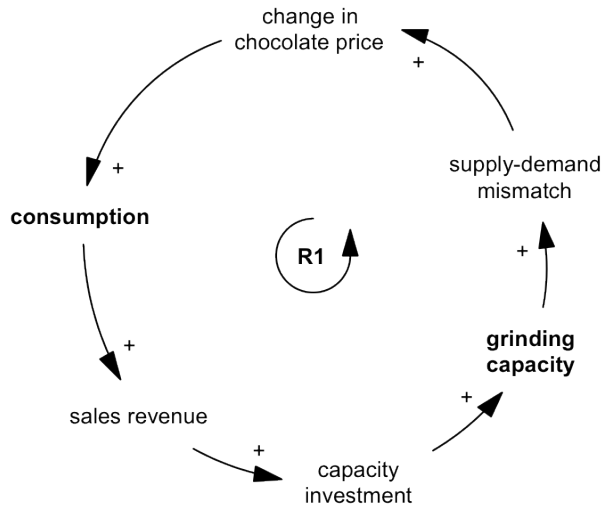
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Appendix A: Glossary of Key Terms

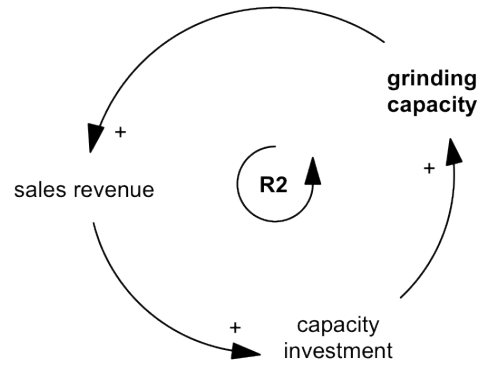
Chocolate confectionery	Part of the confectionery goods segment with cocoa content. The rest are sugar confectionery, biscuits and chewing gum.
Couverture	Industrial chocolate rich in cocoa fat content, the material from which finished chocolate products are made, the coating material used in the manufacture of chocolate confectionery, biscuits, or ice cream.
Grinding capacity	Producer's capacity to perform to initial cocoa bean processing (grinding) usually accompanied by roasting.
Hedging	Risk-management strategy used in limiting or offsetting probability of loss from fluctuations in the prices of commodities and transfer of risk without buying insurance policies.
Industrial (chocolate) processor	A manufacturing company involved in initial processing of cocoa beans (grinding and roasting) and subsequent production of couverture (melting).

Appendix B: Causal Loops

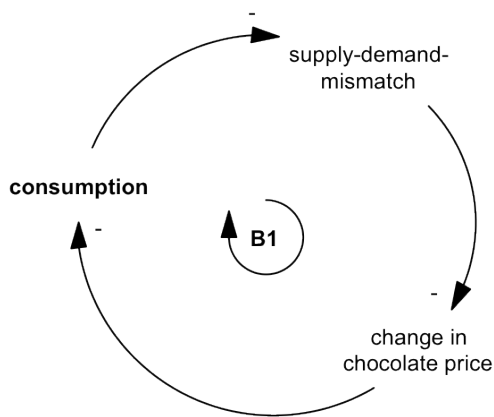
Supply-demand equilibrium (reinforcing loop)



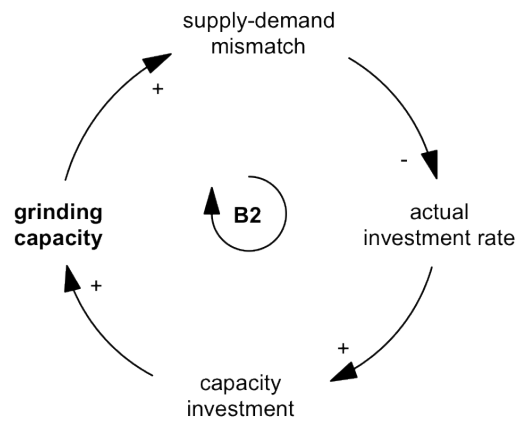
Expansion cycle (reinforcing loop)



Price-setting mechanism (balancing loop)



Investment decision (balancing loop)



Appendix C: Variables and Equations

Variable name	Unit	Initial value	Explanation	Formula
actual investment rate	dmnl.	n.a.	Share of sales invested in capacity for a given period	=IF THEN ELSE(supply-demand mismatch>0,0, general investment rate)
annual per capita consumption growth rate	dmnl.	n.a.	Consumption growth due to higher income and changing preferences	=0.02+0.2/(0.4*Time+5)
annual population growth rate	dmnl.	n.a.	Forecasted world population growth	=0.001 + 0.00953/(0.01*Time+1)
change in cocoa price	dmnl.	n.a.	Annual change of cocoa price	=RANDOM NORMAL(-0.483813, 0.764305, 0.054945 , 0.283211 , 0)
change in price	CHF / (thousand tonnes*year)	n.a.	Price delta due to search for market equilibrium and exogenous changes in main resource prices	=Chocolate Price*IF THEN ELSE(supply-demand mismatch<0, IF THEN ELSE(weight of cocoa in total price*change in cocoa price*hedging rate>price adjustment, weight of cocoa in total price*change in cocoa price*hedging rate, price adjustment), price adjustment)
Chocolate Price	CHF / thousand tonnes	3500	Actual market chocolate price available for final consumers	=INTEG(change in price)
Consumption	thousand tonnes	1600	Total quantity of chocolate confectionery consumed in the market	=INTEG(consumption increase - consumption decrease)
consumption decrease	thousand tonnes / year	n.a.	Annual demand shrinkage due to population decrease or rising prices	=Consumption*IF THEN ELSE (annual population growth rate<0, (-annual population growth rate)* (1-MIN(price effect on consumption,0)),-MIN(price effect on consumption,0))
consumption increase	thousand tonnes / year	n.a.	Increase of annual demand due to increase in total population, per-capita consumption and more affordable prices	=Consumption*IF THEN ELSE (annual population growth rate>0, annual population growth rate*(1+annual per-capita consumption growth rate)*(1+MAX(price effect on consumption,0)),annual per-capita consumption growth rate*(1+MAX(price effect on consumption,0)))

Appendix C (continued)

Variable name	Unit	Initial value	Explanation	Formula
demand elasticity	dmnl.	-0.35	The change of demand given price change of 1 percent	=constant
depreciation	thousand tonnes / year	n.a.	Natural reduction of production capacity in each period	=Grinding Capacity*depreciation rate
depreciation rate	dmnl.	0.005	Depreciation as percent of capacity	=constant
general investment rate	dmnl.	0.05	Investment in capacity as percent of sales	=constant
Grinding Capacity	thousand tonnes	1400	Production capacity and a measure of supply	=INTEG(investment-depreciation)
hedging rate	dmnl.	0.95	Fraction of risk mitigated	=constant
investment	thousand tonnes / year	n.a.	Capital investment in capacity in a given period	=DELAY FIXED(actual investment rate*sales revenue/Chocolate Price, 2, 0)
price adjustment	dmnl.	n.a.	Relative change of price due to change of supply	=-supply-demand mismatch/Consumption*supply elasticity
price effect on consumption	dmnl.	n.a.	Rate of change in consumption due to market forces in search of equilibrium	=demand elasticity*change in price/Chocolate Price
sales revenue	CHF / year	n.a.	Total revenue earned in one year	=MIN(Consumption, Grinding Capacity)*Chocolate Price
supply elasticity	dmnl.	0.35	Change of supply given price changes of 1 percent	=constant
supply-demand mismatch	thousand tonnes / year	n.a.	Difference between supply (capacity) and demand (consumption)	=Grinding Capacity-Consumption
weight of cocoa in total price	dmnl.	0.55	Share of cocoa in chocolate price formation	=constant

Appendix D: Sales Revenue Calibration Output Data

Behavior of sales revenue (in CHF million) before and after calibration

Behavior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Actual	2,410	2,548	2,621	3,571	4,048	4,061	4,261	4,106	4,815	4,880	4,524	4,554	4,800
Model (initial)	2,858	3,055	3,257	3,616	3,945	4,242	4,504	4,734	4,775	4,751	4,704	4,683	4,687
Model (calibrated)	2,660	2,856	3,059	3,395	3,709	3,997	4,257	4,485	4,685	4,711	4,693	4,664	4,659

Appendix E: Simulation Output Data for Stocks

Behavior of chocolate consumption (in thousand tonnes) in three selected scenarios

No.	Investment	Hedging	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
A	9%	0%	1,548	1,512	1,498	1,512	1,528	1,545	1,561	1,577	1,594	1,610
B	5%	95%	1,591	1,582	1,576	1,578	1,587	1,601	1,618	1,635	1,652	1,669
C	1%	50%	1,575	1,556	1,546	1,535	1,522	1,513	1,499	1,491	1,478	1,467
No.	Investment	Hedging	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	9%	0%	1,610	1,626	1,643	1,659	1,659	1,655	1,657	1,673	1,689	1,704
B	5%	95%	1,669	1,686	1,702	1,717	1,728	1,742	1,759	1,776	1,793	1,810
C	1%	50%	1,467	1,458	1,458	1,458	1,446	1,455	1,462	1,459	1,457	1,460

Behavior of chocolate price (in million CHF per thousand tonnes) in three selected scenarios

No.	Investment	Hedging	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
A	9%	0%	3.97	4.38	4.64	4.62	4.48	4.29	4.12	3.99	3.88	3.80
B	5%	95%	3.68	3.86	4.02	4.12	4.18	4.20	4.17	4.09	4.02	3.96
C	1%	50%	3.78	4.04	4.24	4.47	4.72	4.94	5.22	5.46	5.77	6.06
No.	Investment	Hedging	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	9%	0%	3.80	3.74	3.70	3.68	3.79	3.92	4.00	3.97	3.92	3.89
B	5%	95%	3.96	3.94	3.93	3.95	3.98	4.00	3.95	3.87	3.80	3.75
C	1%	50%	6.06	6.35	6.54	6.73	7.07	7.15	7.24	7.49	7.73	7.89

Behavior of grinding capacity consumption (in thousand tonnes) in three selected scenarios

No.	Investment	Hedging	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
A	9%	0%	1,372	1,365	1,482	1,597	1,717	1,729	1,721	1,712	1,704	1,695
B	5%	95%	1,372	1,365	1,427	1,488	1,550	1,615	1,683	1,733	1,725	1,716
C	1%	50%	1,372	1,365	1,372	1,379	1,386	1,392	1,399	1,406	1,413	1,420
No.	Investment	Hedging	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	9%	0%	1,695	1,687	1,678	1,670	1,661	1,653	1,692	1,730	1,740	1,731
B	5%	95%	1,716	1,707	1,699	1,690	1,693	1,769	1,844	1,883	1,873	1,864
C	1%	50%	1,420	1,427	1,434	1,441	1,448	1,455	1,461	1,456	1,454	1,460

Note: Time step of 0.0325 was used to generate these data; A = Aggressive scenario, B = Base case scenario, C = Conservative scenario.

Appendix F: Validation Test Data

Integration error test for sales revenue (in CHF million)

No.	Time step (years)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	0.007	5,044	5,265	5,731	6,137	6,486	6,729	6,743	6,686	6,635	6,622
2	0.0325	5,043	5,265	5,731	6,138	6,486	6,729	6,744	6,686	6,633	6,617
3	1	5,038	5,255	5,757	6,199	6,571	6,845	6,873	6,825	6,701	6,617
No.	Time step (years)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	0.007	6,622	6,643	6,682	6,688	6,780	6,963	6,947	6,866	6,809	6,787
2	0.0325	6,617	6,635	6,677	6,673	6,745	6,961	6,952	6,873	6,811	6,786
3	1	6,617	6,570	6,560	6,585	6,562	6,558	6,595	6,985	7,039	7,011

Note: Year-beginning values are used for comparison.

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