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Struggling with Uncertainty: The State of Global Agri-Food Sector in 2030

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Abstract

Multiple tools, including surveys, exploratory and confirmatory factor analysis, and cross-impact analysis were employed to identify likely scenarios for the agri-food system in 2030. A principal finding of the research is that global warming is perceived as almost inevitable and will lead to major changes in global food production, processing, and trade. However, the dynamic nature of the food chain offers many possibilities to mitigate the negative supply system impacts of global warming through efficiencies gained by increasing firm concentration in the agri-food sector through the application of biotechnology, or adaptations in local food production.

Keywords: Scenario analysis, expert opinion, global food system, exploratory factor analysis, confirmatory factor analysis, Smic-Prob-Expert

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Introduction

According to the definition of Jarke, Bui, and Carroll (1999) a scenario is a "description of a possible set of events that might reasonably take place." During the last several decades, a large number of scenarios have been developed to predict the future state of the world or specific regions (Glenn, Gordon, and Florescu 2009; Kuhlmann and Edler 2003). Some of these scenarios are industry-specific, focusing, for example, on the future of transportation systems (Shiftan, Kaplan, and Hakkert 2003), while others couched their predictions in vague, ethereal terms (Raskin et al. 2002).

In recent years, we have seen increasing public and scientific attention toward the future of the agri-food sector. Numerous scenarios have been prepared focusing mainly on the effects of climate change on agricultural production. The changing ecological situation (Lorenzoni et al. 2000; Ericksen, Ingram, and Liverman 2009) and socio-economic environment (Schafer and Victor 2000) of agri-food systems make a compelling case for the application of scenario development and analysis to this sector. Our aim is to investigate the perspectives of food system experts on the future of the agri-food sector and to develop several scenarios that illustrate the future of the world's food system.

Understanding the possible paths for the development of the agri-food sector is important for several reasons. First, the sector is characterized by high human and physical capital requirements and a long time horizon for return on investment (Christóbal 2008). Second, the agri-food complex exhibits strong linkages to other sectors of the economy for inputs and outputs and, therefore, the sector's accelerative and multiplicative effects have a considerable influence on the dynamics of national and regional economies. Moreover, governmental and managerial decisions affecting the agri-food sphere exert a considerable influence on the socio-economic structure and equilibrium of entire geographic regions (van Ittersum et al. 2007). Third, the development of the agri-food system has wide-ranging implications for the natural environment (Steenge 2004). Therefore, the identification of potential future scenarios may aid in better harmonizing the economic, social, and natural consequences of food and fiber production.

The remainder of the paper is organized as follows. We first discuss scenario planning, its development, and its application to business and the agri-food sector. We then discuss the methods used in this research, followed by a presentation of the results of a survey of an international group of agri-food specialists. Next, we report the results of exploratory factor analysis and identify and discuss the underlying constructs, which we evaluate using confirmatory factor analysis. We then assess the probability of various outcomes and develop several scenarios using a panel of industry experts. Finally, we conclude by discussing the implications of our findings. Because of the numerous results that accompany the application of the several analytical methods we employ, we have chosen to focus on what we consider to be the major results and our interpretation of the findings. This comes at the expense of completeness and we leave it to the reader to consider the results that we do not discuss and to develop alternative interpretations.

Scenario Planning

Modern scenario planning may be traced to the first years of the Cold War era (Nye 1994). Herman Kahn (1960) is generally credited with developing the methods for scenario development while working at Rand Corporation for the U.S. military (Fahey and Randall 1998). Kahn employed the term "scenario" to describe future states in relation to the possibility of thermonuclear war.

The 1970s saw the application of scenario planning to the world of business. Pierre Wack, an executive with Royal Dutch/Shell developed "scenario planning" to create scenarios that did not rely on forecasts that assumed "tomorrow's world will look much like today's" but rather considered the possibility of a major change in the business environment (Wack 1985). His work at Royal Dutch/Shell is credited with helping the company prepare for the energy crisis of 1973.

Huss and Honton (1987) argue that the value of scenario planning is in providing a tool for the forecasting of long range, complex, and highly uncertain business environments. Wilkinson and Eidinow (2008) add that scenario planning aids decision-makers in identifying uncertainties and their potential effects so that they can formulate appropriate responses. In recent years, scenario planning has been studied and used by academia, business, consultants, policymakers, governments, and NGOs in a variety of contexts and many authors have published on the subject, including Godet and Roubelat (1994), Schoemaker (1995), Phelps et al. (2001), and Mietzner and Reger (2005), to name a few.

Global Food System Projections

McCalla and Revoredo (2010) note that there have been at least 30 quantitative studies projecting the global supply and demand for food. This number has grown over the last several years and the number of studies that forecast various elements of the food system is extremely large when we consider research that is more narrowly focused on individual elements of the global food system. For the purpose of this literature review, we have chosen to focus on those studies that make future projections of key elements of the global food system, such as energy, water, and the global supply and demand for food, regardless of whether the scenario analysis method was used. We do so in order to provide a robust view of the projections using various forecasting techniques. Some of the more comprehensive studies in the categories of natural resources, climate change, and global food supply and demand are discussed below. Given the thousands of forecasting studies that have been published on the future of the global food system, this literature review is necessarily a small sample of the published works.

Natural Resources

Land. Many of the published studies focusing on natural resources address a single resource, such as land, energy, or water. Land use studies typically address the multiple demands for land, including urban, crop and pasture, forestry, and conservation uses. Lambin and Meyfroidt (2011) note that land is becoming increasingly scarce due to urbanization, greater demand for cropland, and deforestation. They estimate that the current land reserve could be exhausted by 2050. Seto et al. (2011) estimated that urban land cover will increase from 430,000 km^2 to 12,568,000 km^2

with the most likely estimate of 1,527,000 km^2. They note that increased urban development will put millions of people at risk to the effects of climate change and challenge conservation efforts. Increased urbanization and the increasing scarcity of land available for agricultural uses were common themes in many of these studies.

Water. As with land, there is general agreement in the literature that water will be an increasingly scarce resource. Alcamo, Flörke, and Märker (2007) estimate that water stress will increase in approximately two-thirds of the world's total river basin area, with increasing stress being largely attributable to greater water withdrawals. Hejazi et al. (2014) develop socio-economic scenarios to evaluate future water demand. They develop six scenarios, with names such as, "Collapse," Muddling Through," and "Social Conservatism," They conclude that water is likely to be a limiting factor in the future with an increased reliance on groundwater, water reuse, and desalinization. Veolia Water (2013) estimates that 36% of the global population currently lives in water-scarce regions and that 39% of global grain production is not sustainable with regards to water use. They estimate that a "business as usual" approach could put 52% of the world population and 49% of grain production at risk of having insufficient water.

Energy. Studies that examined energy tended to focus on either energy as an input to agriculture (e.g. fuel or fertilizer) or as an output (e.g. ethanol or biodiesel). For example, Frei et al. (2013) developed two scenarios focusing on energy production and use through 2050. The "Jazz" scenario foresees a world driven by consumer demand, affordability, and quality with multi-national companies and price conscious consumers being the major players. Investments in nuclear energy and large hydro energy projects would be limited but there would be better access to unconventional resources. The "Symphony" scenario foresees an emphasis on sustainability and energy security with governments taking the lead role. Neither of the scenarios developed by the World Energy Council foresee a world where biomass utilization shows significant growth. Several studies examined the production of biofuels as a driver of agricultural prices. One study (USDA, ERS 2008) found that biofuel production led to short-term increases in food commodity prices, but that global demand would be the primary contributor to long-term increases in commodity prices. Both Ajanovic and Haas (2010) and Zhang and Wei (2010) found no substantial relationship between the production of biofuels and long-term price increases in commodity prices.

Climate Change

Publications addressing climate change as well as those addressing climate change and agriculture number in the thousands. Probably the most widely cited research on climate change and its impact is the Intergovernmental Panel on Climate Change (IPCC). In a 2007 report, the IPCC predicted that global average temperatures will increase by 2^0C to 4^0C, that close to a third of global coastal wetlands will be in danger of being submerged, and that millions of people are likely to face food and water shortages. Parry et al. (2004) estimates climate change will be responsible for placing 30 million to 220 million people at risk of hunger without taking into account the effect of CO_2 fertilization. When the CO_2 fertilization effect is considered, the risk falls to between 12 million and 20 million people. Rosenzweig and Parry (1994) argue that a more nuanced approach is needed to consider the effects of climate change on specific regions and countries. They predict that disparities between the productive capacity of the developed and developing world will increase with climate change. Fischer et al. (2005) find that total cereal production will not be greatly impacted by climate change at the global level, but that there will be differential impacts on cereal production and hunger in various regions of the world with the tropical semi-arid regions and developing countries suffering the greatest decreases.

Global Food Supply and Demand

Research on the global supply and demand for food typically addresses factors such as population, agricultural production, food prices, calorie consumption, and malnutrition. Several comprehensive studies, including some that employ scenario analysis, are described here to provide some perspective on the breadth of the various global food system analyses. Chen and Kates (1994) examine factors including the number of undernourished people, population, dietary changes, income distribution, relative poverty, and economic integration. They develop scenarios for 2060 including "Food Secure" and "Basic Linked System," as well as 12 climate change scenarios. The European Commission (2012) developed scenarios for Europe that addressed population demographics, renewable energy use, world population, food prices and malnutrition. The scenarios were entitled, "Nobody cares: Standstill in EU Integration," “Fragmented Europe - EU under Threat," and "EU Renaissance." Nelson et al. (2010) developed three scenarios for 2050, "Optimistic," "Baseline," and "Pessimistic," that included population, GDP growth, price changes for maize, wheat, and rice, and child malnutrition. Pinstrup-Andersen et al. (1999) forecast demand for food, cereals, and meat, cereal imports, food prices, and malnutrition of children under five years of age for both developing and developed countries in 2030. The Institute for the Future (2011) developed four scenarios, for 2030 labeled, "Growth," "Constraint," "Collapse," " and "Transformation." They focus on issues such as calorie consumption, the food supply chain, food scarcity, and technology. Hoogwijk (2003) developed three scenarios based on the type of diet with scenarios called "Vegetarian Diet," "Moderate Diet," and "Affluent Diet."

We cannot readily summarize the findings of the various studies, particularly those involving scenario analysis, as they do not lend themselves to calculating averages or even ranges. Rather, it is insightful to view the way that the authors characterize the future states and the factors that they include in the analyses. Many of the scenarios focus on whether the system will be in balance or out of control. Others describe the positive or negative nature of the outcomes. Still others characterize the systems by describing key characteristics that describe key features, such as the type of diet that might predominate. It is also insightful to look at the variables included in the studies. Many of the variables, such as those mentioned above, including populations agricultural production, food prices, calorie consumption, and malnutrition appear in numerous studies. However, other factors, such as water availability, dietary components, system of economic organization, and energy and other agricultural inputs, appear in relatively few studies. Of course, the real value of scenario development lies not in looking at the outcomes, but in understanding the complete story that the scenario describes, how the various factors influence the outcomes, and particularly how the factors work together, often leading to an outcome that may be far different than could be envisioned by examining the impact of any individual factor. McCalla and Revoredo (2001) argue that, notwithstanding the inaccuracies of forecasts, the models have been able to focus the attention of policy makers on major issues that need attention.

Methods

In this study, we drew on several different research methods that have been widely applied in management research and forecasting to develop the scenarios and associated probabilities. The methods employed reflect the specific research objectives as well as practical limitations such as securing access to and commitment from agribusiness experts. Ideas regarding possible future states were generated using the brainstorming technique (Osborn 1963). These ideas were then screened by a small group of experts based on the significance and relevance of the items so as to achieve a manageable number of potential future states. To evaluate the probability of the prospective future states, we employed expert probability estimation, as discussed by Hogarth (1975), with two large groups of experts. The future state probabilities were then analyzed to identify the underlying constructs using exploratory factor analysis and confirmatory factor analysis, methods commonly employed in management research (Scandura and Williams 2000). Scenarios were generated utilizing the consensus probability assessments of experts and employing the Smic-Prob-Expert cross-impact analysis tool, so as to combine the favorable aspects of qualitative and quantitative research methods as recommended by Godet (2000). The research process is summarized in Figure 1 and detailed in the following paragraphs.

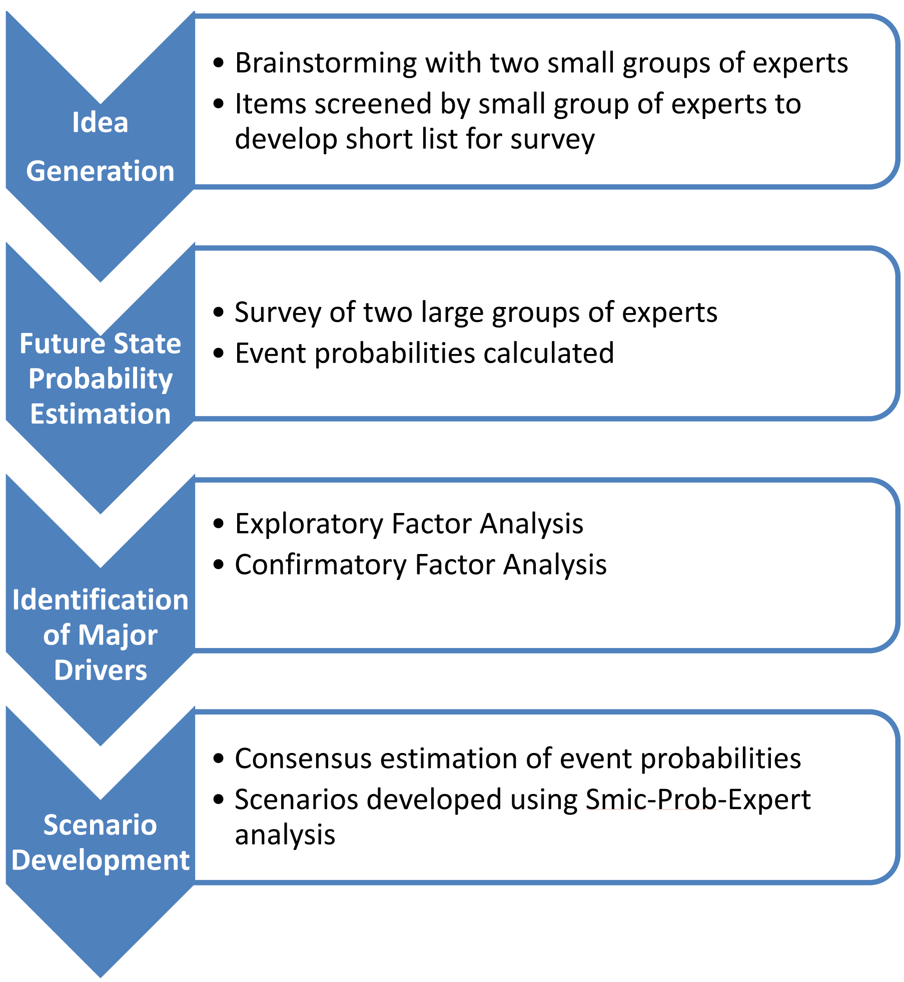

Figure 1. Research process flow

In order to generate reasonable and realistic scenarios, we began with a combination of a direct-question survey and an expert-based, scenario-analysis process whereby we utilized the expertise of large and small groups of industry specialists. We employed a typology of scenarios as described by van Notten et al. (2003), who identified 14 scenario types and characteristic choices associated with each type of scenario (Table 1). The characteristic choice employed in this study is highlighted in bold.

Table 1. Scenario-analysis characteristic descriptions

Overarching Themes	Scenario Type	Characteristic Choice*
A. Project Goal:	I	Inclusion of norms: **descriptive** vs. normative
Exploration vs.	II	Vantage point: **forecasting** vs. backcasting
Decision Support	III	Subject: **issue-based**, area-based, or institution-based
	IV	Time scale: **long-term** vs. short-term
	V	Spatial scale: **global/supranational** vs. national/local
B. Process Design:	VI	Data**: qualitative** vs. quantitative
Intuitive vs. Formal	VII	Method of data collection: **participatory** vs. desk research
	VIII	Resources: extensive vs. **limited**
	IX	Institutional conditions: **open** vs. constrained
C. Scenario Content	X	Temporal nature: **clean** vs. snapshot
Complex vs. Simple	XI	Variables: **heterogeneous** vs. homogenous
	XII	Dynamics: peripheral vs. **trend**
	XIII	Level of deviation: alternative vs. **conventional**
	XIV	Level of integration: high vs. **low**

Source: van Notten et al. (2003).
Note. Boldface type indicates the type of scenario used in this study.

We began the process of identifying possible future states for the agri-food system by holding two brain-storming sessions with industry experts. Participants were encouraged to suggest trends without discussion or criticism. Nine experts participated in the first session and 10 in the second. The first session was held in an agricultural region, Dusnok, Hungary, with support from the Regional Agricultural Chamber. The nine participants included six farmers, two owners of medium-sized food processing companies, and one representative from a nation-wide input-trading organization. Seven of the participants had degrees in higher education and four had substantial international experience. The second session was held at Corvinus University of Budapest in Budapest, Hungary. The participants included three representatives from medium-sized food processing companies (two were owners), three representatives from the Hungarian Ministry of Rural Development, and four agricultural researchers. Four of these participants were members of the Hungarian Association of Food Science and Technology, a scientific NGO.

The brainstorming sessions led to a total of 63 different ideas concerning the future development of the agri-food chain. This large number of items required consolidation so that a manageable number of potential events could be presented to the expert panels for evaluation. As a guideline we used the findings of Parenté and Andersen-Parenté (1987) who suggest that when using the Delphi-method, the upper limit of items that can be reasonably processed is 25.

Three experts evaluated each of the 63 statements based on three criteria: global character, importance and relevance from the point of view of food industry, and specificity from the point of view of the actual research. One expert was a professor emeritus from Serbia with considerable international experience gained as a consultant for FAO and UNIDO. Another expert was been an international lawyer from Nigeria, with considerable experience in the field of rural development in northern (Sub-Saharan) Nigeria. The third expert was a professor at Corvinus University of Budapest and an expert in food security and the impact of climate change on agriculture.

The process of reducing the number of statements resulted in the initial elimination of 27 statements. Seven statements were eliminated because they reflected processes of local importance, three were eliminated because they were unimportant from a practical perspective, another three were omitted because they were irrelevant from the point of view of the development of the agri-food sector, and fourteen were eliminated because they did not reflect directly on the development of agri-food sector. The remaining 36 statements were reformulated and consolidated into 20 future state statements.

The final version of the questionnaire was prepared with the assistance of nine members of the Program Planning Committee of 19th Annual World Forum and Symposium of the International Conference of the International Food and Agribusiness Management Association (IFAMA). This committee had a broad representation of international experts from many different fields, was geographically diverse, and included members from both industry and academia.

Respondents were asked to estimate the probability of occurrence of the 20 different states using a seven-point probability scale. The scale described the probability of an event occurring as 0% to 5%, 6 to 20%, 21 to 40%, 41% to 60%, 61 to 80%, 81 to 95%, and 96 to 100%. The seven-point scale was utilized in order to simplify the task for respondents and maximize the response rate. To avoid the possibility of bias based on the order in which the possible events were presented, the order was determined by a random-number generator.

The sample was drawn from two sources. All registered participants of the annual IFAMA conference (Budapest, June 2009) received the questionnaire by e-mail via the IFAMA office. Experts from Central Europe were selected from participants in several scientific conferences held during the period of February to May 2009 in Hungary, Romania, and Serbia. The meetings included the 4th International Conference for Rural and Agricultural Development, at Debrecen University, Debrecen, Hungary and preparatory meetings of the Techfood project “Solutions and Interventions for the Technological Transfer and the Innovation of the Agro-food Sector in South East Regions” held at the Bucharest Academy of Economic Studies, Bucharest, Romania as well as the Faculty of Agriculture at Belgrade University and Serbian Scientific Research Institute of Economic Sciences, both in Belgrade, Serbia.

IFAMA members and Central European experts were sent 350 and 280 questionnaires, respectively. The IFAMA group completed 109 questionnaires and the Central European group returned 97 questionnaires for response rates of 31% and 35%, respectively. The geographic distribution of all 206 respondents is summarized in Table 2.

The data from the 206 observations were recorded and summary statistics were calculated. This provided a perspective on the raw probabilities of future states as viewed by the expert panels and served as input into the next stages of the scenario development process.

Table 2. Geographic distribution of respondents

International Specialists	
North-America	51
South and Central America	22
European Union	22
South Africa, Australia, India	14
Total	109
Central-European Specialists (non-IFAMA members)	
Hungary	67
Serbia	8
Ukraine	9
Romania	13
Total	97
Grand total	206

The next step was to use exploratory factor analysis to identify the underlying constructs associated with the relatively large number of future states. Exploratory factor analysis is typically used to identify latent constructs in data matrices with correlated variables (Floyd and Keith 1995). This eigenvector–based, multivariate analysis is a theoretically optimal, linear scheme (in terms of least, mean-square error) for compressing a set of high dimensional vectors into a set of lower dimensional vectors. Factor analysis is based on a correlation and covariance matrix and assumes that the observed variables are measured continuously, are distributed normally, and that the associations among indicators are linear. Because our expert responses were measured on an interval scale, we used the Categorical Principal Component Analysis (CATPCA) method to analyze the data (Linting et al. 2007). Based on CATPCA output there appeared to be some underlying factors, also known as background or latent variables, that were not measured directly and which may have served as the basis for respondents' expectations.

We used the CATPCA results to establish the relationship between the directly observed and latent variables by constructing a model of key agri-food chain events and future states that we tested using confirmatory factor analysis. This combination of exploratory and confirmatory factor analysis is consistent with the general logic behind the application of different types of factor analysis, reflecting the inherent, successive approximation commonly used with these methods (Schriesheim and Eienach 1995; Anderson and Gerbing 1988). In contrast to exploratory factor analysis or principal component analysis, where all loadings are free to vary, confirmatory analysis tests hypotheses relative to theoretical underpinnings. This analysis can include both directly measurable and latent variables using the CATPCA as input.

In the next phase of the analysis, we used the results of both the exploratory and confirmatory factor analyses to identify the most important future agri-food sector events, which we have labeled as outcomes. Scenarios were developed based on the estimation by a group of experts of the probability that the various outcomes would occur. While a simple questioning of the experts on the probability of the occurrence of future events would be the simplest method, such a process would imply that each event is independent of other events. To properly account for the interrelationships between events, it was necessary to use a method that accounts for the cross-impacts of different processes.

Several algorithms have been developed to account for the effect of one event on another. The goal of these cross–impact algorithms is the manipulation and harmonization of probability estimates (Cho and Kwon 2004). We chose the Smic-Prob-Expert cross-impact analysis tool, developed by team a team led by Michael Godet (Godet and Roubelat 1996; Bradfield et al. 2002). Duperrin and Godet (1975) state, "in practice, the opinions given in response to certain specific questions about non-independent events disclose some degree of inconsistency with the overall opinion (which is implicit although not expressed), revealed by the answers given to all the other questions." These primary opinions must be corrected, is such a way as to conform to various constraints. The mathematical foundations of the Smic-Prob-Expert method used in estimating the probability of the various scenarios are presented in Appendix A.

The Smic-Prob-Expert software is capable of generating a hierarchical rank of scenarios, based on their probabilities. The input for the analysis includes three components, a vector of *a priori* estimations of the probability of the different outcomes and two square matrices. The first matrix contains the experts' estimation of the pairwise probability of the co-occurrence of events. The second matrix contains the estimated probabilities of the occurrence of processes in pairwise form, should the other process in the pair not occur.

Developing the input matrices for Smic-Prob-Expert analysis turned out to be extremely complicated. Originally, a Delphi–type questioning of experts had been planned. However, even after two rounds of the questioning there were still considerable differences. Subsequently, a two-hour workshop was organized in July, 2009. Six experts, a moderator, and one of the authors of this article participated in the workshop. All of the experts had at least ten years of international experience in agri-food research in a variety of geographical locations, under different socio-cultural conditions (Africa, China, Serbia, Northern Cyprus, and Hungary). The outcome probabilities were estimated by consensus and the probabilities were then used to develop the scenarios and their probability of occurrence.

Several limitations should be considered in interpreting the results discussed in the following section. First, the input for the scenarios, starting with the identification of the future state variables and ending with the estimates of the conditional probabilities of the outcomes, was subject to the judgments of the chosen experts. The various panels of experts were selected to ensure that the chosen experts had ample expertise across a broad range of issues affecting the global food system. Nevertheless, a disproportionate number of experts were from Central Europe. It is also important to acknowledge that, as with any research, the interpretation of the results will be subject to the perspective of the writer. We, therefore, encourage the reader to view the results in that light and form his or her own opinion on what the findings mean.

Results

Descriptive Analysis

In the first phase of the research, we attempted to characterize respondents' evaluation of the probability of the various events regarding the future state of the agri-food sector. In some cases response patterns could be described by Erlang or lognormal functions, but in most cases the distributions did not fit any common probability density functions.

In analyzing the responses, it became obvious that many of respondents believed that the agri-food complex will face significant new challenges over the coming decades (Table 3). For example, both groups believed that as a consequence of global warming, water will become one of the most important limiting production factors. The Central-European experts assigned a somewhat higher probability to this event than did the IFAMA group perhaps because they have observed decreasing precipitation and many different adverse climate predictions possibly foreshadowing the increased frequency of severe droughts (Arnella 1999; Bartholy, Pongracz, and Gelybo 2007).

There was good agreement that we should expect increasing energy prices and the internalization of environmental externalities. This prediction is in line with the majority of forecasts from other sources (Yergin 2006). More than half of respondents also predicted a further increase in food imports by China and India. This reflects the generally accepted view that incomes will continue to rise in these countries and result in shifting patterns of trade in food and agricultural products (Kaplinsky 2006; USDA, ERS 2008). At the same time, the majority of respondents attached a low probability to finding a solution to the global malnutrition problem and for a decrease in the prices of agricultural commodities. These rather pessimistic expectations support the opinions of other experts who argue that if no corrective action is taken, the target set by the World Food Summit in 1996 (halving the number of undernourished people by 2015) will not be met (Rosegrandt and Cline 2003). Based on these predictions, we may anticipate an agri-food sector that will play an even more important role in the world economy in the decades to come. The threat of global warming, increasing food demand in emerging economies, and the continuing need for food aid for the world's poorest countries highlight the significance of preserving the productive capacity of world food system.

Another important future tendency, as viewed by our expert respondents, will be the challenge of meeting the demands of diverse consumer segments. This phenomenon will manifest itself in increasing interest in organic products and tailor-made nutritional products. Moreover, a growing demand for locally produced foods may be expected.

Table 3. Experts' assessments of the probability of future state events through 2030

Future State Variables	International Experts (percent)	Central-European Experts (percent)
1. Water becomes a limiting factor of production-output (WATER)*	82.8	94.5
2. Increasing interest in bio-products (BIOPROD)*	72.8	60.3
3. Increasing energy prices and environmental taxes considerably increase prices of food produced in distant regions (FOODPRICE)	72.4	69.8
4. Increasing interest in specific, tailor-made nutrition, supported by the latest methods of medical science (NUTRIFOODS)	68.7	66.2
5. Increasing trust in locally produced food products (TRUSTLOCAL)	68.6	69.7
6. Increased agricultural and food import in China and India (EMKTS)	68.4	64.2
7. General proliferation of genetically modified agricultural products globally (GM)	67.8	72.1
8. Increasing role of bio-mass in energy production (BIOMASS)	67.4	69.8
9. Further concentration of agricultural production (AGRCONC)	64.7	68.9
10. Increasing urbanization, some regions lose their population even in developed states (URBAN)	63.6	61.6
11. Further and increasing migration from third world to the developed states (MIGRATE)*	59.7	72.8
12. Increasing threat of agri and food terrorist attacks (BIOTERROR)	58.8	64.5
13. Increasing trust in biotechnology (ACCEPTGM)*	58.7	65.6
14. Drastic decreases in the number of small-scale, family-owned retail shops (TRADECONC)	54.4	58.8
15. Global warming considerably decreases production potential (LOWOUTPUT)*	53.4	68.4
16. Many high-tech agri production parks near big metropolitan areas (Metropolitan Agriculture) (METROPAGR)	38.7	36.8
17. Increased influence of religion and traditions on eating habits (TRAD)	23.2	25.4
18. Concentration of food production will narrow to 30-40 firms producing the overwhelming majority of the world's food (FOODCONC)*	18.6	29.4
19. The number of malnourished people decreases to at least one-quarter of the current number (MALNUTR)	17.6	16.8
20. Real price of agricultural commodities will decrease considerably (PRICEDECR)	15.1	16.7

Note. The probabilities were calculated by replacing the interval ranges with mid-point values and multiplying each value by the number of experts who selected each probability range. An asterisk (*) indicates a statistically significant difference between the two groups based on the results of the Mann-Whitney test.

In most cases, the probability assessments of the two expert groups were similar. For four of the future states, the Central European experts' assessments were higher by 10% or more than their international counterparts. These events included decreased production potential as a result of global warming, water becoming a more limiting factor of production, increasing migration from the third world to developed states, and increasing concentration of food production. One explanation is that the assessments may reflect the experience of the group members. For example the expectation of increased concentration in food production may reflect the current low concentration of the food trade in Central and Eastern Europe relative to that of Western Europe, where significant concentration in the food trade occurred in the 1980s and 1990s (Juhász, Seres, and Stauder 2008). In only one case, increasing interest in bio-products, did the international experts assign a substantially higher probability to the future state than did the Central European experts. In no case did the probability estimates between the two groups differ by more than 15%.

For some variables, the expert responses showed sharp differences of opinions within the combined groups as to what the future holds. For example, approximately one-fourth of the respondents estimated that increasing acceptance of biotechnology is rather improbable (probability of 20% or lower), while roughly one-fourth of the respondents seemed confident in the increasing acceptance of biotechnology (probability of 81% or higher). This may be explained by the great differences in the assessment of the potential of genetically modified agricultural products among different groups (Lusk and Rozan 2006).

The experts do not predict that changes in firm concentration within the agri-food system will be uniform throughout the various subsectors, i.e. production, processing, and distribution. For example, approximately two-thirds of the experts foresaw further concentration in the agricultural production sector. However, a relatively small percentage of respondents accepted the opinion of some experts (Steiner 2000) that mergers and acquisitions in the food industry will lead to a small number of firms (30 to 40) that will produce most of the world's food. The probability of a further, drastic decrease in the number of small-scale, family-owned food shops was estimated at slightly more than 50%.

Exploratory Factor Analysis

The input data obtained from the questionnaire is categorical (experts' estimations of ranges of probability of the occurrence of events, processes, or states) and we have therefore used categorical principal component analysis (CATPCA), as explained above. This method has proven to be an efficient method for analyzing the underlying constructs in which a large number of variables are involved, some of which may not be measurable. The principal component analysis yielded seven components with an eigenvalue of one or greater. However, the contribution of the seventh factor was marginal and the variable was omitted. The internal consistency of scales was evaluated by using Cronbach's alpha. This statistic was greater than 0.65 for each of the remaining principal components. Because only two factors loaded on factor 4, Cronbach's alpha was not calculated for this factor.

Because the factor analysis yielded results that were difficult to interpret, we employed factor rotation. We chose the most commonly-used method, Varimax rotation, developed by Kaiser

(1970). A principal advantage of this method is that the variables tend to have either high or low loadings on the factors. Put another way, each state variable tends to be associated with a relatively small number of factors making the results more easily interpreted. Abdi (2003) states that "because the rotated axes are not defined according to a statistical criterion, their raison d'être is to facilitate the interpretation." Although the application of other rotation methods may have led to slightly different results (Schmitt 2011), we did find that the Varimax method lead to meaningful results. The component-structure before and after rotation is summarized in Table 4.

Table 4. Summary results of the categorical principal component analysis

Principal Component	**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**			**Chronbach's Alfa**
Number	Total	Percent of variance	Cumulative percentage	Total	Percent of variance	Cumulative percentage	
1	5.744	28.718	28.718	2.625	13.123	13.123	0.826
2	2.209	11.046	39.764	2.542	12.710	25.833	0.799
3	1.802	9.009	48.773	2.418	12.092	37.925	0.789
4	1.523	7.617	56.390	2.333	11.663	49.588	-
5	1.282	6.408	62.799	1.899	9.496	59.084	0.685
6	1.132	5.660	68.459	1.504	7.521	66.605	0.657
7	1.010	5.050	73.509	1.21	6.050	72.655	0.515

Note. Cronbach's alpha is not reported for principal component 4 since only two variables load on this factor.

The results of the principal component analysis indicate the possibility that underlying the observed variables are some well-defined latent variables. These six, unobservable and unmeasurable latent variables, may be interpreted based on the variables that load on (or have the strongest relationships with) these factors (Table 5). We identify the six principal components by giving them each a name that reflects the underlying processes.

The majority of variables that have a significant loading on the first principal component, LOCAL, are related to factors that support the development of local food production systems. These include variables related to metropolitan agriculture, urbanization, trust in locally produced food products, and increases in prices of food from distant regions. Likewise, the variables related to the second principal component, WARMING, are generally related to the phenomenon of global warming. For the third factor, CONCENTRATE, the highest loading factors pertain to the concentration of firms within the global food system. Two of the three areas of possible concentration, including concentration in the agricultural production and retail sectors, load on this component. The variable concerning trust in locally produced food products has a significant negative loading on CONCENTRATE, indicating that further concentration within the agri-food sector is deemed less likely given growing trust in locally produced foods. For the fourth component, BIOTECH, the highest loading factors are related to statements regarding the acceptance and use of biotechnology and the use of biological products in energy production (biomass). Paradoxically, the loading of another item, GM, the global proliferation of genetically modified agricultural products, received a loading value less than 0.3 and was not included in the table for the BIOTECH factor. This result may be due to the divergence of opinion among the experts regarding the prospects for GM products. The highest loading factors for the fifth factor, INDIV, pertain to the increasing importance of individualization in food consumption patterns, including the increased importance of traditional eating habits and tailor-made, nutritional foods. The sixth principal component, SUPPLY, has positive loadings for potential changes associated with the global food supply, including lower output, greater imports in emerging economies, and higher food prices, as well as a negative loading for malnutrition, which presumably means increased consumption.

Table 5. Principal component factor loadings of state variables on outcome variables

	Principal Component					
State Variables	LOCAL	WARMING	CONCENTRATE	BIOTECH	INDIV	SUPPLY
WATER		0.790				
BIOPROD	0.570				0.416	
FOODPRICE	0.473					0.477
NUTRIFOODS					0.784	
TRUSTLOCAL	0.648		-0.346			
EMKTS						0.784
GM			0.456			
BIOMASS				0.351		0.739
AGRCONC			0.683			
URBAN	0.443				0.355	0.462
MIGRATE		0.708				
BIOTERROR	0.593					0.456
ACCEPTGM				0.706	0.304	
TRADECONC			0.707			
LOWOUTPUT		0.641				0.424
METROPAGR	0.701					
TRAD					0.811	
FOODCONC		0.656				-0.405
MALNUTR	0.532					-0.627
PRICEDECR						-0.766

Note. The numbering of the principal components is the same as in Table 4, where the first principal component is named LOCAL, the second, WARMING, and so forth. Only values above 0.300 are presented.

Confirmatory Factor Analysis

To better understand the structure of respondent's future expectations, we formulated a conceptual model to describe the relationship between the observed, directly-measured variables and their underlying latent (unobserved) constructs as expressed in the exploratory factor analysis. Confirmatory factor analysis was conducted by employing structural equation modeling, based on the Analysis of Moment Structure method (Arbuckle and Wothke 2004). The approach of this method is similar to regression analysis. We specified a multivariate system of equations representing the relationships between the latent and observed variables with the latent variables allowed to freely intercorrelate. As is general practice, directly observed variables are portrayed as rectangles, circles represent the unobservable, latent variables, statistically significant standardized regression coefficients between observed and latent variables are shown as single-headed arrows, and double-headed arrows represent correlations relationships between pairs of latent variables.

The results of the structural equation model are presented in Appendix B. The Chi-square of the model was 0.12, possibly a consequence of non-normality of the data. The Sattorra-Bentner scaled chi-square was 0.071 is considered acceptable. The adjusted goodness-of-fit index was 0.89 and the Browne-Cudeck criterion was 0.86. In summary, the model appears to have an acceptable fit.

The results of the confirmatory factor analysis generally support our conceptual model. However, we were unable to determine a statistically significant model that included the latent variable, CONCENTRATE, and this variable was omitted from the model presented here. Some of the key findings and our interpretations are discussed in the following paragraphs.

There is a strong, significant relationship between the global warming latent variable (WARMING) and two observed variables, the expectation of decreasing agricultural production due to global warming (LOWOUTPUT) and the expectation of the increasing importance of water in agricultural production (WATER). We also see that the latent variable SUPPLY, which we use to describe concerns and tensions associated with the global food supply, is projected to impact several aspects of the food system. Supply issues are expected to lead to increased malnutrition (MALNUTR), increased food imports in emerging markets (EMKTS), and a decreased chance of a decline in food prices (PRICEDECR). The strongest linkage among the latent variables is between global warming and supply issues suggesting that these two issues are likely to be coincident.

The increased importance of local food systems (latent variable LOCAL) is expected to give rise to growth in metropolitan agricultural production systems (METROPAGR) as well as increased interest in bio-products (BIOPROD). In another expression of consumer preferences, individualization in food consumption patterns (latent variable INDIV) is a strong driver of the increased importance of tailor-made nutritional food products (NUTRIFOODS).

Finally, the latent variable BIOTECH has a relatively weak association with the observed variable, ACCEPTGM, which measures society's acceptance of genetically modified food and BIOMASS, representing an increased role for biomass in energy production.

Event Probabilities

The input-data for the scenario analyses were based on the results of the expert workshop as described above. We drew on six basic outcomes, which correspond to the six principal components of the categorical principal component analysis. Although the variable CONCENTRATE was discarded from the confirmatory factor analysis, we decided to include the variable in the development of the future scenarios. Despite being the weakest of the latent constructs, it represents an important aspect of industry structure. These six outcomes are as follows:

- Increasing global warming (WARMING);
- Further concentration of the agri-food industry, including agriculture, food processing, and trade (CONCENTRATE);
- Increasing importance of local food supply systems (LOCAL);
- Increasing use of biotechnology in agricultural production (BIOTECH);
- Increasing importance of satisfying individual food demands (INDIV); and
- Increasing global food supply issues (SUPPLY).

The group of six experts was asked to develop the input matrices based on the summary survey results. Their charge was to estimate the probabilities and conditional probabilities of the six outcomes described above, including: 1) the probability of occurrence of a given outcome without taking into consideration the other outcomes (*a priori* probability); 2) pairwise estimation of the probability of each event occurring given that the other event in the pair occurs (Appendix A, equation 8); and 3) pairwise estimation of the probability of each event occurring given that the other event in the pair does not occur (Appendix A, Equation 9). In this way, we obtained a vector of *a priori* probabilities consisting of six elements and two matrices of conditional probabilities. We then calculated simple averages of all of the individual estimations. The final estimates were determined by group discussion until a consensus was reached. The vector of *a priori* probabilities and the two matrices of conditional probabilities served as the input to the Smic-Prob-Expert software for the generation of the scenarios. The *a priori* and conditional probability estimates are presented in Tables 6, 7, and 8.

Table 6. *A priori* Probabilities of Events

Event	**Probability of Occurrence**
LOCAL	0.81
WARMING	0.87
CONCENTRATE	0.65
BIOTECH	0.82
INDIV	0.85
SUPPLY	0.78

Table 7. Conditional probabilities of different events based on the occurrence of conditional events

	Probability Event					
Conditional Event (Event Occurs)	**LOCAL**	**WARMING**	**CONCENTRATE**	**BIOTECH**	**INDIV**	**SUPPLY**
LOCAL	-	0.87	0.55	0.72	0.85	0.69
WARMING	0.92	-	0.74	0.90	0.82	0.95
CONCENTRATE	0.60	0.87	-	0.92	0.81	0.77
BIOTECH	0.71	0.87	0.70	-	0.87	0.72
INDIV	0.90	0.87	0.65	0.88	-	0.78
SUPPLY	0.92	0.87	0.77	0.90	0.75	-

Table 8. Conditional probabilities of different events based on the non-occurrence of conditional events

	Probability Event					
Conditional Event (Event Doesn't Occur)	**LOCAL**	**WARMING**	**CONCENTRATE**	**BIOTECH**	**INDIV**	**SUPPLY**
LOCAL	-	0.84	0.78	0.91	0.58	0.72
WARMING	0.68	-	0.57	0.64	0.70	0.57
CONCENTRATE	0.84	0.54	-	0.65	0.85	0.59
BIOTECH	0.75	0.92	0.60	-	0.61	0.84
INDIV	0.62	0.84	0.87	0.73	-	0.82
SUPPLY	0.54	0.67	0.51	0.54	0.82	-

In the following discussion, we examine how the expert panel viewed the likelihood of each of the six events both independently and in relation to the other events. In addressing the global warming and supply issue variables we discuss how these expert assessments compare with those from other forecasting and scenario analysis studies as well as the assessments of other experts. Because the number of studies relating to these events is extremely large, we have chosen to limit our discussion to only a few, representative studies that we deem most relevant based on the extent to which the studies address factors relevant to global agriculture and food systems.

The subject of global warming and climate change has received a great amount of attention by politicians, scientists, activist groups, and the public in general. Moreover, a great deal of research has been devoted to the topic. Among our experts, there is a strong consensus that global warming is almost certain. This is our strongest and most consistent finding with an estimated likelihood of 0.87. Interestingly, the pairwise probability estimates indicate that the prospect of global warming is perceived to be generally independent of the occurrence or non-occurrence of other events (Tables 6 and 7). Only when the CONCENTRTATE or SUPPLY events are not expected to occur is the probability of WARMING deemed to be substantially less. One interpretation is that supply issues and further concentration may be seen as indicators of more rapid development and that the absence of these events may be interpreted as an indicator of slower development which in turn may make severe climate change less likely.

Our results are highly consistent with the results of many recent studies and reflect growing consensus in the scientific community that global warming is inevitable. The IPCC estimates various scenarios for climate change with projected increases varying between 1.8^{0}C to 4^{0}C for the period of 2000 to 2100 (IPCC 2007). In another study, Rogelj, Meinshausen, and Knutti (2012) estimate global temperature increases of 2.3^{0}C to 4.6^{0}C above the pre-industrial level by 2090 to 2099.

The impact of global warming on agriculture is less certain and will likely depend on other factors. Gornall et al. (2010) argue that climate change will have both positive and negative impacts on agriculture and that the outcome is location dependent. Some regions are likely to benefit from increased rainfall while others will experience a decrease in precipitation. Likewise, some crops are expected to benefit from increased temperatures while others will suffer. Despite the predictions of variable responses to climate change, Jaggard et al. (2010) note that the increased prevalence of extreme events, including heavy rainfall, flooding, extreme heat, and droughts will negatively affect food production overall. The IPCC (2007) also predicts an overall reduction in crop yield and lower livestock productivity as a result of climate change.

We view the possibility of supply issues (SUPPLY) as closely related to that of climate change. This is supported by our expert panel's evaluations. While the independent probability expectation of supply issues is 0.78, this increases to 0.95 should WARMING occur. Indeed many of the potential supply issues could be triggered global warming, including water availability, crop and livestock productivity, restrictions on the use of fossil fuels, and the susceptibility of agricultural production to extreme events such as droughts and floods.

Supply issues, particularly those focusing on specific resources, such as land, water, or energy, have been the focus of many studies. Lambin and Meyfroidt (2011) note that the supply of land not currently in production is expected to be exhausted by 2050. Alcamo et al. (2007) predict that water stress will increase in the majority of river basins (62% to 76%) and that the principal cause will be increasing water withdrawals. Hejazi et al. (2014) foresee that a growing demand for water will result in low to severe water scarcity in most regions of the world by 2050, with the severest scarcities occurring in the Middle East, India, and China. Aleklett et al. (2010) conclude that peak oil production has already occurred and that there will be a "gentle" decline between 2008 and 2030 in production in their "Uppsala" scenario. The expectation of our panel of experts that supply issues will likely be an important characteristic of the agri-food sector are consistent with the many studies that foretell increasing scarcity of some of the primary inputs to the agri-food sector, specifically, land, water, and energy.

The increasing use of biotechnology in agricultural production (BIOTECH) was estimated to have a probability of 0.78. In contrast with some of the other factors, particularly global warming, the BIOTECH factor is not expected to have a large impact on the occurrence of other events. That is the occurrence or nonoccurrence of this event does not generally influence the experts' assessment of the likelihood of other events. We feel that it is significant that the BIOTECH factor was assigned such a high probability of occurring by the panel, especially given the controversy surrounding the technology in much of the world. While an overwhelming majority of the global scientific community supports the application of modern biotechnology (Varshney et al. 2010; Ahmad et al. 2012), the political debate is far from over. Even the United

States, which has traditionally been at the forefront of the application of biotechnology, there is a move in many states to mandate labelling of genetically modified foods.

The expert group assigned a high probability estimate (0.81) to the increased importance of local food production systems (LOCAL). Moreover, the probability that local food systems will grow in importance is estimated to be higher than its *a priori* estimate should the world experience increased individualization in food demand (INDIV), increased food supply issues (SUPPLY) and increased global warming (WARMING). Our interpretation is that global warming, supply issues, and individualization of consumer demand will lead to an increased emphasis on local food production.

The importance of satisfying individual food demands (INDIV) had an *a priori* estimate of 0.85. The results of the pairwise, conditional probabilities indicated that the INDIV variable did not vary much with the occurrence of other events. However, the demand for individualized foods was perceived as much less likely should the increased importance of local food systems or the increased acceptance and use of biotechnology not occur. We believe that it is likely that the demand for local and individualized food may be driven by the similarities in consumer preferences associated with the outcomes. While the link between the use of biotechnology and individualization of food demand is less clear, we see the application of biotechnology as key to the development of specific products, such as nutraceuticals, that will enable the production of individualized food products.

The further concentration of businesses in the agri-food chain (CONCENTRATE) was deemed to be the least likely of the six outcomes, although it was estimated to have a roughly two-thirds chance of occurring (0.65). In contrast to some of the variables WARMING and BIOTECH, the concentration of firms in the agri-food sector is viewed as being dependent on other outcomes. The expert panel expected increased concentration in the agri-food sector to be more likely in the event that global warming (WARMING) or global supply issues (SUPPLY) occur. This can be seen by comparing the relatively high probability assigned to firm concentration should global warming or supply issues develop as compared to the *a priori* estimation of the probability of agri-food firm concentration. On the other hand, the expert assessment of the probability of further industry concentration drops when it is assumed that global warming or supply issues do not develop. We believe that this assessment is due to the presence of scale effects associated with issues that might accompany global warming or supply problems. In other words, larger firms may be better equipped than smaller firms to deal with the significant challenges associated with global warming and supply issues.

Scenario Analysis

Based on the expert estimations of *a priori* and conditional probabilities of the six different outcomes, we generated a set of scenarios using the Smic-Prob-Expert algorithm. The output of the algorithm is a set of scenarios with different combinations of the six outcomes. Although 38 scenarios were generated, only the three scenarios with a probability of at least 10% are presented and discussed below. The three scenarios along with a descriptive name and the probability of the scenario's occurrence are presented in Table 9. The subsequent discussion will focus on how the various events within the three listed scenarios relate to each other and add "color" to the main features of each of the scenarios.

Table 9. Three most likely scenarios for the Agri-Food Industry

Scenario Name	Scenario Characteristics	Probability (%)
PANTA RHEI (Everything Moves)	Includes… - increasing effects of global warming - increasing concentration of agricultural, food processing and trade - increasing importance of local food production systems - increasing use of biotechnology - increasing individualization in food consumption - increasing food supply problems	26
DISTRIBUTED FOOD SYSTEMS	Includes… - increasing effects of global warming - increasing importance of local food production systems - increasing use of biotechnology - increasing individualization in food consumption Without - increasing concentration of agricultural, food processing and trade - increasing food supply problems	19
CONCENTRATED SUPPLY SYSTEMS	Includes - increasing effects of global warming - increasing concentration of agricultural, food processing and trade - increasing use of biotechnology - increasing individualization in food consumption Without... - increasing importance of local food production systems - increasing food supply problems	12
All other scenarios		43

The highest probability scenario (26%) is characterized by presence of all of the principal outcome variables. We call this scenario PANTA RHEI[1] or Everything Moves. PANTA RHEI forecasts a future of concentrated agri-food systems, characterized by considerable changes in

[1] Πάντα ῥεῖ (*panta rhei*) "everything flows," or "all things are in flux"–a Greek philosophical statement, falsely attributed to Heracleitos. This phrase is attributed to Theodorus, an associate of Protagoras (Chappel 2004).

the conditions of agricultural production (supply issues and global warming), increased application of biotechnology, and local and individualized food production.

One way to view this scenario is that it represents a collection of all of the outcomes viewed as likely by the expert panel. It includes three outcomes that represent the continuation of strong trends affecting the agri-food system and which have been well-documented: global warming (IPCC 2007), increased firm concentration within the agri-food sector (Watts and Goodman 1997), and increased emphasis on local food systems (Feagan 2007). A fourth outcome, global food supply issues, may be viewed as related and at least somewhat dependent on the global warming outcome. We view the final two predicted outcomes, the growing demand for individualized food products and the increasing use of biotechnology, as less certain. Both of these outcomes represent relatively recent trends and in the case of genetic engineering the path to public acceptance has been problematic in much of the world.

The presence of all six outcomes in the PANTHA RHEI scenario may seem somewhat contradictory. In our analysis of the conditional probabilities, we saw that some variables are perceived as more or less likely depending on the occurrence or nonoccurrence of other variables. However, under PANTHA RHEI all of the events are expected to occur. This begs the question of how all outcomes might occur simultaneously despite apparent contradictions between some outcomes. For example, increased concentration in the agri-food chain is in apparent conflict with the growing importance of local food systems. Of course, there are multiple pathways whereby the events might occur and in fact relate to each other. We can envision a world wherein increased concentration in the production of food may be a viable way to confront the challenges of global warming and the associated supply issues because of the increased efficiencies that might be achieved. However, increasing firm concentration does not necessarily imply increasing geographical concentration. It is entirely possible, if not likely, that demand for locally produced food may be met by large firms with sophisticated production and operation systems that focus on regionally- or locally-appropriate production systems. Hawkes and Murphy (2010) argue for this nuanced view, whereby we experience increasing globalization even as firms engage in local production through what they call "multi-domestic strategies."

The second scenario, DISTRIBUTED SYSTEMS, has a probability of 19%. It foretells a world that emphasizes local production without further concentration of agricultural production and distribution capacities and without major food supply issues. Global warming is expected to occur as is the increased use of biotechnology and greater individualization of the food supply. This scenario provides insight into how an unexpected configuration of events might occur based on adaptation within the global food system in response to external events.

One factor that could give rise to this scenario is rising energy prices, possibly in response to global warming, which would lead to considerable increases in transportation costs (Egger et al. 2013). Higher energy prices would make food produced in distant locations relatively more expensive than that produced locally, other things equal. This scenario highlights the increasing tendency to internalize the full cost of energy, which could lead to a shift to more local food production systems (Fouquet 2011). Moreover, this scenario is consistent with the local food movements' emphasis on reducing "food miles." This scenario, with the absence of increased supply pressures, is supported by results of Parry et al. (2004). According to their simulation results, a less concentrated (more regional) food production system would result in lower yield reductions than would a system with more concentrated production. A system as described by our DISTRIBUTED SYSTEMS scenario would meet Dahlberg's (1992) vision of a food system that achieves a global balance between food, population, resources, and the conservation of genetic and biological diversity by emphazing the importance of local and regional markets, maintaining farm and regional diversity, rural revival, decentralization, and utilizing local species.

The CONCENTRATED SUPPLY SYSTEMS scenario (probability of 12%) foresees a world without increasing supply pressures and is in some ways the opposite of the DISTRIBUTED SYSTEMS scenario. It portrays a world with more concentrated production, processing, and distribution systems without an increased emphasis on local production. Global warming is expected to occur along with the increased use of biotechnology and growing individualization in the food supply.

As we discussed previously, expert opinion was split on the likelihood of increased concentration in the subsectors of the agri-food system, which may in part explain the contradictory visions of how the global food system will evolve. The impacts of increased firm concentration in economic systems in general (Daughety 1990; Brock and Obst 2009), and on the agri-food chain in particular (Sexton 2000), have been heavily debated with strong arguments on both sides of the issue. Apart from the academic debate, it is clear that numerous forces support continued concentration of firms in food production processes. One such force is a persistent tendency towards concentration in the agricultural inputs industry (USDA, ERS 2001). Another force is regional economic integration that promotes geographical concentration, a phenomenon that has been demonstrated in the case of the European Union (Krieger-Boden et al. 2008), and ASEAN countries (Kuroiwa 2012). Yet, a third force is the increasing activity of multinational companies in the agri-food sphere (Rama, 2005).

On the other hand, proponents of emphasizing local food production argue that reducing the number of miles that food travels benefits the environment (Pretty et al. 2008). However, there is increasing evidence that focusing primarily on food-miles may lead to serious unintended consequences or be less effective than other strategies in increasing sustainability. Ballingall and Winchester (2010) have shown that decreasing the number of miles that food travels could actually have a negative effect on world's poorest economies without yielding a significant reduction in environmental damage. Weber and Matthews (2008) show that the greenhouse gas emissions associated with food are dominated by the production phase (83%) and that long-distance transportation and the final delivery from producer to retail contributes to only 15% of life-cycle emissions. They argue that a much more effective strategy to lowering a household's climate footprint is to shift consumption away from red meat to chicken or fish. While a move away from local production appears to run counter to current consumer preferences, it may be the preferred option once consumers better understand the full implications of their choices.

Shaping the Global Food System of 2030

We have chosen the title of the concluding section deliberately so as to highlight the possibilities that our described in our analysis. It would be misleading to view scenario modeling from a probabilistic perspective whereby we simply look at the most likely scenarios and plan accordingly. While there is value in examining the probabilities associated with the scenarios, viewing them from this perspective misses the point. We see the true value of the analysis in what it contributes to our understanding of the situation, the relationships it reveals, and the conversations, research, and policy analysis it will inspire.

Maack (2001) suggests that there are four primary uses for scenario analysis, managing risk, building consensus for change, augmenting understanding about the future, and monitoring and scanning changes in the environment. Each of these uses will prove beneficial and insightful for the scenarios we have developed for the agri-food sector in 2030. Food production is inherently risky and it is likely to become more so as we deal with the unfolding implications of climate change. It is imperative that we identify the key variables in this complex system and understand the relationships among them in order to identify the critical levers for change that will lead to a stable and robust global food system in 2030 and beyond.

It is with this perspective that we view the scenarios we have developed and ask several questions, including: What are the key variables and the relationships between them? How can we manage and influence change as well as minimize risk? What do the most likely scenarios tell us about the future and the opportunities to shape the global food system in 2030?

As we examine the scenarios, the major outcomes, and future state variables, it is tempting to view the factors in light of the probabilities assigned to them. For example, our panel of experts believes that the global warming outcome has approximately a 90% chance of occurring. While global warming is viewed as almost inevitable, it is not a simple binary outcome, that is, it is not as if global warming will either occur or not occur. It would be more accurate to think about the extent to which global warming will happen. In fact, Keith (2014) argues that we could reduce global warming in short order by spraying tiny droplets of sulfuric acid into the upper atmosphere (this does not come without its own environmental costs). None of the events or outcomes is known with certainty and all of them may be and likely will be influenced by actions taken by people, organizations, and governments.

Two variables that play a central role in the scenarios we have developed are global warming and food supply issues. They are key outcomes because they are considered to be very likely to occur, they are expected to have a large impact on the system, and they are interrelated (supply disruptions are expected to increase due to global warming). Moreover, the supply issues that result from changing worldwide moisture and temperature patterns, specifically the possibility of reduced and more variable yields (including total crop failure), will likely represent the most serious impacts of global warming on the global food production system. Indeed, the strongest relationship between outcomes in our model was between global warming and supply disruptions.

Two key industry variables that have the potential to shape the global agri-food landscape emerged in our analysis: the use of biotechnology and the concentration of firms in the industry. We view these as important because of the possibilities for these outcomes to influence the ability of industry to respond to changing circumstances and their impact on consumers. The use of biotechnology in agriculture, particularly genetic engineering, has been a lightning rod for the expression of consumer concern. Regardless of the outcome of regulatory and labeling disputes, biotechnology must be viewed by policymakers as a critical tool to modify plants and animals so that yields may be maintained in the face of climate change. Specifically, biotechnology could prove useful in developing heat- or drought-tolerant crops. Again our model showed strong relationships between the use of biotechnology and the global warming and supply disruption variables.

The level of industry concentration will also be of great interest to policymakers as issues of monopoly power and control over the food supply make this an issue of high interest to both governments and consumers. Moreover, the concentration of firms in the agri-food sector and the extent to which we rely on local food systems will be important determinants of the structure of the global food system. Will food production, processing, and distribution be controlled by a few, large, centrally-organized firms, or will we have a more distributed system where decisions are made at the regional level? Regardless of the organizational form, will the world rely on highly-concentrated, mass production systems or numerous, local, diversified, specialized growers, or will we see some intermediate outcome? What combination of these factors will most effectively meet the challenges posed over the next decades and satisfy consumers as well? Additionally, what role will rising consumer demand for individualized food products play in this evolving system?

The three scenarios that we describe exhibit stark differences that should give us pause. They should cause us as citizens, societies, policymakers, interest groups, and governments to consider the nature of the food system we want envision for the coming decades and what must be done to shape that system. Many of the factors and outcomes involve long-term, complex issues that will require early action to achieve the desired outcomes. Global warming is well underway and the decisions we make today will have a limited impact on temperatures in 2030. Nevertheless, the scenarios we describe paint alternative visions of the future that can serve as a catalyst for discussion surrounding what outcomes are most desirable, what actions must be taken, and how we will measure progress toward meeting the goals that are established.

With regards to global warming and the supply disruptions that it may cause, the scenarios we describe contain two contrasting visions of the world in 2030. In both cases global warming occurs. However, in one scenario (PANTHA RHEI) it occurs with major supply issues while in the others (DISTRIBUTED SYSTEMS and CONCENTRATED SUPPLY SYSTEMS) global warming occurs without major supply disruptions. The discussion surrounding these very different scenarios will certainly center around which scenarios are more desirable, which outcomes are most favorable, and what steps must be taken to achieve the desired outcomes. With regards to global warming and the potentially severe impact it may have on global food supplies, we can envision many possible responses that would address the most severe effects of global warming. These include investing in research to adapt crops and focusing on water conservation and/or building additional water storage capacity in order to mitigate some of the worst disruptions to the food system caused by climate change. Likewise, each of the other outcomes (use of biotechnology, firm concentration, local food production, and individualization) should be explored as they were revealed to be key variables that will influence the important future state variables that will define the global food system in 2030.

The scenarios that we describe should encourage a discussion of how we approach the major issues facing the global food system. Historically, we have often addressed problems with targeted solutions that address the symptoms but not the underlying issues. Will this be our answer to emerging problems or might we take a more holistic perspective that delivers solutions that assure the health of the entire system? Scenario analysis can help elucidate the choices and encourage discussion of a broad set of alternatives so that outcomes are not foregone conclusions. If we look far enough into the future and address emerging issues before we are in crisis, we have a greater opportunity to consider a variety of approaches, experiment with solutions, monitor key indicator variables, and ultimately develop responses that are better-suited to the problem and more consistent with societal values.

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Appendix A

Mathematical foundations of the Smic-Prob-Expert approach (Source: Duperrin and Godet, 1975)

For the estimation of the probability of an event:

(1) $\mathbf{H} = (e_1, e_2, \ldots e_n)$,

where **H** represents the list of events denoted as e_i.

The probability that an event will occur is denoted by P(i). The conditional probability of event e_i when e_j event occurs is denoted by P(i/j) and the conditional probability of the occurrence of e_i if the e_j does not occurs is denoted by $P(i/\bar{j})$, subject to the following constraints.

(2) $0 \leq P(i) \leq 1$;

(3) $P(i/j)P(j) = P(j/i)P(i) = P(ij)$,

referring to the estimation of the probability of event e_i when the event e_j occurs: and

(4) $P(i/j)P(j) + P(i/\bar{j})P(\bar{j}) = P(i)$,

referring to the estimation of the probability of event e_i when the event e_j does not occur.

In a system **S,** consisting of n separate events, there will be r possible states, where $r=2^n$.
The separate events are considered to be non–recurring during the time period T being studied.

Each state E_k has an unknown probability, Π_k, where $\sum \Pi_k=1$.

For each separate event e_i we can determine individual and conditional probabilities, espressed as a function of Π_k.

(5) $P^*(i)= \sum_k \Theta_{ik}\Pi_k$,

where $\Theta_{i,k} = 1$ if e_i forms part of E_k and $\Theta_{i,k} = 0$ if e_i is not part of E_k.

The conditional probability P*(i/j) can be expressed as a function of Π_k and P*(j) as follows:

(6) $P^*_{(i/j)} = \dfrac{\sum_{k=1}^{r} t(ijk)\Pi_k}{P^*(j)}$,

for all *i*,*j*, where $t_{(ijk)} = 1$ if e_i and e_j are part of $\boldsymbol{E}_k$, and $t_{(ijk)}=0$ if e_i and e_j are not part of $\boldsymbol{E}_k$.

In an analogous way, the conditional probability of the occurrence of P(i) in the case of the non-occurrence of P(j) can be expressed as:

$$(7)\ P^*_{(i/\bar{j})} = \frac{\sum_{k=1}^{r} s(ijk)\Pi_k}{1 - P^*(j)},$$

for all *i*,*j*, where $s_{(ijk)} = 1$ if e_i and $\underline{e}_j$ are part of $\boldsymbol{E}_k$ and $s_{(ijk)} = 0$ if e_i and $\underline{e}_j$ are not part of $\boldsymbol{E}$.

In this way the algorithm is capable of incorporating the expert-estimations in such a way that the results conform to the following constraints:

$$(8)\ 0 \leq P^*(i) \leq 1,$$

for the probability of occurrence of P*(i) event;

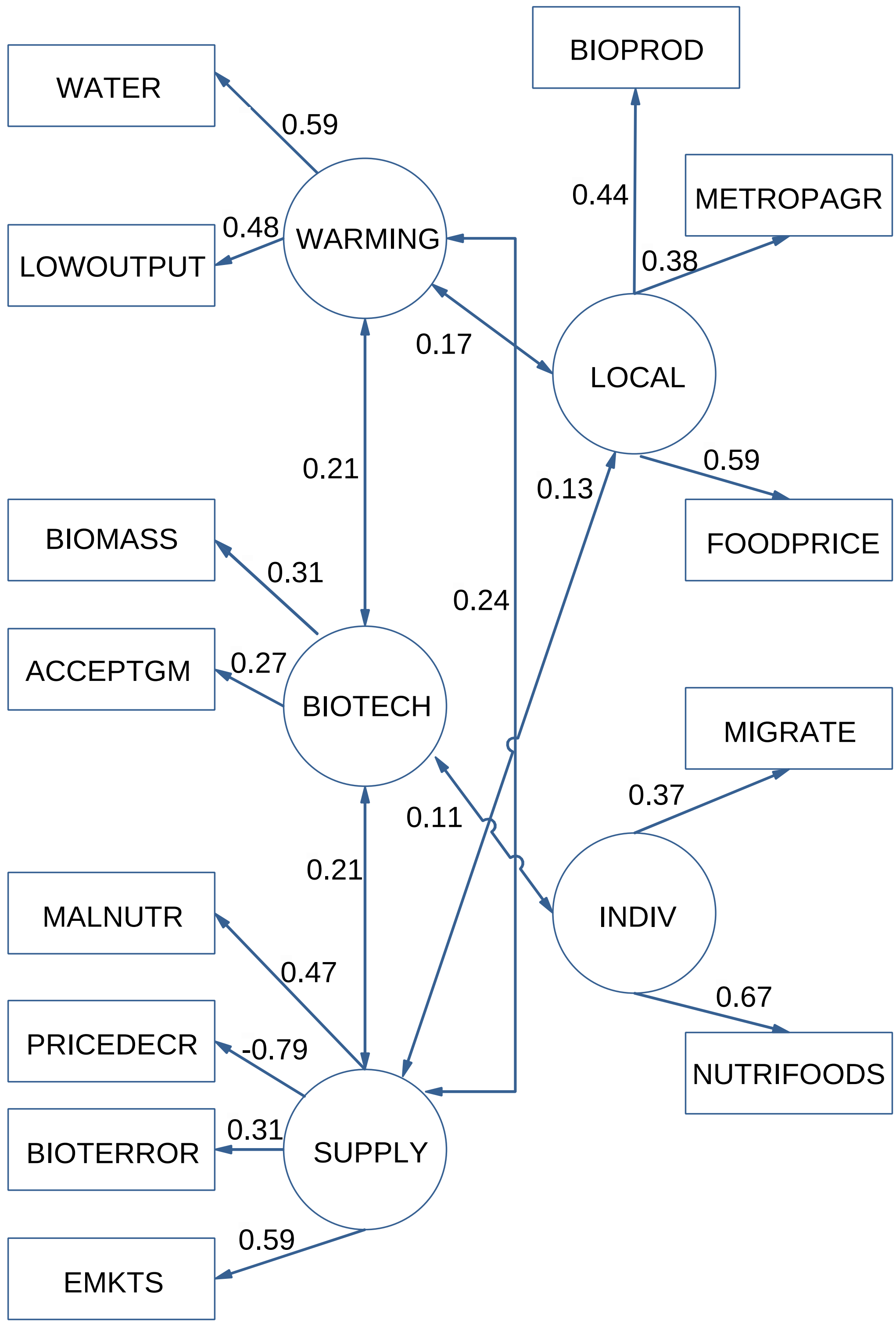
$$(9)\ P^*(i/j)P^*(j) = P^*(j/i)P^*(i) = P^*(ij),$$

for the conditional probability of P*(i) event, if P*(j) event occurs; and

$$(10)\ P^*(i/j)P^*(j)+P^*(i/\bar{j})P^*(\bar{j})=P^*(i),$$

for the conditional probability of P*(j) event, if P*(j) event does not occur.

Appendix B



Structural equation model of the future of the agri-food sector

Note. The values shown between latent and future state variables figure are standardized regression coefficients; the values between the latent variables are correlation coefficients.

