Envisioning and Enabling Sustainable Smart Markets

Wolfgang Ketter

Erasmus Research Institute of Management - ERiM

Inaugural Address Series
Research in Management

ERASMUS UNIVERSITEIT ROTTERDAM

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Envisioning Sustainable Smart Markets

Address delivered at the occasion of accepting the appointment of
Professor of Next Generation Information Systems
at Rotterdam School of Management, Erasmus University Rotterdam,
on Friday the 20th of June, 2014

Prof. Wolfgang Ketter

Rotterdam School of Management
Erasmus University
P.O. Box 1738
3000 DR Rotterdam
E-mail: wketter@rsm.nl

Samenvatting

Veel van ‘s werelds meest urgente problemen zoals klimaatverandering, bevolkingsgroei, armoede, ondervoeding en aantasting van het milieu vragen niet alleen maar om oplossingen, maar verlangen ook om meer duurzame manieren van samenleven te vinden. Marktmechanismen kunnen effectief zijn om dergelijke grootschalige problemen omtrent de allocatie van middelen op te lossen, maar dat zijn zij slechts indien het marktontwerp de maatschappelijke kosten weerspiegelt.

De groei en verspreiding van geavanceerde informatie- en communicatietechnologieën betekenen dat nieuwe *smart markets* een manier bieden om dit te bereiken en dat zij centraal zullen staan in veel gebieden van economische activiteit. Het volume van data en de snelheid van transacties vormen echter problemen voor het menselijk besluitvormingsvermogen. Informatiesystemen kunnen een centrale rol spelen in het bedenken van oplossingen – vooral met de ontwikkeling van intelligente softwareagenten die ondersteuning bieden bij de besluitvorming.

Deze oratie neemt de uitdagingen en kansen die onderzoekers van informatiesystemen ondervinden in beschouwing en schetst een agenda voor duurzaam *smart market* onderzoek die is gebaseerd op de samenwerking tussen verschillende disciplines. Het is gericht op de drie overlappende gebieden: market and learning agent ontwerpen, marktevaluatie met de hulp van autonome learning agents en de realtime ondersteuning van besluitvorming. Voorbeelden van bestaande projecten met duurzame *smart markets* voor elektriciteit (smart grid) en veilingen van snijbloemen en planten (Nederlandse bloemenveiling) dienen ter illustratie.

Abstract

Many of the world's most urgent problems such as climate change, population growth, poverty, malnutrition and environmental degradation not only demand solutions but also require us to find more sustainable ways of living. Market mechanisms can be effective in solving large-scale resource allocation problems of this kind, but only if the market design reflects the social costs.

The growth and spread of advanced information and communication technologies mean that new smart markets offer a way to achieve this and will become central to many areas of economic activity. However, the volumes of data and speed of transactions involved place a burden on human decision-making capabilities, and information systems can have a central role to play in helping to devise solutions – in particular, in developing intelligent software agents to provide decision support.

This address looks at the challenges and opportunities involved for information systems researchers, and sets out an agenda for sustainable smart markets research, centered on collaborative approaches. It focuses on three overlapping areas: market and learning agent design; market evaluation using autonomous learning agents; and real-time decision support. Examples are included of current work on sustainable smart markets for electricity (smart grid) and for flowers (Dutch Flower Auctions).

Content

1. Introduction

"If not now, when?"
Zen philosophy

Dear Rector Magnificus,
dear colleagues,
dear friends and family,
Liebe Familie und Freunde,
dear distinguished guests.

The world is full of challenges. Serious, big, and pressing challenges, such as poor nutrition and obesity, access to water, deforestation and climate change, not enough food or malnutrition, healthcare, pollution, and poor labor skills. What separates this time from other times is the global scope and scale of these challenges. We are all aware of rising sea levels and its impact on the Netherlands. Recent studies show that global climate change associated with growing greenhouse gas emissions is predicted to raise sea levels by 20 to 110 centimetres by 2100, on average by 60 centimetres (Dasgupta et al., 2009). Climate change will have dramatic negative consequences for freshwater supply and agriculture. This is a serious global threat! Why are we having so much trouble dealing with these challenges? What tools do we have to address them? How do we adapt and scale these tools to facilitate decision-making in these complex environments? These are the questions I have been working on for years, and I invite everybody to join me in this journey.

Markets have become the primary mechanism by which we make decisions in our society, and they are driven by the self-interest of participants. In recent years, markets have been reshaped by advances in information and communication technologies. This is especially visible in the growth in internet-enabled business-to-consumer (B2C) transactions by firms such as Amazon and eBay. The value of business transactions for the G20 states is predicted to reach $4.2 trillion in 2016 (Dean et al., 2012). There are even stronger developments in the business-to-business (B2B) landscape, with market studies in the United States estimating that it is now about double the size of its B2C counterpart (Hoar et al., 2012). As a consequence of this increase in online market transactions we have seen an explosion of digital data, so-called *big data*, in every sector of the global economy (Economist, 2010).[1] Markets nowadays need to be designed so that they

1 According to the research firm IDC, from 2005 to 2020 the global volume of data will grow by a factor of 300, from 130 exabytes to 40,000 exabytes, or 40 trillion gigabytes. This major shift from data scarcity to data abundance brings great challenges for market design, but also opportunities for participants across the world.

can handle this large amount of data in a way that is both *robust* and *efficient*. A robust market is one in which there are no loopholes in the market design that allow outcomes to be manipulated; an efficient market is one that guarantees an efficient allocation of resources among market participants[2].

In a sense, we can see a market as a distributed optimization mechanism that relies on large numbers of individual decisions by individuals and firms. So can we use markets to address large societal problems? Many of these problems have of course arisen through market interactions. For example, tropical deforestation is a rational response to the international market value of timber. Why is this? One reason is that markets do not consider external costs unless they are imposed through market design. This is the *tragedy of the commons*. For example, individual commercial fishing enterprises have no incentive to preserve fish stocks, because that would simply cut their income without necessarily protecting the fish. The only way to preserve fish stocks is for everyone to agree on limits, and for nobody to cheat. This is why we have licenses and bag limits for recreational hunting and fishing, and why it takes international treaties and enforcement to manage ocean fish stocks. In the short term, of course, this raises the price of fish. A crucial research question in this regard is how we can evaluate different market designs with respect to common values.

Markets can be very effective in solving large-scale resource-allocation problems by aggregating the preferences of their participants. Many important societal challenges could be viewed as resource-allocation problems if all parties affected by market outcomes were able to participate. Ways in which market design can be modified include providing consumers with additional information or using Pigovian taxes. Fair-trade coffee and renewable energy tariffs are examples that include additional purchase information. These allow people to make more informed choices. Pigovian taxes include, for example, alcohol and tobacco taxes designed to help change people's behavior or a carbon tax that helps people to internalize the costs associated with carbon pollution.

2 The efficient allocation of resources is measured with the help of "Pareto efficiency", a state of resource allocation in which it is impossible to make any one individual better off without making at least one individual worse off. This concept is named after Vilfredo Pareto (1848–1923).

Global Disruptive Forces

In my opinion, the challenges I have just outlined are symptoms of deeper underlying forces. I believe, after critical discussions with my colleagues worldwide, that all these problems arise from the following *global disruptive* forces:

- Economic development and population growth
- Disruptive technologies

These forces are exposing weaknesses in our markets and institutions. I will elaborate on each of them in some detail, and lay out a research agenda that helps to tackle these forces with market-oriented approaches (as opposed to regulatory solutions or just reacting to disasters). I will take a holistic view on markets, including both the market rules and the way participants interact and make decisions to achieve their goals. I will illustrate this approach by providing examples of sustainable smart markets for flowers and electricity.

Economic Development and Population Growth

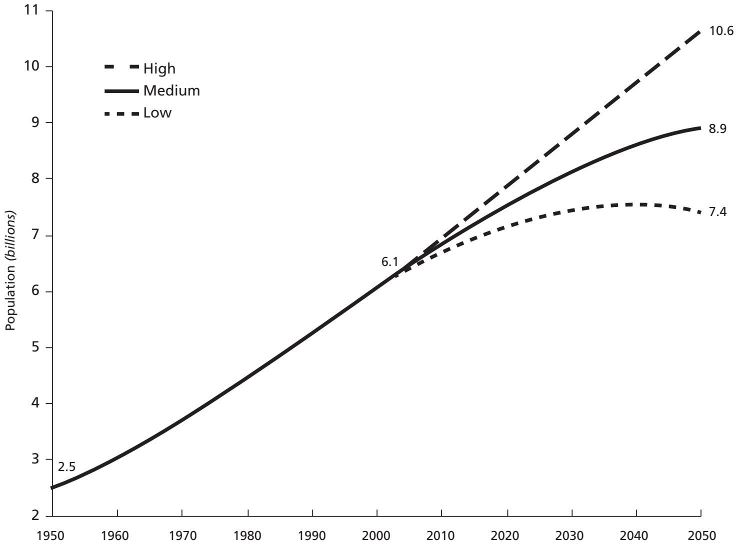
Economic development and population growth are strong disruptive forces that influence how we make decisions, especially at the societal level. The large growth in world population[3] (see Figure 1), especially in developing countries such as Africa, China and India – and the concurrent drive for higher living standards – raises the need not only for food resources, but also for energy[4]. Since conventional energy generation based on fossil fuels such as coal involves high levels of environmental pollution, we have to strive for a means of generating energy that is truly sustainable. Carbon-free energy generation will not contribute further to climate change[5].

3 T9.22 billion people in 2075 (United Nations, 2004).

4 Interesting observation: The production of meat requires more energy per kJ than soya beans, for instance, but for many people increased meat consumption is synonymous with a higher standard of living.

5 E.g., Electricity production is responsible for the largest share of greenhouse gas emissions: in 2011, US electricity production contributed 33% of the country's overall greenhouse gas emissions Over 70% of our electricity comes from burning fossil fuels, mostly coal and natural gas (US Energy Information Administration, 2011).

Figure 1: Estimated world population, 1950-2000, and projections for 2000-2050



(Source: United Nations, 2004)

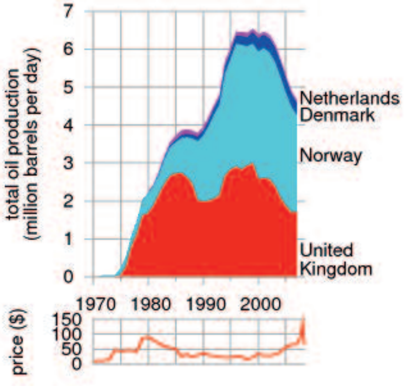
Overall economic development and population growth leads to resource limits; climate change is evidence that we are hitting a resource limit (Whiteman et al., 2013). The public is becoming more aware of *climate and resource limits as disruptive forces* that have dramatically changed the landscape of business and society (MacKay, 2008). For instance, access to food and fresh water are essential for all of us, but a large part of the world's population does not have that access. To survive, each of us requires some portion of earth's resources and its ability to absorb our waste, but it now takes the earth eighteen months to regenerate what we use in a year. That is unsustainable, and even at today's levels the world population already requires the equivalent of 1.5 earths.[6] Moderate scenarios from the United Nations suggest that if current population and consumption trends continue, then by about 2050 we will need the equivalent of almost three earths to support us. We need to change the way we live, and the decision-making that goes with it, to become fully sustainable (Wackernagel and Rees, 2013).

Another example is finite fossil fuel reserves. Almost 60 years ago Hubbert (1956), in his seminal paper, pointed to the finite supply of fossil fuels. Peak oil is still a widely and hotly debated topic around the world. Scientists argue about how long reserves will last, and predictions vary widely – it could be 50 years or

6 http://www.footprintnetwork.org/en/index.php/gfn/page/world_footprint/

maybe 200? Who knows, but one thing is sure – we have to act now. Those reserves will run out eventually and probably sooner than we like to think. North Sea oil production, for instance, already peaked years ago (see Figure 2).

Figure 2: Total crude oil production from the North Sea, and 2006 oil price per barrel in US$.



(Source: MacKay, 2008)

Peaks are generally a function of cost and technology. Most of the newer "discoveries" such as tar sands, or shale oil and gas in North America are not in fact new, but have been uneconomic until the price got high enough. And most of those newer reserves are still relatively small by historical standards. Individual wells in North Dakota, for example, have useful lives of just a few years.

So what kind of consequences does this have for all of us? One important one is of course climate change. There are three clear reasons why we need to act on climate change. First, the burning of fossil fuels causes carbon dioxide concentrations to rise. Second, carbon dioxide is a greenhouse gas. Third, an increase in the greenhouse effect raises average global temperatures, and has many other effects.[7] Rising sea levels and warmer and more acidic oceans could cause major changes in ocean currents. These are just a few of the disastrous consequences of our behavior – posing a threat to people's lives around the world, including those living in the Netherlands. Much more money has to be spent on building additional protection against rising sea levels.

7 See http://www.skepticalscience.com/looking-for-connections.html for an insightful movie on the history of CO_2 emissions from the burning of fossil fuels.

Since we live in a world which has limited capacity, we should be proactive in our behavior and make ecological limits central to our decision-making. Achieving sustainability will require major changes in market economies, such as internalizing the cost of pollution and environmental degradation.

Disruptive Technologies

I was trained in different disciplines such as electrical engineering, software engineering, computer science and information systems, and not as a social problem-solver. But I do believe that the key social problems of our time cannot be solved by one discipline alone. That is why I am passionate about information systems, a highly interdisciplinary field of research that can contribute a lot not only to explaining problems, but also to providing solutions.

In 1967, Gordon Davis, Gary Dickson, and Tom Hoffmann at the University of Minnesota (UoM) started the first formal academic degree program in Management Information Systems (MIS) (Davis, 2006)[8]. Since then the University of Minnesota has been known as the cradle of information systems (IS). The field has changed dramatically since its inception, but it was always at the cutting edge of technology. IS researchers analyzed, designed, and developed technologies which had impact for business, society, and policy. Information systems are essentially about using technology to increase productivity and create new business models. The current academic field of information systems has its roots in the 1990s and 2000s, when scholars started to research *disruptive technologies* such as the internet, and examine their impact on the business, societal, and policy landscape. Current and emerging disruptive technologies are creating information-rich and fast-paced business environments that can present severe challenges for human decision-making capabilities.

For instance, the personal computer *democratized* computing in the early 1980s put processing power in the hands of more and more knowledge workers. In the mid-1990s two major innovations appeared: the World Wide Web (WWW, Berners-Lee, 1990) and large-scale commercial business software such as enterprise resource planning (ERP). The Web made available more of the world's knowledge than had ever before been possible, and ERP gave companies the ability to tap into new markets and sales channels. Over time, these advances were combined with other developments – and the benefits keep on accumulating. The Web, for instance, became much more useful to people once

8 I am grateful that I was able to obtain my PhD degree from that very institution under the supervision of Alok Gupta and Maria Gini, two world-class scholars in the area of information systems and artificial intelligence, and from time to time by Gordon Davis himself, who is still with the department as an emeritus professor. I truly admire Gordon's ability to tell great stories to bring a topic alive and to engage audiences worldwide.

Google made it easier to search, while a new wave of social, local, and mobile applications such as Facebook and What'sApp have become an integral part of many people's lives. Corporate systems have been extended to smart phones so that managers can stay connected, and tablet computers now provide much of the same functionality as PCs.

Naturally, disruptive technologies challenge existing business models (Christensen, 2013). For instance, by creating iTunes, iPod, iPhone, and App Store in the 2000s Apple established a whole new business ecosystem that challenged the entire phone and music industries. The iPhone revolutionized the way we communicate and live. Another example is Amazon's transformation from an online bookstore to an online marketplace and provider of cloud platforms. Amazon started selling services rather than products, and its competitors became clients.

Our technologies are racing ahead, but many of our skills and organizations lag behind. So it is urgent that we understand these phenomena, discuss their implications, and come up with strategies that educate people and allow them to use the increased power and ubiquity of technology. Technological progress – in particular, improvements in computer hardware, software, and networks – has been so rapid and so surprising that many present-day organizations, institutions, policies, and mindsets are struggling to keep up. Organizations that embrace those technologies increase productivity, and they are able to create new and innovative business models based on them.[9]

In many cases markets and political structures[10] have not adapted to these global forces. For instance, the Dutch Flower Auctions (DFA), which I will be discussing later on, are facing challenges of scale and sustainability. The scale has changed because of disruptive technologies such as worldwide transportation and high-speed data-processing. The volume of data that bidders must process has become so large that it challenges the cognitive capabilities of human decision-makers. The current structure requires massive quantities of flowers and plants to be transported into and out of Amsterdam on a daily basis, creating large external costs. I will discuss the specific challenges and opportunities for the flower auctions later on.

9 Even before the credit crunch brought such dire financial consequences, Brynjolfsson and McAfee (2006) believed that the root of our current economic situation is not a great recession, or a great stagnation, but rather that we are in the early throes of a great restructuring.

10 In addition, political structures are often driven by very high inertia and short-term thinking, which leads to risk aversion.

Together, these global disruptive forces result in large-scale societal challenges, often referred to as wicked problems (Rittel and Weber, 1973). They arise in complex socio-technical systems which involve interaction between many different factors: social, technological, economic and political. The resulting behavior of these systems cannot be explained by considering each of its parts in isolation. This makes it difficult to design targeted interventions to correct perceived misbehaviors within the system (von Hayek, 1989; Kling, 2007). Worse still, even where promising interventions are identified, isolated interventions are often ineffective (Sovacool, 2009), and the prohibitive cost of potential negative social consequences makes it impossible to do a thorough evaluation of potential interventions realistically, fast, and at scale.

Research has a central role to play in helping policymakers understand how market design and its rules can affect outcomes for society and for market participants. Therefore, the mission I have developed for my new role as Chair on Next Generation Information Systems is:

> **Responding to global disruptive forces through efficient and robust decision-making using intelligent agents in sustainable smart markets.**

One could view many 'wicked problems' such as climate change as failures of market design, in which the relationship between society and market participants is broken. For example, current energy markets transfer costs from market participants (producers of fossil fuels, drivers of gas-guzzling vehicles) to society at large in two ways: through taxes spent on subsidies, and through external costs shifted from market participants to present and future generations of society. I envision sustainable smart markets to be a *Rosetta Stone*[11] in this complex challenge.

In the section that follows, I will define what I mean by sustainable smart markets.

Sustainable Smart Markets

"Charging a flat rate for electricity is like charging a flat price per pound for all items in a grocery store. What would happen if everything that came out of the cow — steak, hamburger, suet, bones, and hide — were priced at the average cost per pound?" – Alfred Kahn (quoted in McCraw, 1984, p. 226)

11 Back in 1799, the discovery of this black basalt stone, inscribed with hieroglyphics, demotic and Greek characters, was the first vital stage in helping to unlock the mysteries of Egyptian hieroglyphics.

In Kahn's example above, the result would be that everyone would always eat steak (Sovacool, 2009)! This quote illustrates a fundamental limitation of many traditional markets: data is sparse, because participants do not have the time, interest, or resources to gather and use richer data in their decision processes. Increases in computational power, advances in user interface design, and the fluidity of electronic communication, together with the arrival and growth of the internet, have brought into being many of the theoretical conjectures made by Malone et al. (1987). In their seminal article they already agreed that cheap, ubiquitous availability of information and communication technologies (ICT) would herald a shift from hierarchies to markets. Over time, markets have moved from physical places to internet spaces (Kambil and van Heck, 2002).

Rapid advances in computational power and evolution of computer networks have enabled researchers to design complex market structures where computational intelligence is needed to facilitate human decision-making. Research in computer science, economics, management and information systems is pushing the envelope on market structure, organization, design, and decision support in the increasingly complex and co-dependent markets in which our modern organizations operate. The term *smart markets* has been defined in management science (McCabe et al., 1991; Gallien and Wein, 2005) as:

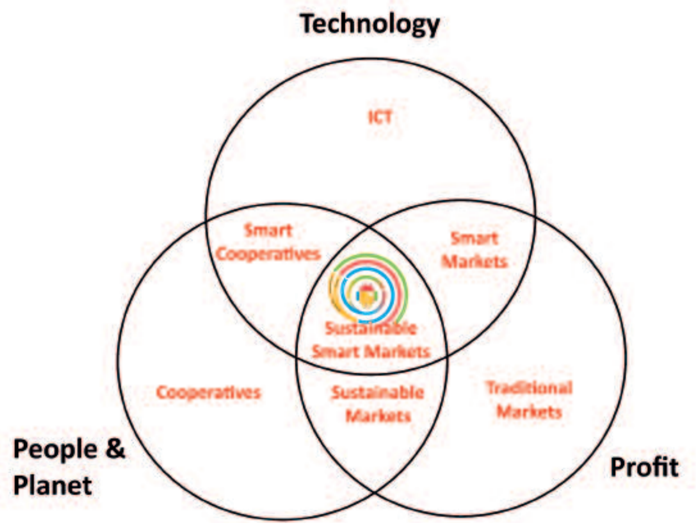
> *Exchange institutions supported by a computer executing an optimization algorithm to solve an allocation problem associated with each given set of bids.*

In other words, trading in these markets requires significant information gathering and computational decision support that can be far beyond the cognitive capacity of humans. Although this approach goes back at least as far as Stanley et al. (1954), improvements in computational power and network communications now enable these allocation problems be solved in seconds rather than days. The need for sustainability requires that we expand the set of stakeholders to include all who are affected by environmental damage or resource depletion, and I therefore want to generalize this idea to:

> *Sustainable Smart Markets expand the set of stakeholders through integrated market design, decision support and evaluation to achieve the best results for all stakeholders, including society and future generations as well as direct market participants.*

Figure 3 shows different types of markets and embeds them within an adapted version of the triple bottom line[12] of people, planet, and profit (United Nations, 1992). For the purpose of this address I fold people and planet together in one circle and add the technology circle. I will be focusing on the markets shown in the profit circle.

Figure 3: Types of markets.



My primary focus is on addressing the sustainability challenges that are caused by global disruptive forces. Therefore, I want to provide appropriate tools and information to decision-makers such as policymakers, regulators, manufacturers, and customers so that they are able to make best possible decisions (Bichler et al., 2010)[13]. The need for synthetic intelligence is already apparent in several markets, and indeed smart markets already exist in sectors such as energy, flower production, online retailing, and negotiations. Operations management also addresses the challenges of sustainability using techniques such as *Closed-loop supply chains* (Fleischmann et al., 1997) and *cradle-to-cradle design* (McDonough and Braungart, 2010).

12 Triple bottom line incorporates the notion of sustainability into business decisions.

13 The initial Smart Market research agenda is joint work with Martin Bichler and Alok Gupta and appeared in *Information Systems Research*, December 2010.

Sustainable smart markets require a wide spectrum of research, from optimization techniques to game theoretic formulations, as well as research on individual behavior and preferences, market mechanisms, and even organizational design. It also calls for many new methodological developments, from new statistical methods to artificial intelligence techniques and simulation. In addition, we will need to develop computational research platforms that can model complex business, economic and social environments. Computational platforms of this type can simulate an ecosystem at an industry and societal level, and provide a range of capabilities to support research, such as experiment-management frameworks, documented advanced programming interfaces (APIs), and tools for log analysis. With an active community of developers, a variety of research agendas can be pursued. These platforms help us to explore multi-echelon systems so that we can study relationships among simulated entities, and between those simulated entities and the larger world, in a holistic manner.

I now present the research agenda for Sustainable Smart Markets, and the opportunities it offers for information systems researchers.

2. Research Agenda

"Imagination is more important than knowledge."
Albert Einstein

Traditional mechanism design treats decision-makers as rational entities with infinite cognitive capacity. However, in reality the human mind has limited cognitive capacity. We tend to make decisions using rules of thumb, or heuristics, which stem from our own experiences (Kahneman and Tversky, 1979; Simon, 1979). An important area of study for information systems scientists is the design and implementation of (artificially) intelligent software agents and decision support tools that can effectively assist humans in their decision-making efforts (Wellman, 1993; Wooldridge and Jennings, 1995), particularly in environments that are information-rich and time-critical. Software agents that are capable of learning and that can augment human behavior have the potential to enhance human performance significantly, since they open up possibilities for automating, improving and coordinating decision processes (Peters et al., 2013a). These learning agents can act on behalf of a user with some degree of independence or autonomy using representations of user goals and preferences. In order to achieve their goals in sustainable smart markets, agents need to account for the actual preferences and augment the cognitive capacities of their users. However, even human decision-making that is agent-augmented cannot be fully rational.

My primary objective as the Chair in Next Generation Information Systems is to research, develop, and apply sustainable smart markets and learning software agents to support human decision-making capabilities in domains such as sustainable smart energy and flower markets. My colleagues and I will contribute specifically to interdisciplinary research and development in the areas of market and learning agent design, market and autonomous learning agents evaluation, and real-time decision support using interactive learning agents, and we will apply those techniques to solve wicked problems.

These software agents need to learn the preferences of their users, as well as the dynamics of the multi-echelon market environment in which they must operate (Ketter et al., 2012). User preferences, and their influence on decisions, have been extensively studied in economics and related fields, but many important problems remain untouched. One of the big challenges is how to adapt existing static representation methods to model user preferences dynamically, in a compact form. This is important for fast-evolving domains such as smart energy markets or internet-enabled businesses.

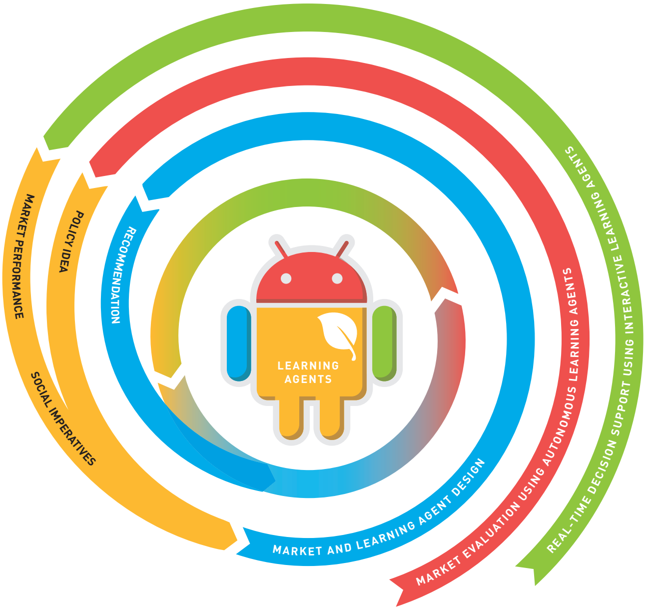
Current market design approaches assume that participants are fully aware of their own preferences, but *preference elicitation* is a formidable task for learning agents. First, users face well-documented difficulties in articulating their preferences accurately (Shiv and Fedorikhin, 1999). For example, to participate in combinatorial auctions, a type of smart market in which participants can place bids on combinations of discrete items, or "packages", rather than individual items or continuous quantities, bidders need to know their preferences, i.e. valuation for an exponential number of bundles. Second, even when attempts are made to focus user attention using well established methods for eliciting preferences, the methods involved tend to be cumbersome and give inconsistent results. Finally, in competitive environments, users may not want to divulge their preferences. However, in an incentive-compatible market design, competitors are motivated to express their preferences truthfully.

Mechanism design theory deals with such questions, but we know little about incentive-compatibility in repeated and interrelated markets. For instance, multi-echelon markets such as supply chains consist of multiple self-interested entities, each operating according to its own objectives and policies. Decisions in one market also influence outcomes in other markets. Furthermore, the preferences of the same individual, relating to price elasticity perhaps, might be different when faced with a different decision, environment or economic regime – for example, in situations where there is over-supply or scarcity (Ketter et al., 2009; 2012).

The agenda I am presenting offers numerous research opportunities for IS researchers to design, evaluate, and use intelligent software agents for decision-making in smart markets and to avoid many of the shortcomings of previous research. I divide the research agenda into three overlapping streams and suggest novel work in analytical, empirical, and experimental research using agent-based multi-echelon smart market platforms. To act rationally, the agents must choose among different actions and means of expression; to intelligently support the actions of decision-makers, they must understand and respond to user choices. Therefore, the agenda I propose includes (Figure 4):

- *Stream 1:* Market and Learning Agent Design
- *Stream 2:* Market Evaluation using Autonomous Learning Agents
- *Stream 3:* Real-time Decision Support using Interactive Learning Agents

Figure 4: Sustainable Smart Markets research streams.



Stream 1: Market and Learning Agent Design

The research activities in Stream 1 are concerned with designing smart markets that can help to solve the kinds of large-scale societal and business challenges identified earlier. This is important: markets have expanded in scope and scale, and decision-makers are now confronted with markets that are more diverse and that have more complex rules and conditions, making it difficult to use all the information that might indeed be available or computable. A prime example of a market design failure (or a failure to exploit a complex market because of the difficulty of understanding its operational rules) was California's electricity market crisis in 2000–2001, which had a disastrous impact on both the state and the companies involved (Borenstein, 2002).

Traditionally, market designs have been researched using classical game theory and mechanism design, where issues of equilibrium (to ensure efficient outcomes) and incentive compatibility have dominated the theoretical concerns. However, practical sustainable smart market designs require us to give explicit consideration to sustainability, to computational aspects, to the preferences of market participants, and to the social goals that the regulatory policies are designed to bring about [14]. This has led to many new insights at the intersection of computer science, economic theory, psychology, operations research, and information systems.

The goal of this first research stream is to:
Design smart market mechanisms that achieve efficient, robust, and sustainable outcomes, given the collective (Stream 2) and individual (Stream 3) preferences of market participants and the social context.

The European Union's Emission Trading System, for instance, was intended to reduce greenhouse gas emissions (i.e., to satisfy a collective preference expressed through political will). It failed because the market became flooded with free carbon emission permits which ended up having little value, and perhaps also because there was no effective feedback mechanism to ensure that the needs of society and future generations were taken into account (Economist, 2013). As evident in the German Energiewende, there is also a conflict between social goals and the goals of market traders (Economist, 2014).

Business decisions represent choices that combine a variety of observable factors, *market dynamic*s, with explicit goals and implicit preferences of the market participants. These decisions are reflected in transactions. For example, energy markets are characterized by a range of exogenous influences, including daily, weekly, and seasonal variations in supply and demand as well as competitor behavior, fluctuations in fuel price, political factors, regulatory changes, reputation, tax regimes, and weather conditions.

Learning implicit preferences by observing market dynamics and actual transactions, and constructing a model that can account for these observations, is a challenging task. With its high volume and frequency, the data is currently significantly ahead of market design theory; the task of a rational agent is to try to process these large quantities of data in order to maximize the expected utilities. This offers IS researchers exciting opportunities to develop novel statistical methods and probabilistic machine learning algorithms that can create insights into existing and future smart market designs and new theoretical frameworks, such as how to model the latent behavioral characteristics of different market participant groups offline, and then perhaps

14 The social goals have to be implemented by regulators in the form of market rules.

to use the results in Stream 2 to dynamically predict future market regimes and participants' decisions in real time (Ketter et al., 2012). Understanding how the preferences of market participants influence their behavior is crucial, and this knowledge should then be used to update the smart market design, using mechanism design, for instance (see Stream 2).

In my opinion, this is an important development that IS scholars should contribute to. The IS community is in a good position to do so, as research in this area requires using a combination of behavioral, economic, and design science techniques.

To showcase the benefits of agent-based decision-making in smart markets, I will now give an example from my own research – as I will also do at the end of the other two streams. For illustrative purposes, I have divided commodity supply chain environments into three categories: non-perishable, semi-perishable, and highly perishable. For this address I will focus my examples in Streams 1 and 2 on highly perishable commodities (Sustainable Smart Electricity Markets) and in Stream 3 on semi-perishable commodities (Sustainable Smart Flower Markets).

Example 1: Design of a Sustainable Smart Electricity Market

Across the developed world most electricity is generated from fossil fuels in large, central power plants. In the USA, for instance, 68% of electricity comes from fossil fuel and 20% from nuclear sources. Both sources have been heavily criticized for their environmental impact (US Energy Information Administration, 2013a). The average US power plant converts only a third of its primary fuel into usable electricity, while 6% of generated electricity is lost to the aging power lines that connect generators with consumers (US Department of Energy, 2003). The investments required to maintain and update these lines have been held back by budget cuts and lengthy approval processes, and the consequences of these delays are starting to show as disruptions such as the 2003 Northeastern blackout which left millions of households and businesses without power (Fox-Penner, 2005).

Emerging research on sustainable smart electricity markets is facilitating one of the most important transformations of our time – the emergence of sustainable energy systems and a revolution in the efficiency and reliability of electricity consumption, production and distribution. As demand for electricity by hundreds of millions in the developing world is growing rapidly and nations become increasingly concerned about the efficiency and sustainability of traditional energy sources and systems, devising effective and economically practical solutions is becoming ever more critical.

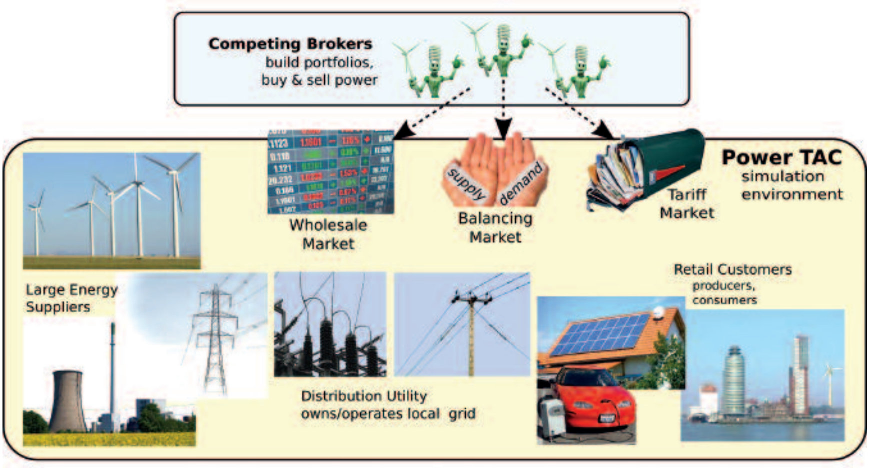
The traditional top-down approach to electricity supply and grid management is being seriously disrupted by a range of forces, including the penetration of variable, intermittent, and geographically distributed supply from renewable sources. Together with consumers becoming more involved in managing their power consumption and in small-scale production, and the emergence of electric vehicles, this is expected to bring about increasingly complex and dynamic smart electricity markets. Such smart markets, in turn, will rely on intelligent analysis of information to inform stakeholders' frequent decisions, and on effective integration of stakeholders' actions. The smart grid aims to address these challenges by intelligently integrating the actions of all stakeholders connected to it (Burger and Weinmann, 2012, Simoes et al., 2011, Sissine, 2007).

Over the past few years, I have led (together with John Collins from the University of Minnesota) the development of the Power Trading Agent Competition (Power TAC, Ketter et al., 2013a)[15], a state-of-the-art computational simulation platform for sustainable energy market research (Ketter et al., 2014) (see Figure 5). Power TAC brings to life several recently proposed IS research agendas on energy and sustainability (Bichler et al., 2010; Melville, 2010; Watson et al., 2010; Elliot, 2011).

The scenario models a competitive retail power market in a medium-sized city, in which consumers and small-scale producers of electricity may choose from a set of electricity power providers, represented by competing broker agents. The brokers are self-interested, autonomous agents, built by individual research groups to participate in the competition; the rest of the scenario is modeled by the Power TAC simulation platform. In the real world, intelligent brokerage is a potential business model for energy retailers, commercial or municipal utilities, or cooperatives. Since brokers incentivize customers to become active participants within the smart grid, they thereby provide "an opportunity to create shared value – that is, a meaningful benefit for society that is also valuable to the business" (Porter and Kramer, 2006).

15 www.powertac.org

Figure 5: Power TAC Scenario



Power TAC provides a low-risk means of modeling and testing market designs and other policy options for retail power markets. Research results from Power TAC will help policymakers create mechanisms that produce the intended incentives for energy producers and consumers. The results will also help to develop and validate intelligent automation technologies that can support the effective management of participants in these market mechanisms. It is the basis for our own analyses but it is also made available to research groups from around the world. I will discuss the competition aspect of Power TAC in Stream 2.

Stream 2: Market Evaluation using Autonomous Learning Agents

The performance of markets arises from the interaction of market design and the behavior of participants; well-designed markets can effectively align social goals with the preferences of market participants by defining an appropriate set of rules and incentives (Krishna and Perry, 1997). However, the real-world performance of market designs can be difficult to predict, and serious market breakdowns such as the California energy crisis (Borenstein et al., 2002) have made policymakers justifiably wary of experimenting with new retail-level energy markets. Therefore, Stream 2 research activities are concerned with evaluating smart markets design for wicked problems before they are released into the real world. But how do we do this?

The goal of this second research stream is to:
Build executable models of markets and participants. Use them to learn participant strategies and evaluate market designs against their original goals. Using experimental outcomes, update market designs (Stream 1) and re-evaluate (Stream 2) until the original market design goal is achieved.

To achieve this goal we need to study and benchmark the developed complex models of markets and participants within a controlled environment. Fortunately, IS has a rich tradition of studying and resolving socio-technical challenges for which "solutions cannot be deduced from scientific principles alone" (Hevner and Chatterjee, 2010). Events like power blackouts or recent financial market flash crashes have left the public wondering whether "we may be becoming critically dependent on large-scale IT systems that we simply do not understand" (Cliff and Northrop, 2012). But even though the IS discipline seems well positioned to engage in these debates, its impact in terms of resolving societal challenges has remained limited (Straub and Ang, 2011; Lucas Jr et al., 2013). Although there are various reasons for this, two reasons can be seen as particularly important:

Research methods have not been sufficiently scalable:
IS research has historically favored the individual, group, organization, and market levels of inquiry over the societal level (Sidorova et al., 2006). The limited scalability of the single-investigator model of IS research may well play a significant role in this.

Solutions are needed, not solely insights:
Decision-makers in government and industry are increasingly looking for solutions in addition to mere insights (Aken, 2004). Researchers must expand their vision to include "inventing new systems that address information needs not covered by current systems. They must not only be observers and historians of technology, but make technological contributions" (Nunamaker and Briggs, 2012).

Earlier, we have seen the difficulties that wicked problems on a societal scale pose to IS researchers. We contend that several obstacles limit the ability of current research methods to tackle complex problems that are large in scale and scope, that have not yet been addressed, that progress rapidly and where the social costs of making the wrong interventions would be prohibitive.

To tackle these issues, we propose *Competitive Benchmarking (CB)*, a novel IS research method that builds on the Trading Agent Competition (TAC), a competitive research approach pioneered by the Trading Agents community (Greenwald and Stone, 2001; Wellman, 2011; Ketter and Symeonidis, 2012), and that specifically addresses these obstacles[16]. TAC challenges researchers to devise autonomous software agents for complex, uncertain environments such as supply chains (Collins et. al, 2010) and keyword auctions (Jordan and Wellman, 2010), and to benchmark and improve them iteratively. This practice has been found to foster creativity, improve learning, and facilitate innovation through deep introspection (Garvin, 1993; Shetty, 1993; Drew, 1997).

CB emphasizes the importance of rich-problem representations that are – in contrast to the competitive element within TAC – developed jointly by stakeholders and researchers, and it leads to actionable research results, complete with comprehensive supporting data. CB supports both behavioral IS research (insights) and design science research (solutions). It also improves on TAC by providing human-system interaction facilities that can be used in training human decision-makers and in decision support studies (see Stream 3). Such facilities are valuable in complex environments such as future energy markets.

Example 2: Power Trading Agent Competition (Power TAC)

Power TAC is an instance of Competitive Benchmarking for research on sustainable energy systems. To date, Power TAC has brought together more than a dozen research groups from various academic disciplines, plus stakeholders from utilities to customer lobby groups, to competitively design, evaluate, and improve the broker agents. Cornerstones of Power TAC are annual championships, and pilots that provide additional opportunities for informal benchmarking. To date, pilots have been held at IJCAI 2011 in Barcelona, at AAMAS 2012 in Valencia, and at IEEE SG-TEP 2012 in Nuremberg. The first official Power TAC championship was held at the AAAI conference in Bellevue, Washington, in July 2013. [17]

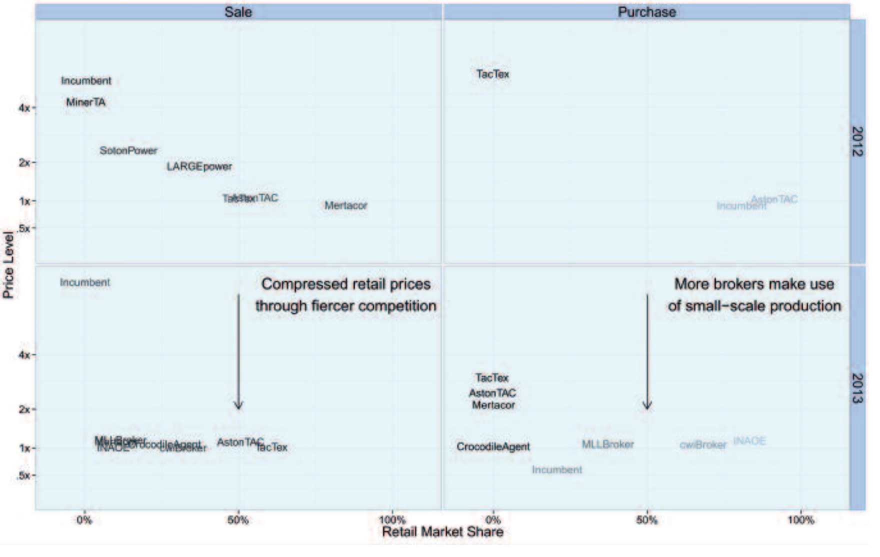
16 This work is currently under review at *Management Information Systems Quarterly* (MISQ, Ketter et al., 2014). A short version of this paper was presented at the prestigious Conference of Information Systems and Technology in Minneapolis in October 2013 (Peters et al., 2013b).

17 AAAI = Conference of the Association for the Advancement of Artificial Intelligence; AAMAS = International Conference on Autonomous Agents and Multiagent Systems; IJCAI = International Joint Conference on Artificial Intelligence; SGTEP= IEEE Conference on Smart Grid Technology, Economics, and Policies. The second official tournament took place at AAMAS 2014 in Paris in May. Since this tournament was still going on at the time of writing this address, it was not possible to include these results.

As we continue the Power TAC tournament over the years to come, we hope to see the development of highly competitive retail markets with low and stable electricity prices for consumers. Overall electricity consumption should remain constant or decline, electricity should increasingly come from renewable sources, and brokers should rely less on balancing power as their forecasting abilities improve. Conversely, small-scale producers should benefit from high and stable prices in return for their willingness to produce locally from renewable sources.

The results from the first two competitions suggest that many of these objectives could be met. Most importantly, broker designs have matured, as suggested by the reduced need to balance power, and retail markets have become significantly more competitive. These findings are further illustrated confirmed in Figure 6 which illustrates brokers' retail market strategies for the sale (left) and purchase (right) of energy. The left-hand side of the figure shows a remarkable reduction in overall price levels for consumers relative to the incumbent monopoly, as well as a reduction in price differences between brokers. The right-hand side of the figure additionally shows that brokers now routinely include small-scale production in their sourcing strategies, which suggests that participants have been probing into more advanced design options in the most recent iteration.

Figure 6: Brokers' strategic retail market positioning.



CB is one way to evaluate smart market designs and individual trading agent strategies. Generally, the information systems community is in a good position to help shape this development, for a number of reasons. Many of its faculty members have an interest in sustainable, complex, trading environments and multi-echelon markets, and have developed considerable expertise and institutional knowledge of developing innovative IT artifacts based on design science research.

Stream 3: Real-time Decision Support using Interactive Learning Agents

The need for instantaneous or real-time intelligence typically arises in dynamic markets where uncertainty in supply, demand, quantity, quality, etc., creates complex utility functions in multiple dimensions. In such environments, it is often difficult even to express preferences over a complex set of options adequately, leave alone make a decision. Obviously, increased computational power and improved algorithms for optimal decision-making have led to significant progress over the decades, and we can now solve problems in seconds that might have taken days only a decade ago. However, many decision support systems still lack the ability to interactively communicate with users and elicit the preferences required. A decision support system can only meet goals of a user once it knows that user's preferences. In addition, we need a way to incorporate these preferences in order to update existing market designs so as to cater to current market regimes.

The goal of this third research stream is to:

Develop interactive decision-support agents that learn individual and firm level preferences and market dynamics. Given experimental outcomes, both lab-based and real-world, and new regulatory policy, update the market design (Stream 1) until the original market design goal is achieved.

Two issues have hampered – and still hamper – the adoption of agents in industry (Maes, 1994). The first is *competence*: in order to be helpful, an agent must acquire relevant knowledge, and must learn from the user in what circumstances to make recommendations. The second is trust: the agent must behave in a way that inspires trust in its user. We have identified a third challenge, *adjustable autonomy*, that is specific to fast-paced, information-rich business environments where human cognitive capacities are severely tested (Bichler et al., 2010). For an agent-based approach to be successful, the agent must be able to make low-level decisions autonomously, provide timely, well-grounded suggestions for higher-level decisions, and leave the human decision-maker in final control. IS researchers can contribute to this research by designing and developing adaptive learning agents to assist human decision-makers in real-time multi-echelon market environments.

Researchers should focus especially on enhancing the adaptive learning component of such agents. Agents could raise the level of abstraction that a person is able to deal with, predict what steps are appropriate to take next, help to speed up the user's decision-making process, and improve the quality of that process. Research is therefore needed to develop and evaluate highly personalized software agents that complement the cognitive and computational capacity of humans, while leveraging the experience and contextual knowledge of seasoned decision-makers. These agents will collaborate with their users to gather and present information, and recommend action.[18] For this it is essential that the agent learns the goals and preferences of its user.

When an agent is learning those preferences, it has not only to communicate its predictions to the user, but must also know the extent to which the user disagrees with them. To address this question, computer science researchers have typically used ad-hoc combinations of various parametric and non-parametric prediction modeling methods to create the best fit for any given context. However, how to establish a process of communication where an agent understands how well its recommendations were received and how to improve its own performance for a given user is an open question. For example, should an agent provide an "optimal" answer given a set of predefined parameters, should it provide an "optimal answer", or should it present a list of alternatives that a human decision-maker could choose from? Also, the decisions regarding the timeliness or desirability of a recommendation (i.e., whether or not the recommendation would be perceived as non-intrusive) have not been studied much and are significant research areas where IS researchers could make a huge contribution, given the IS literature on technology acceptance and usage. Finally, adjustable autonomy (i.e., the degree of autonomy that an agent or automated decision support system should have) is a completely open research question, especially in dynamic and complex market environments.

One of the key virtues of a sustainable smart markets framework of this type is that these models can be refined via multiple kinds of *feedback* (see Figure 4). We differentiate between *individual feedback, collective feedback based on regulatory policy, and market participation.*

18 To push research in this important and exciting area, we established the Learning Agents Research Group at Erasmus (LARGE) in April 2007.

Since the individual models suggested are typically probabilistic and capture the relationship between high-level preferences and transaction decisions, the preference models can be used to predict customized transaction decisions for each user. Discrepancies between these predictions and the actual choices of users provide a natural error signal for probabilistic models, which can be used to update model parameters in real time. The exact methods and approaches used to provide these various types of feedback, and the computation of errors itself are challenging, and this is an ongoing research area that needs significant attention. At this point I want to focus on the direct interaction between software agents and human users.

One instance of this is Microsoft's experimental platform[19], which has been very successful in accelerating innovation through reliable online experimentation with actual users. The platform enables new ideas to be tested quickly using the best-known scientific method for establishing causality between a feature and its effects: randomized experimental design. The basic methodology in controlled experiments is to expose a percentage of users to a new treatment, measure the effect on important outcomes metrics of interest, and run statistical tests to determine whether the differences are statistically significant, thus establishing causality. There is great scope for many more smart research platforms like this, since firms need to understand the aggregate evolution of customer preferences and to adjust their decision models and website interfaces accordingly so as to increase customer satisfaction and achieve KPIs.

In summary, to make individual decisions to achieve the user's goals, agents not only need to understand the consequences of their actions, they also need a policy for choosing what to recommend to the decision-maker. That policy may include considering the instantaneous or long-term effects of choices, but the agent must have a means of evaluating and computing these effects. Preferences achieve this, and are the key for agents to make decisions in a rational way. An agent therefore needs to be able to model the impacts of decisions over time in a non-disruptive, indirect manner, and update the user with explicit feedback so that the user can gain confidence and trust in the agent's abilities.

On a collective preference level (3 and 4), we have to ask ourselves, what are the observable and measurable factors that we can use to improve and update an existing market design (Stream 1)? Given that we have validated some policy

19 See http://exp-platform.com, now merged with Bing.

ideas (Stream 2), we have now to test and evaluate them in laboratory and real-world pilot projects, and eventually in real-world markets (Stream 3). Given a set of individual agents participating in a smart markets, we can observe the collected feedback on market outcomes. These outcomes may then be used to update the original market design (Stream 1). Now, I want to look at an example of this research approach.

Example 3: Sustainable Smart Flower Markets: The Dutch Flower Auctions

The empirical context used in the Sustainable Smart Flower Market study is the Dutch Flower Auctions[20]. They serve as efficient centers for price determination and exchange of flowers between suppliers and buyers (Kambil and van Heck, 1998). On weekdays, up to 40 auctions occur simultaneously between 6.00 am and 10.00 am. Flowers are auctioned as separate lots, which are defined as the total supply of a given homogeneous product from a given supplier on a given day. The size of a lot can vary from a few units to more than a hundred units, and each unit consists of 20 to 80 stems, depending on the type and quality of flower.

The Dutch Flower Auctions use the Dutch auction mechanism[21]. They are implemented using fast-paced auction clocks (see Figure 7) that initially point to a high price, and then quickly tick down in a counterclockwise direction. As the price falls, each bidder can bid by pressing a button to indicate that he or she is willing to accept at the current price. The first person to make a bid wins. The winning bidder can then select the portion of the lot being auctioned (which must exceed the minimum quantity set by the auctioneer). If the winning bidder does not choose to buy all of the remaining stock, the clock restarts at a high price and the auction continues. This process is repeated until the entire lot is sold, or until the price falls below the seller's reserve price, in which case any unsold goods in that lot are destroyed. On average, each transaction takes 3 to 5 seconds. In total, roughly 125,000 transactions take place daily.

20 The first worldwide stock market crash was actually caused by a bubble in the trade of tulip bulbs. Lack of regulation and poor quality control were just two of the factors that led to the abrupt crash in February 1637 (Dash, 2001).

21 The Dutch auction (or descending auction) was invented in the 1870s by a Dutch cauliflower grower who wanted to simplify the selling of his product so he could concentrate on his crops. (see Kambil and van Heck, 2002).

Figure 7: Dutch Flower Auctions.

A set of simultaneous, multi-unit sequential Dutch auctions. In addition to the current asking price, on each auction clock bidders can also find information about the current seller, the winning bidder, the characteristics of the flowers being sold, the minimum purchase quantity, the quantity available and certain packaging information (for example, how many stems are included in a unit).

The auctioneers in the Dutch Flower Auctions represent the growers. As such, their main objective is to realize high revenues[22]. It is also important for them to achieve a quick turnaround since flowers are perishable goods. By controlling key auction parameters such as starting prices, minimum purchase quantities and reserve prices, the auctioneers can influence the dynamics of the auction. However, these parameters are currently not optimized because the auctioneers cannot process all the available information from the market effectively or efficiently enough to make informed decisions. Instead, they rely mainly on their experience and use their intuition to decide how to set these key auction parameters. Due to the limited availability of proprietary data, empirical research on the optimal design for the Dutch Flower Auctions is very rare. Our research is among the very first to explicitly model the sequential aspects and to address the design issues of these auctions.[23] I am currently working with Yixin Lu (Rotterdam School of Management, RSM), Eric van Heck (RSM), and Alok Gupta (Carlson School of Management, University of Minnesota) in this important research area.

22 To be more precise, it is a trade-off between throughput (volume/speed) and revenue.

23 To the best of our knowledge, the paper by Van den Berg and van der Klaauw (2007) is the only research that adopts a structural econometric approach to studying the design of the Dutch flower auctions. However, since they chose to investigate auctions where the minimum purchase quantity corresponded to the total quantity available in any given auction, they are not dealing with the sequential aspects of these auctions.

From the managerial perspective, our DFA research provides valuable insights to practitioners, especially the auctioneers, in terms of their decision-making about key auction parameters. As Klemperer (1999) pointed out, "auction design is not one size fits all." In the case of the Dutch Flower Auctions, we have shown that decisions over what minimum purchase quantities to set must be tailored to the local circumstances, especially the current market conditions. For example, in order to push more products on to the market on peak days such as Valentine's Day, auctioneers must speed up the auction process by increasing the number of minimum quantities of flowers that a buyer has to purchase during an auction. Although this might result in a decrease in the average revenue per auction, the total revenue can still be increased as more auctions can then be fitted in to the daily auction schedule. Given the cognitive and computational limitations of human decision-makers, we propose to augment auctioneers' capabilities by deploying software agents. These agents can help auctioneers to optimize the key auction parameters under different market conditions (Lu et al., 2013b).

An agent, for instance, can give iterative recommendations for an auctioneer to set the starting price and minimum purchase quantity of each auction, taking into account various internal information (such as bidder population and historical data) and external information (such as news and weather). We have run a large number of experiments with more than 250 participants in the Erasmus behavioral lab to research the effect of clock speed on bidder surplus. Auctioneers from FloraHolland also participated in the experiments, and were enthusiastic about the real-life feel of our simulated auction environment. We have built up a deep relationship, and have run real field experiments on one auction clock for three weeks at the Naaldwijk location. This is really outstanding and gives our research real-world business impact,and it also allows for publications in top academic journals, which likewise have considerable real-world impact.

In Power TAC, much of the Stream 3 research work is currently done by research groups developing competing agents at other institutions. At this point we have shown that Power TAC is a robust simulation of retail power markets. Now that we have this platform we are able to thoroughly research sustainability challenges and the associated policy implications. To remain the gold standard in computational energy market modeling, and to stay at the forefront of a highly dynamic research field, Power TAC has to be extended on a continuous basis. This is a complex, long-term software engineering task.

3. Impact

"The important thing is not to stop questioning.
Curiosity has its own reason for existing."
Albert Einstein

How can we maximize the impact of this research agenda?
Here are some ways we can do it.

Mission 1: Academic and Industry Collaboration

One key characteristic of our research is its interdisciplinary nature. This has led to many new insights at the intersection of computer science, economic theory, psychology, operations research, and information systems. I honestly believe that large-scale societal challenges cannot be solved by one discipline alone. Therefore, I will continuously focus on bringing the right set of people together to work on grand challenges.

Interdisciplinary collaboration was one of the major driving forces when I founded the *Learning Agents Research Group at Erasmus (LARGE)* and *the Erasmus Centre for Future Energy Business*. Another is the continuous drive to bring groundbreaking research into practice and use these applied insights in turn to improve our theoretical models. This is a true virtuous cycle and a win-win situation for all parties involved!

We are just coming to the end of another successful Erasmus Energy Forum. This annual Forum event is unique in that it brings together many stakeholders to discuss "the future of energy, and the energy of the future." Our events have brought together diverse representatives from industry, politics, and academia, in front of large and influential audiences. It is rare that speakers representing so many parts of the industry and other key stakeholders – the grid, producers, IT, politicians and academics as well as forward-thinking major consumers such as Port of Rotterdam – are able to collaborate in a public forum. We aim to establish a pan-European community focusing on the future energy landscape.

We also organized the 2012 IEEE Conference on Smart Grid – Technologies, Economics, and Policies in Nuremberg, Germany, another big success. We have just co-organized a very stimulating Dagstuhl seminar on "Multi-agent systems and their role in future energy grids." I thank all the attendees worldwide for their active participation and their insightful contributions. We have already initiated follow-up meetings to collaborate closely in the future.

Another form of collaboration is of course the Power TAC project: the annual competitions bring researchers from around the world together to push the bar a notch higher. In addition to this tournament mode, Power TAC can also be run in a pure research mode and tailored to your particular needs. Over the last few years, for instance, we have seen research groups around the world using Power TAC to study norms and sanctions (Brazil, UK, and USA), microgrids (Mexico) and reputation (Brazil).

Mission 2: Policy Guidance

There is intense debate among policymakers worldwide about the design and regulation of future electricity markets. The energy crisis in California and the large-scale blackouts in the US and more recently in India have vividly illustrated the need for a sound ex-ante understanding of the consequences that novel regulatory schemes have on electricity markets. Our primary goal with Power TAC is to develop that understanding. For example, we are currently studying the integration of electric vehicles, the influence of dynamic pricing on demand response, and the design of a novel two-tier model for regulating capacity.

Mission 3: Cognitive Augmentation

In our society, people are constantly facing information overload. A major challenge is to evaluate which information is important and which not, and to act properly upon it. As Simon (1971) said, “a wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the overabundance of information sources that might consume it.”

In his seminal work, Turing Award winner Douglas Engelbart picks up on Simon’s insight and argues that “Human beings need a methodology and training that organizes their efforts at the levels of scale that are appropriate to the problems they are trying to solve.” His intellect augmentation is such a method (Engelbart, 1995). It provides a model of technology that is deliberately designed so that human abilities will increase in response to using it.

In this regard, our research has useful implications for augmenting human decision-making processes in real-world business environments and we should push the envelope to improve agent–human communication and decision-making. One example is our work on developing a decision-support tool for the auctioneers at the Dutch Flower Auctions (Lu et al., 2013). Another is our work on minimally intrusive preference elicitation and decision-making in the Smart Grid (Peters et al., 2013).

Mission 4: Education

I am committed to enhancing the quality of the courses relating to the field of Next Generation Information Systems in the BSc, MSc, MPhil, and PhD programs offered by the Department of Technology and Operations Management, and especially to "bringing research into the classroom." In recent years I have been proud to teach the MSc core course "Designing Business Applications", the elective course "Next Generation Business Applications", the PhD courses "Multi-agent Systems Research", and "Information Management Research" – which are the fundamental courses on Next Generation Information Systems.

Now it is time to extend the teaching to the demanding challenges of the energy business itself. It is a business that is capital-intensive and has very long investment horizons, yet it is being forced into a series of swift and radical transformations. Fuelled by a mixture of regulatory changes, ongoing ICT innovations and advances in areas such as renewable generation, storage, and electric mobility, these transformations have industry leaders and politicians looking for answers. Together with RSM Executive Education, we have developed an in-depth executive curriculum for managers in the energy industry and in energy procurement that will prepare participants to navigate and shape the energy landscape of the future.

Furthermore, I want to continue to play a central role in shaping the education and curriculum offered by our department and by Rotterdam School of Management more generally. I am passionate about helping young researchers develop their own research agendas, and I intend to be closely involved in the coaching of junior faculty and PhD students. This is, after all, one of the main reasons why we are at a university.

4. Acknowledgements

"I'm here not because I am supposed to be here,
or because I'm trapped here,
but because I'd rather be with you
than anywhere else in the world."
Richard Bach, The Bridge Across Forever

There's an old saying "Victory has 100 fathers and defeat is an orphan.[24]" In my case I think it's more than 100 mothers and fathers that supported me over the years. I won't have time to list them all, but I would like to highlight a few people who have supported and inspired me over the years. My apologies already to those that I have unfortunately forgotten to list here!

Distinguished Board, President, and Deans of Erasmus University, Vereniging Trustfonds Erasmus University Rotterdam, and Members of the Appointment and Advisory Committees,

I feel honored and privileged to be part of such a vibrant, visionary, and talented community of scholars, students, and staff. It is a true pleasure to jointly work and realize our mutual goals in research, education, and service.

Distinguished colleagues at Erasmus University,

Within the University, the Erasmus Research Institute in Management (ERIM) has been truly supportive. In particular, Wilfred Mijnhardt, Executive Director ERIM, has pushed the organizational envelope of my research programme tremendously and was instrumental in helping me in setting up the Erasmus Centre for Future Energy Business. I always enjoy our energizing meetings and visionary discussions.

Running successful centers such as the Learning Agents Research Group at Erasmus and the Erasmus Centre for Future Energy Business, with its annual Erasmus Energy Business Forum, would not be possible without the work of many wonderful people involved. Their great work is what makes these events happen, and therefore I thank you all a whole lot. In particular, Govert Buijs, Johan van Dijk, Esther Duijnisveld, Cheryl Eiting, Joep Elemans, Gabi Helfert, Ronald Huisman, Ksenia Koroleva, Veerle van Laere, Olivia Manders, Marcel van Oosterhout, Laurens Rook, Marianne Schouten, Maaike Siegerist, Saskia Treurniet, Steef van de Velde, Marno Verbeek, Tineke van der Vhee, Catherine

24 Cf. [1942 G. Ciano Diary 9 Sept. (1946) II. 196] La vittoria trova cento padri, e nessuno vuole riconoscere l'insuccesso.

Walker, Ingrid Waaijer, Justine Whittern, Larissa Wiltenburg, Tijn Witsenburg, and Cordine Wischhoff.

Theo Backx, head of RSM's department of Executive Education and Organizational Development and of the RSM Advisory Board, and previously for Corporate and Alumni Relations as well, has been a great mentor. Theo has taught me how to talk in the board room and trained me in how to set up strategic business partnerships at various levels. He was instrumental in helping me to set up the advisory board for the Erasmus Centre for Future Energy Business. Theo, you are a true leader and I am very thankful for your wonderful mentoring.

Since the advisory board is absolutely a part of the success for our energy centre, I would like to thank several people, but especially Jan Christian Koenders, Executive Vice President sales and operations of BMW, USA. Jan Christian was the first chair of the advisory board and was enormously helpful in setting up great industry collaborations and keynote speakers for energy forum. Volker Beckers, previous Group CFO and Group CEO of RWE npower and current chairman of the board, has really professionalized the organization and operation of the advisory board. He has been instrumental in expanding our reach all over Europe and especially within the UK. In addition, Volker gave a wonderful keynote speech at the second Energy Forum which is remembered by many, and shows his great leadership in the area of energy management and beyond. Volker provides continuous invaluable feedback on the strategy and operations of the energy centre. Finally, I am very grateful on a personal level for his excellent mentoring.

We are very fortunate to have other great leaders on the advisory board of our energy centre. I am very thankful to Markus Bokelmann (CEO, E-ON Netherlands), Jan-Paul Buijs (Manager CIO Office, Enexis, and a great partner in our Executive Education), Mira Huussen (Director, Smart Energy Essent), Erik van der Heijden (Director Smart-Grid, Siemens Netherlands), Ruud Melieste (Corporate Strategy Department, Port of Rotterdam Authority), Dirk Schlesinger (Global Lead, Internet Business Solutions Group, Cisco Syst. Inc., and a great partner in our grant applications), and Jessica Stromback (Executive Director at Smart Energy Demand Coalition and Chair of VaasaETT Global Energy Think Tank).

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Research needs an application, and building a fruitful partnership with business is challenging. Therefore, I am tremendously grateful for the wonderful collaboration with FloraHolland. It's a true virtuous circle between science and business: a win-win situation for everybody involved. I would especially like to thank Theo Aanhane, Ellen van Dijk, Peter van Nieuwkoop, and Enno Smit.

Distinguished co-authors,

Impactful research nowadays is done in great teams. I believe that teams which are highly interdisciplinary have the power to solve the huge challenges that our society is facing. I feel so privileged to work with all of you, because every day together we push the bar up a notch higher and broaden our horizons. Collaborating with so many great minds is one of the most joyful activities of my job, and therefore I am so grateful to you all.

Dear students,

Encountering so many young, talented, and driven people at Erasmus University is truly wonderful! I love the spirit of the youth, and I will do everything what I can to make you successful in this world. It is a great and fulfilling opportunity to make a small contribution to your development.

Dear Konstantina, Markus, Micha, and Yixin,

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It's wonderful that so many of you are here today. Without you, life would not be the same! Spending time with you is truly joyful and energizing. You give me guidance during rough times and keep me grounded when my imagination goes through the roof again. Thanks much for being there!

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Enabling Sustainable Smart Markets

Impactful Business Cases

Wolfgang Ketter

Erasmus Research Institute of Management - ERIM

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Address delivered at the occasion of accepting the appointment of
Professor of Next Generation Information Systems
at Rotterdam School of Management, Erasmus University Rotterdam,
on Friday the 20th of June, 2014

Prof. Wolfgang Ketter

Rotterdam School of Management
Erasmus University
P.O. Box 1738
3000 DR Rotterdam
E-mail: wketter@rsm.nl

Content

Foreword Alok Gupta

It is my honour to be invited to write this foreword for Professor Wolf Ketter's inaugural address. Years ago, someone asked me in a public forum what my greatest accomplishment and contribution to society have been as an information systems researcher and professor. My answer was to point to one of my accomplished former students and say that helping shape some of the research thoughts in his life as a student is what I consider to be my greatest contribution to the society. Wolf is certainly among the best examples of students that I have the pleasure to guide and collaborate with over the years, and I am very proud of his accomplishments that have been achieved in a relatively short period of time. More importantly, the research he is engaged in now is going to make a significant direct contribution to societal welfare.

In this address Wolf has provided details of his motivation, the approaches he is taking and some accomplishments that he has achieved. The core of his research work takes advantage of rapidly evolving computing power and techniques to build and explore new solutions that could not be thought of before. Traditionally, research in business and social environments is built over time with researchers picking interesting and promising ideas over time, and building a body of research over decades. Wolf Ketter is bringing a change in this paradigm by building a community of researchers who compete and learn from each other in rapid competitive environments for important societal challenges such as the future of energy markets. While the rest of the community is still trying simply to use social communities as a research platform for exploring social issues, Wolf's research is taking the next step of building a community of researchers that will bring about a leapfrogging of research progress. It is a remarkable achievement and vision for a young researcher.

A foreword of this kind is incomplete without mentioning the personal traits of an individual or talking about what drives a person. Therefore, I would like to say a few words about Wolf's work ethic and research approach. Wolf is by far one of the most open-minded researchers I have met. When we first met, he came from a background that did not consider the social and environmental constraints in decision environments. In my discussions with him, I provided some broad insights and assumed that it would take him years to develop frameworks that would be detailed enough to implement within a computational environment. However, he worked day and night, and within a few months produced a remarkable set of tools which laid the foundations for his innovative dissertation work that eventually won an INFORMS ISS Design

Science award. He has shown similar discipline and application in all his research work, whether it is innovations for the Dutch Flower Auctions or the new energy markets research. His ability to recognise his weaknesses and build strength around those weaknesses makes him a great young researcher.

Personally, my association with Wolf has been very enlightening, interesting and motivating. His energy is infectious and gets the best out of everyone associated with him. Given his energy, dedication and work ethic, I am sure that we have only witnessed the beginning of a great academic career. As his advisor, his accomplishments are a source of personal and professional pride for me, and I wish Professor Wolf Ketter all the best for his future.

Alok Gupta
Department Chair, Information and Decision Sciences
Curtis L. Carlson Schoolwide Chair in Information Management

Foreword Volker Beckers

The last few years since the financial crisis will eventually be remembered for the dramatic transformation of the energy sector in Europe. For decades the sector saw steady changes through increase in demand, improved efficiency of the sector as a whole in the wake of privatisation in some countries, and liberalisation thereafter. Demand grew steadily even through difficult times and political crises, and investment was based on a reasonably predictable future – but things changed!

Climate change targets were embedded on different levels. Governments in Europe and in other parts of the world started to implement necessary changes through incentive schemes to sponsor embryonic, and in part immature technologies in the renewable sector and to drive change in the generation mix through schemes like the Emissions Trading Scheme. In some countries this was tightened even further through penalties on fossil fuels (e.g., a carbon tax in the UK). Incentive schemes have made residential consumers investors in small-scale generation – and eventually "Prosumers" – thus turning them into informed buyers (and sellers) of electricity who are effectively helping to challenge the status quo of large central generation.

With more and more intermittent and less predictable supply of electricity and priority dispatch of renewables having an impact on existing and new-build power plants, the landscape for large incumbent players has changed. The business focus for vertically integrated players has been down-sized, with the generation portfolio switching to lower carbon technologies whilst also withdrawing older conventional (fossil fuel) generation. In this context, governments have become more concerned about *security of supply*. But also political crises where supply of fuels or technology was used to achieve political targets has further amplified the situation (e.g. Ukraine).

On both dimensions, organisations became the vicarious agent of government, investing in new generation, changing their portfolio, and contributing to the low-carbon agenda. But this has come at a cost to energy companies and thus to consumers of electricity. Combined with the political target of driving change and funding the budget to subsidize low-carbon technologies, this was amplified through levies and taxes at the point of consumption. *Affordability* of electricity has since become the issue for consumers. It is widely accepted that electricity is the fuel of choice as a substitute or replacement for fossil fuels in most areas, i.e. for light and heat in homes, surface transport and industrial production processes. Electricity prices in many countries are, however, further burdened with levies and taxes to fund this transformation towards a low-carbon economy.

Achieving the necessary, ambitious carbon-reduction targets, having electricity available 24/7, and doing this at affordable cost – these three dimensions define the *Trilemma* for the sector.

The energy sector has started to transform itself but policymakers are sceptical about existing market frameworks supporting necessary changes within the set time frame. At the same time, consumer trust is impaired and has become a barrier to resolving the Trilemma in an acceptable and sustainable way.

At the Erasmus Centre for Future Energy Business, the starting point for research is a sustainable supply of electricity which is affordable, available and in accordance with climate change targets. By using available information and data, and building models to estimate and check (investment) rate of return assumptions, decision makers are supported in narrowing down the solution space on investment options. Policymakers can extrapolate the consequences of changes in the legal and regulatory framework, which in turn is the basis for factual dialogue and should help to inform all stakeholders on the common objective of resolving the three dimensions of sustainable electricity. On the one hand, it is about understanding the consequences of decisions made by each stakeholder group but at the Centre we are also investing in research in Smarter Energy. This is not just measuring electricity enhancing awareness but also about facilitating change in consumer behaviour and making networks more resilient to infrastructure change through more small-scale, decentralised generation.

We are the beginning of this journey, and Wolf Ketter and his team at the Erasmus Centre for Future Energy Business have decided to invest research in the field of sustainable electricity. The use of multidimensional models, IS technology and smarter devices will be key elements in resolving this complex equation and these three (at first glance) conflicting objectives – clean, secure and affordable electricity! This is a fascinating field of research which challenges the paradigms of the electricity sector of the past but will create those sorts of changes, causing the kind of disruptive events we have seen in other industry sectors as well.

Wolf Ketter has shown remarkable thought leadership in this emerging area worldwide with his known passion for seeing the "big picture" and his (always necessary) passion for the detail. He is able to energise the people around him to execute cutting-edge research. As Chairman of the Energy Centre advisory board, I find it wonderful to see how Wolf bridges the gap between research and practice to have not only academic impact, but impact also in the real world. This journey has just started; the response to the annual Energy Forum this year and last year, and the high-calibre speakers involved, is testament to the quality of the work at the Centre.

I am looking forward to many more interesting endeavours with him and his team, and wish him all the very best for his future.

Volker Beckers
Chairman of Advisory Board
Erasmus Centre for Future Energy Business

Enabling Sustainable Smart Markets

Impactful Business Cases

Introduction

*"We can not solve our problems
with the same level of thinking that created them."
Albert Einstein*

When science and business join forces in an environment where common goals can be explored, each party learns much from the other and the end-results yield benefits for everyone. This is the motivation behind Rotterdam School of Management's Centres of Excellence. The Learning Agents Research Group at Erasmus (LARGE) and the Erasmus Centre for Future Energy Business (ECFEB) are prime examples of these centres. This virtuous circle – in which business learns from science and science from business – is one that we live and breathe.

In the words of our Dean, Professor Steef van de Velde, "these centres provide a powerful platform for reciprocal learning. They represent an entirely new organizational structure."

I really believe that research needs an application, and that impactful research is best done within interdisciplinary teams. Here I present examples of sustainable smart markets from the smart energy and the flower industry which use this powerful collaborative model. In addition, several industry and scientific leaders have provided their perspectives on the work we are doing together and the contribution it can make to them and their organizations. I am very grateful for their great collaboration and that they have taken the time to share their insights with us.

Wolfgang Ketter, PhD
Professor of Next Generation Information Systems

Smart markets in practice: smart grid

Secure and sustainable energy supply is on the agenda for governments around the globe, but one thing is certain: tomorrow's energy market will look very different to what we experience today. Smart grid technologies, involving dynamic pricing and smart metering, will be with us soon – and intelligent software agents will be an integral part of those new systems.

Here Wolf Ketter outlines how work by the Erasmus Centre for Future Energy Business and the Learning Agents Research Group (LARGE) is making a major contribution to these new technologies.

With traditional means of electricity supply, achieving the crucial balance in the grid was relatively easy because generation was top-down. But as we move away from fossils fuels to a more complex mix involving intermittent renewable sources such as sun and wind, balancing supply with potential demand has become much harder.

It requires us to rethink the way we consume energy. Traditionally the demand side has been dominant: whenever consumers wanted energy, the supply side made the adjustments needed to cope with resulting peaks in demand – when people returned home from work, for example. Now, with supply more volatile, energy retailers are looking to move to dynamic pricing so that when there is excess supply on the grid, people draw off and use that energy. Imbalances in the grid can lead to outages, with potentially severe – even fatal – repercussions. So the demand side needs to adjust to the supply.

Clearly that is extremely difficult to achieve. It requires the right economic incentives that will persuade people to change their behaviour so that they consume energy when it is available – and prices are usually the means to do this.

Market and learning agent design

What we have been working on here is a new financial balancing mechanism, specifically one to help balance *local* retail energy markets. Ideally we can then incentivise people to consume energy where it is actually produced, making significant reductions in transportation costs, for example.

Within our Power TAC trading simulation, a key task for the competing brokers – i.e. our autonomous software agents – is to develop a portfolio of energy tariffs for customers, both residential and business. The simulation models the population of a small city, and some customers are both producers and consumers, being equipped with solar panels and wind turbines. All customers are assumed to have smart meters, and their energy consumption and production are reported every hour.

With customer behaviour being variable, and dependent in part on weather conditions, the challenge brokers face in creating their portfolio tariffs is complex: it involves eliciting customer preferences, predicting both future energy prices and consumer power usage 24 hours ahead, and trading in the wholesale market.

The tariffs offered are not static – they can change up to four times a day. Brokers can introduce replacement tariffs, forcing customers to switch, or can offer inducements to switch to a more attractive tariff. Customers must make a trade-off between cost and convenience, but, as in the real world, their decisions are not always entirely rational, and inertia must also be factored in.

The power of the simulation itself is that it allows us to evaluate the impact of the various tariffs within the wider energy market, and assess how effective they might be in terms of modifying consumer behaviour. Will the potential savings offered by the variable-rate tariffs be sufficiently attractive to induce people to change their patterns of usage? Or will some consumers be prepared to pay more for the simplicity of fixed-rate tariffs or very simple time-of-use tariffs?

We can also reconfigure various models used within the platform to run through different scenarios. This flexibility means we can use Power TAC to model proposals for market design, incentives and taxes or to study the impact of increasing numbers of electric vehicles, for example – another important area of work for us, as indicated in the third of our streams.

Market evaluation using autonomous learning agents

When we look at the practicalities of dynamic pricing, it becomes apparent why intelligent agents have such an important role to play. Clearly no-one would want to change tariff every couple of hours or react to price deals by turning appliances on or off.

So what we are working towards is automating that process from two sides. From the retailer's side, autonomous agents could be used to create personalised offerings, tailored to customer's particular preferences and motivations. And from the consumer side, using agents to work out which tariff is best to switch to, and when, would stop us from having to keep track of tariffs and make a lot of switching decisions.

Before we delegate decision-making to an autonomous agent, however, we need faith in their ability to act effectively for us, and, crucially, to make accurate predictions of what we want. For the past year, our team has therefore been working intensively on agents that can elicit customer preferences and learn adaptively, so that they can become effective tools for decision support. The programs we are building, using machine learning techniques, interact with human decision-makers, find out from experience – through observing their past behaviour – what these individuals typically like, and then develop the capacity to make decisions on their behalf. Our work in this area has included experimental evaluation with adult consumers in the Texan retail electricity market.

In eliciting customer preferences two key difficulties arise. Our choices are typically fairly erratic: from one situation to the next we may make completely different decisions, and it is unclear whether that is just a matter of context or whether that decision does not actually matter to us. It is therefore hard for a machine to look simply at our past choices and extrapolate with any certainty what our future decisions might be. This is where probability theory comes into play.

The other issue is that human attention span is relatively limited. If questioned about what we prefer, we are likely to tolerate only a certain number of questions before becoming bored or frustrated. So the agent needs to be able to draw inferences from relatively small amounts of data.

Another important element is that an agent needs to be capable of assessing the 'value' of a decision, so that it can discriminate between those that can be made autonomously without undue risk of 'regret', and those where it has insufficient information to make an informed choice – or where the decision is best left to the human decision-maker.

We are trying to push the boundaries here in a way that makes sense for business applications. We are therefore interested in agents that learn very quickly, without over-burdening the decision-maker. Agents that learn by looking at just a few answers to certain questions and are then already capable of making fairly informed choices. Because we want agents that can be used in real-time settings where they make decisions on the spot, our goal is also to reduce significantly the computational time required to train the agents before they can be set to work autonomously – one of the shortcomings of many probabilistic models.

Real-time decision support using interactive learning agents

With sales of electric vehicles on the rise, it is likely that by 2020 these will be commonplace on our roads. For the grid, this could present both challenges and opportunities. Charging large numbers of these cars could put the grid under enormous strain: whereas a typical household currently consumes around 10 or 11 kW per day, cars charge at 25 kW per hour. Without some way of counteracting this, there is serious risk of blackouts – and shortage of supply might then be reflected in escalating prices.

Yet electric vehicles could also provide a valuable way of balancing the grid. One stumbling-block has been the lack of a suitable, cost-effective means of storing excess wind or solar energy for future use. New developments in battery technology mean that we should soon have car batteries that offer a viable way of doing this: while each battery might store only relatively small amounts of energy, a fleet of electric vehicles could become a virtual power plant, with fleet owners having the option to sell the stored energy back to the grid.

Intelligent software agents could play a crucial role in helping fleet owners to manage their stock effectively. Trading in the wholesale market on behalf of the fleet owners, the agents can use energy market data to determine when it is more advantageous to charge a car and when to turn it into a virtual power plant. This has been tested extensively using Power TAC, and the results look very promising.

Our research already suggests that using electric cars in this way could have significant benefits: we calculate that by offering cleaner energy, these virtual power plants could reduce CO_2 emissions by 2.4% and the average electricity price by 3.2%.

Another important development aimed at helping to balance the grid is our AMEVS algorithm (Adaptive Management of Electric Vehicle Storage), designed to run within the car of an individual owner.

Here an agent learns and adapts to the driver's personal preferences and habits, using them to optimise charging times for the vehicle and spread the charging across different periods in the day – in the process helping to balance the grid by reducing peaks in consumption. A similar, though simpler, version of personalised charging is already being used by Tesla Motors, allowing the driver to take advantage of lower night-time electricity tariffs.

Once again, we will be using Power TAC as a test bed for our algorithm, with the ultimate aim of releasing it on to the market in the near future.

We are also starting behavioural experiments designed to give us a better understanding of how humans make decisions in the smart grid. What influences their decision-making in uncertain conditions, and how can software agents facilitate that process?

Connecting up cutting-edge scientific research in information systems, behavioral economics and cognitive neuroscience, this work will have important practical implications for the energy field – ranging from the development of managerial guidelines on how to persuade consumers to select smart energy tariffs to better ideas for designing the smart homes of the future.

What is so exciting about all of this work is that it is not only helps in advancing important new smart grid technologies – many of the techniques are not confined to the energy market but could also be applied to many other settings. In reality we are only scratching the surface of what could be done, and that is what makes it such a hugely rewarding field to work in.

Wolf Ketter's key collaborators in the work described here are Markus Peters, Konstantina Valogianni, Micha Kahlen, Jan van Dalen and Ksenia Koroleva at ERIM, John Collins of the Minnesota Institute of Technology, University of Minnesota, Dmitry Zhdanov, University of Connecticut, and Laurens Rook, TU Delft.

Further details of related work can be found on the following websites:
Erasmus Centre for Future Energy Business: www.rsm.nl/energy
Power TAC: www.powertac.org
Erasmus Energy Forum: www.rsm.nl/ef
Learning Agents Research Group: www.large.rsm.nl

Smart markets in practice: the Dutch Flower Auctions

Each weekday, at 6 am, bidding gets underway at the Dutch flower auctions. It's a hectic and fast-paced environment: 38 auction clocks run simultaneously, and in a typical day around 125,000 transactions take place. Representing around 60% of the world's flower trade, and bringing in more than 4bn euros per year, these auctions are a vital part of the Dutch economy. With such high stakes, finding new ways to optimise performance through the use of smart market technologies can offer significant business advantage, as Wolf Ketter explains.

Given the sheer volume of transactions, it is important for the auctioneers, acting as market operators and representing the growers, to conduct the auctions in a way that enables them to meet their main objective of maximising revenues. Smart markets offer the potential to do just that, which is why we have been working closely with FloraHolland, which runs six auction sites, for around seven years.

RSM already had a long-standing relationship with the Dutch flower auctions through the work of my colleague Professor Eric van Heck who has been studying this industry over the past 20 years. This has led us to work on developing a smart market system which uses advanced computational tools in the form of intelligent software agents to provide decision support to auctioneers – helping to improve the efficiency of the auctions and enabling the auctioneers to achieve higher revenues.

The system and its challenges

Flowers are graded before the auctions start and auctioned as separate lots, varying in size from a few units to more than a hundred. Each unit consists of about 100 stems, typically in bunches of 10 to 20, depending on the type and quality of flower.

The Dutch auction mechanism is used, a system invented by a Dutch cauliflower grower back in the 1870s in order to achieve sales at the highest possible price within the shortest possible time. The advantage over the English auction system, where bidding goes upwards, is that there is no need to wait for a series of counter bids: the first bidder wins.

Today, speed remains just as important – flowers are perishable goods, requiring transportation to their end-destination as quickly as possible.

The fast-paced auction clocks tick down from an initial high starting price, in decrements set by the auctioneer. Often prices descend by one cent at a time, but for more expensive flowers the decrements may be larger.

As the price drops, would-be buyers can stop the clock by pressing a button to indicate they are willing to pay the price shown at that point. The first person to bid wins. The winner selects how many of the units to buy (which must be above the minimum set by the auctioneer for that particular auction). If there are still units left, the clock restarts at a higher price than the last bid – and ticks down in the same way as before. The process continues until the entire lot is sold or the price falls below the sellers's reserve price – and any unsold flowers are then destroyed.

The key question for buyers is therefore when is the right time to hit the button? Too early, and they will end up paying a far higher price than necessary. Too late, and they risk losing the product they want. With each round typically lasting only three to five seconds, it is very difficult for bidders to succeed in several rounds within a given lot. However, some bidders will deliberately bid in several rounds for smaller amounts, rather than making a single bid for a larger amount.

Auctioneers face a different challenge. They are constantly having to make a trade-off between throughput and revenue. They have four key auction parameters they can control to help them achieve the best price: starting price, minimum purchase quantity, clock speed and reserve price. However, these parameters are not currently optimised. The rapidity of the transactions means that auctioneers cannot possibly process all this information swiftly enough to make informed decisions in the next round. Instead, they use intuition, and heuristics developed with experience over time, to set the levels in each case.

The advantage of using intelligent software agents is that by learning from the historical transactions as well as from the experience of auctioneers, these agents can predict the future auction states and offer well-grounded recommendations to auctioneers that can help them optimise the auctions in real time. The agents are in no way a replacement for human expertise, but the much greater speed with which they can process information, coupled with their ability to mimic and adapt to changes in human behaviour, make them potentially an extremely valuable tool in the decision-making process.

Research approach

Market and learning agent design

Far less research has been done on Dutch auctions than on English auctions, so a vital initial stage for us has been to learn more what is actually going on in the market, particularly in these complex sequential auctions. Understanding the complexities of the buyer behaviour is essential in designing a truly effective system of decision support.

Access to transaction data on bids submitted both at the auction houses and via FloraHolland's online system has enabled us to do detailed analysis of how professional bidders behave. From this, we have identified four different types of buyer in terms of bidding strategy, and the strategies reflect their business profile and the constraints they operate under.

Early bidders purchase only small quantities, participate in relatively few auctions, and are prepared to pay a high price. These are typically small 'mom and pop' retail florists whose profit margins are generally higher than wholesalers, and the premium they pay reflects the fact that they need to ensure they get specific stock for their shops.

Opportunists buy slightly more, but wait to see how the pricing goes in earlier rounds. If it seems low enough, they then bid late in the auction to achieve a low price. These buyers are typically selling to small convenience stores who want fresh flowers at the cheapest price and are less bothered about specific flower type.

Participators bid quite often, and take part in significantly more auctions than either opportunists or early bidders, purchasing medium quantities and paying a mid-price. They are likely to be buying on behalf of supermarkets where flowers are usually offered in the form of mixed bouquets.

Analyzers buy in large quantities but at a mid-price, and time their bidding carefully, typically making their pitch after participators but before opportunists. As these bidders tend to buy the most flowers and are typically wholesalers, buying at the wrong price or failing to fulfil demand can be more significantly costly for them in terms of maintaining business relationships and reputation.

What the auctioneers really need to know is the distribution of buyer types in any given auction, as this could then help them to optimise the auctioneering parameters.

For example, if early bidders are trying to buy a significant portion of a given lot, keeping the minimum quantity close to a unit would make sense since these bidders buy in small quantities and will pay a high price. But if the population is made up largely of analyzers, raising the minimum purchase quantity would be a better strategy, as it would increase overall daily throughput and ensure that more flowers could be offered to the market – so increasing revenue for sellers. That is particularly important at peak periods such as Valentine's Day.

Market evaluation using autonomous learning agents

In this second stream of work, our objective is to test our earlier assumptions about how a smart market might work in this context, and what the best forms of decision support might be.

We have used our understanding of market dynamics and buyer behaviour to design and build a powerful computational simulation platform with which we can demonstrate the value of using customised software agents in this type of market. This simulation is highly realistic, and can be used in a variety of ways.

For example, to assess the impact of our recommendations for auctioneers we ran a simulation which used our decision support algorithms for unit starting prices. No humans were involved – everything was done by intelligent agents. The results were very promising: had the auctioneers used the recommendations provided, their profits would have increased by 7 per cent.

Through modelling we can introduce and manipulate variables to explore the potential results – what happens, for example, when one or two key players in the market behave differently? What impact might it have on the overall dynamics, and on the prices achieved? Running the simulation with different scenarios offers us a risk-free way of assessing the likely impact of various policy changes and the performance of alternative auction designs.

Real-time decision support using interactive learning agents

One of the strengths of this research – and what differentiates it from other work on auction design – is that it uses a unique combination of theoretical analysis and modelling, lab-based experiments and field studies undertaken in conjunction with the auction sites.

In this third stream, we are also exploring how transparency of information – particularly with regard to the identity of those bidding – affects bidder behaviour and ultimate outcomes. Normally the bidder's identification number is displayed on the auction clock for all to see. In a field experiment at the Naaldwijk site, we tested the effects of withholding bidder numbers, and found that, on average, bidders paid more than when that information was disclosed. This ran contrary to our expectations, and warrants more investigation as it raises interesting questions about possible tacit collusion among buyers.

There is much work still for us to do in all of these areas – and we are also aware that smart market technologies could also offer great advantages from the bidder perspective, which is something to add to our future research agenda. But what drives us forward is the knowledge that our findings thus far undoubtedly promise highly valuable practical benefits for the Dutch flower auctions as well as making an important contribution to the field of smart market research.

Wolf Ketter's collaborators in this work for the Dutch flower auctions include his ERIM colleagues Yixin Lu, Eric van Heck and Jan van Dalen, and Alok Gupta of the Carlson School of Management, University of Minnesota.

More detail on the work described here can be found on the Learning Agents Research Group (LARGE) site: www.large.rsm.nl

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Jan-Christiaan Koenders

is Executive Vice President of BMW’s North American operations, and is a member – and former chairman – of the Advisory Board of the Erasmus Centre for Future Energy Business.

What’s the most useful feature of the Erasmus Energy Forum event?

The Erasmus Energy Forum is an opportunity for cross-pollinating, for understanding others’ businesses and for networking. It gets providers and users together for a cross-functional view of the whole chain, which is particularly important in the energy and automotive industries because both need to understand it. Industries seem to stick to their own core competencies instead of cross-pollinating ideas about infrastructure or pricing models.

For example, it was fascinating to watch the accompanying energy infrastructure rolling out when BMW became one of the first few car manufacturers to introduce electric cars into the Netherlands; it seemed to me that the energy industry was still learning to look at customer motivation from an automotive marketing point of view, such as charging different tariffs for fast-charging and slow-charging cars the same way that mobile phone providers charge for fast and slow data service. Slow charging would still be available in people’s homes, but no-one thought about providing the fast-charge roadside infrastructure in that way, or building a business case for it. Customers are prepared to pay a premium for a 20-minute, 70% fast charge at the roadside.

What do you find most interesting about the Erasmus Centre for Future Energy Business?

Having seen some of this type of work presented at last year’s Forum, it’s fundamentally important that we have people across industries thinking together. Left to themselves, industries might not do it, and consultants would do it at a less fundamental level.

How do you think the work being done at Erasmus University will impact your industry?

EUR researches how economics work between partners in a changing industry – this is key to moving ahead.

What is standing in the way of deeper impact?

Communications are important to get newer players – like the automotive manufacturers – together alongside traditional players such as oil and gas producers, and Wolf Ketter is good at it. He pro-actively invited us to join his advisory board because of our work with electric cars. I don't see many other professors doing this, and the energy industry probably needs more people like him who are not afraid to make a 'cold call' and see what comes out of it.

What do you think should be the next area of focus for this line/area of research?

Preparing marketing models for selling energy according to its use, rather than according to its providers. Why don't energy providers motivate people to use battery devices like cars and computers to flatten out surges in energy demand during the day? Instant-use energy like lights, heating and cooking would be charged for differently. Right now, customers don't know how much energy their computer, their lights, or their car use. People are willing to pay much more when they know what individual devices use – this is a huge area of research in terms of efficient use and could be more important than smart grids.

The first step here is providing transparency to the customer, then using pricing to entice them!

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Dirk Schlesinger

is senior director and global manufacturing lead of the Cisco Internet Business Solutions Group (IBSG).

What’s the most useful feature of the Erasmus Energy Forum event?

It builds a network between academia, business and across different agents, uniting segments, and between old and young. I think those in senior positions might want to bring some of their personal wisdom and experience to the Forum to share with the ‘new energy’ segment, which has a vibrant start-up scene and correlates with youth.

What do you find most interesting about the Erasmus Centre for Future Energy Business?

Wolf’s approach to the Power TAC simulation project. He has integrated a unique element of gamification and friendly competition into his research. A game suits the mindset of young people and brings out the best in them. This approach is less traditional than writing a paper, and more liberal and joyful.

How do you think the work being done at Erasmus University will impact your industry?

Most of the energy industry’s current business models are lacking a way to proactively account for how the consumer will adopt what the regulator is proposing. Trying it out in real life can be expensive and painful – and maybe ‘the lights will go out’ – or you can simulate it using IT, and know the science behind it. It’s imperative to have a scientific base for the demand side of your business case.

What is standing in the way of deeper impact?

Impact is usually limited by the different speed of market entities adapting to change. In fairness, the whole issue is complex, but regulators especially should embrace a degree of experimentation, and admit that there is no grand design – that's not the way that this complex area can be resolved.

What do you think should be the next area of focus for this line/area of research?

It should be embracing the whole notion of 'internet of things' and decentralised intelligence. Research should follow the change from human to machine decision-making by devising grid management algorithms accounting for interaction with the 'human' demand-side.

The IT industry is working on technology that lets you enable algorithms on such different devices as washing machines and transformer stations, and how they interplay without destabilising the system. Cisco doesn't write the algorithms, but we are one of many technology enablers. Users can soon put their applications on to our routing and switching systems that then become device interfaces. But who writes the policy?

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Hans ten Berge

is Secretary General of Eurelectric, the sector association which represents the common interests of the electricity industry at pan-European level, plus its affiliates and associates on other continents.

What's the most useful feature of the Erasmus Energy Forum event?

It's an excellent platform for scientists and politicians to engage in dialogue and give their opinions of energy policy – and to consider what is useful and what is not useful in the long term.

What do you find most interesting about the Erasmus Centre for Future Energy Business?

The theme of energy is a crucial one and it's important that it's studied at the highest level. It's a very logical choice of research subject for a university.

How do you think the work being done at Erasmus University will impact your industry?

The effect on our industry will be through the setting of a policy agenda that is guided by the influence of research to be beneficial to society. We all share an interest, so we're keen to co-operate on that.

What is standing in the way of deeper impact?

A synthesis between the objectives of the industry, shareholder value, the objectives of the politicians, good results in the elections and the objectives of universities, fundamental research, could be the basis for the optimal solutions for society. In my view, the major issue in the energy world is how to eliminate greenhouse gases in a rational and efficient way without the short-term 'changing fashions' effect from politicians. A coherent and logical approach from economics, from technology and from society is complemented by a balanced approach from the University, which has already done quite a lot of thinking and research into these areas.

What do you think should be the next area of focus for this line/area of research?

If finding a rational solution to the problem of greenhouse gases is the major challenge, and if implementing more renewable sources of energy is not the only and most efficient answer – as has been proved in Germany – then economic analysis could help to provide better ways. How should you develop and shape the industry to trigger more investment without subsidies, considering that subsidies are ‘the cannabis of the industry’? They’re addictive but not particularly healthy.

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Jan Paul Buijs,

CIO of Enexis is Manager CIO Office at Enexis, an electricity and gas grid operator in the Netherlands. His responsibilities include IT-enabled business innovations such as smart grids, information technologies and operational technologies (IT-OT) integration and mobile solutions.

What's the most useful feature of the Erasmus Energy Forum event?

I like the collection of speakers at the Erasmus Energy Forum – they look at things from an original angle. It might be because Professor Wolf Ketter comes from a business school and academic context that he is able to attract such speakers. I have been to a lot of sustainable energy conferences, about optimisation from different market roles, strategic thinking and new market models; I think the financing of sustainable energy is a hot topic right now. It's a really interesting story for me.

What do you find most interesting about the Erasmus Centre for Future Energy Business (ECFEB)?

I'm interested in the seminars and information on the website, and check it frequently for updates.

How do you think the work being done at Erasmus University will impact your industry?

Real-time optimisation is a trend for grid operators, and it's in the commercial strategies of large integrated businesses as well. They're moving away from making long-term plans for increasing their generation capacity to planning for flexibility, which ultimately means real-time optimisation. The regulatory structures in each market encourage various developments to the fore, such as demand-side management, grid-operator pilot schemes and virtual power plants. In these developments, the power-operator algorithms developed by ECFEB and Power TAC are very important, especially because of Power TAC's crowd-sourced open platform which connects everyone for open and worldwide competition.

What is standing in the way of deeper impact?

The potential of the Power TAC platform and algorithms is insufficiently known to many utility companies in Europe. Interestingly, it was first used in the massive Dutch flower auction, FloraHolland, instead of in utilities. We should raise more awareness and start applying the power of the Power TAC platform in different optimisation areas in utilities and other industries and co-operate in this in a joint effort. I'm sure those industry players offering optimisation algorithms see the competitive threat of this open source platform, but those that could really make most use of the opportunities haven't seen it.

What do you think should be the next area of focus for this line/area of research?

There are still a lot of questions about multiple targets for optimisation, such as the load on the grid and changing energy prices, to which this platform could be applied. Multi-target optimisation is still an area in development and should be an interesting one to address.

Jan-Paul Buijs, Manager CIO office Enexis, jan-paul.buijs@enexis.nl

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Martin Bichler

holds the Chair in Decision Sciences & Systems in the Department of Informatics at the *Technische Universität München* and researches topics at the intersection of market design, operations research, and computer science.

What’s the most useful feature of the Erasmus Energy Forum event?

It brings practitioners and academics together, enabling them to talk about the fundamental topic of a sustainable future energy supply. New ideas and discussions emerge from business and become incentives for new research. Similarly, research results are transferred to practitioners.

What do you find most interesting about the Erasmus Centre for Future Energy Business?

The work of Wolf Ketter and his PhD students on the Power TAC trading agent competition over the past couple of years has become a visible event in the artificial intelligence community. It’s a wonderful example of researchers providing a platform to analyse complex phenomena. In many cases, analytical modelling cannot capture the complex phenomena arising in real-world markets. Simulations and computational platforms like Power TAC complement the work being done in experimental economics and theoretical micro-economics.

How do you think the work being done at Erasmus University will impact your industry?

My industry is academia. In our research we focus to a large extent on the design of efficient and robust markets. The energy market and the Dutch flower market of FloraHolland are two interesting examples, each with their own challenges and idiosyncrasies that need to be addressed. For example, the highly perishable nature of the flowers and the fast-paced sales necessitated the development of specific auction mechanisms. Even though sequential multi-unit auctions have been around for a while, there's still a lack of models that understand the economic properties of such mechanisms, and the bidding strategies used in them.

What is standing in the way of deeper impact?

Sometimes there can be a disconnect between the issues that practitioners care about and the issues dealt with in the research community, and it takes an individual prepared to reach out to reconnect them. In this respect I think Wolf is doing a wonderful job, producing relevant research results for practitioners.

What do you think should be the next area of focus for this line/area of research?

There are still plenty of research challenges on the applied side of the energy business, such as pricing of renewable energy or economic models for Microgrids. On a more fundamental level, the question of how to model users and bidders is not yet addressed to a sufficient extent. There are established economic models where individuals act as expected utility maximisers, which are good as a baseline, but if you take a closer look the assumptions are often violated. There is much more that needs to be done to produce appropriate models that explain phenomena that we see in real markets.

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"After a hundred years of operation, it is maybe necessary to 'reinvent' the clock system in order to be well adapted to the changing trading conditions. The general objective is to 'add more fingers to press the clock system', to have more demand during the auctioning process. In order to base our changes on hard facts, rather than on 'feelings', the Erasmus University of Rotterdam was asked to carry out an objective study on the future of the clock system. The results so far are really insightful and help us to develop smart real-time decision support systems."

Theo Aanhane
Manager of Auctioning and Quality Systems, Flora Holland

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Rotterdam School of Management (RSM)
Erasmus School of Economics (ESE)
Erasmus University Rotterdam (EUR)
P.O. Box 1738, 3000 DR Rotterdam,
The Netherlands

Tel. +31 10 408 11 82
Fax +31 10 408 96 40
E-mail info@erim.eur.nl
Internet www.erim.eur.nl

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