Quantitative analysis

of

strategic and tactical purchasing decisions

Research School for Operations Management and Logistics

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QUANTITATIVE ANALYSIS
OF STRATEGIC AND TACTICAL
PURCHASING DECISIONS

PROEFSCHRIFT

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de graad van doctor aan de Universiteit Twente,
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Contents

Chapter 1

Scientific maturity of purchasing management research

a rapidly growing puppy that still has to learn some manners

The field of purchasing management (PM) is still young. In this chapter we investigate the status of PM research by looking at the historical development of other research fields that have already matured. For this investigation we categorize scientific research as (1) either deductive (theoretical) or inductive (empirical) and (2) either quantitative (formal) or qualitative. It appears that all mature management research fields include both types of research. Furthermore, we find that in PM the focus has mainly been on empirical research and some qualitative deductive research until now. We conclude that in PM research there is a lack of attention for quantitative deductive research. This conclusion is the rationale for this thesis.

1.1 Introduction

Purchasing management (PM) is a not a new research field, but still relatively young compared to established scientific fields.

In this chapter we investigate the question what the current scientific status of PM research is. Furthermore, if the status of PM is still immature, what changes in research directions could be considered for improving the status? We try to position PM research by looking for similarities in the way established research fields have developed over history.

In the next section we consider what ingredients are necessary for research to be scientific. We start off with some philosophical points of view in this matter. After that we focus on three specific components of scientific research: (1) structure of scientific communities, (2) empirical research and (3) deductive research. In section 1.6 we zoom in on the status of management research and two subfields in particular: operations management and marketing. With this background we will be able to describe the status of PM research in section 1.7, followed by the conclusions in section 1.8.

1.2 What is scientific research?

The goal of scientific research is to provide scientific knowledge about the world in which we live. What scientific knowledge is and what the proper method for gaining this knowledge is, is subject to debate. These two questions form the focus for the philosophy of science. A contemporary overview of the main streams in this debate is given below (see Chalmers, 1978; Keys, 1991).

Nowadays the most common view on what scientific knowledge is and how it can be obtained is still based on *inductivism*. Already Aristotle propagated this view and it became especially popular with scientists like Galileo and Newton during the Scientific Revolution in the seventeenth century. According to inductivism all science starts with observation. With sufficient empirical evidence generalized statements such as laws and theories can be induced. These theories enable a scientist to explain and predict using deductive reasoning. Scientific knowledge is knowledge based on and not contradicted by observation. It is gradually accumulated over time as the number of observations increases.

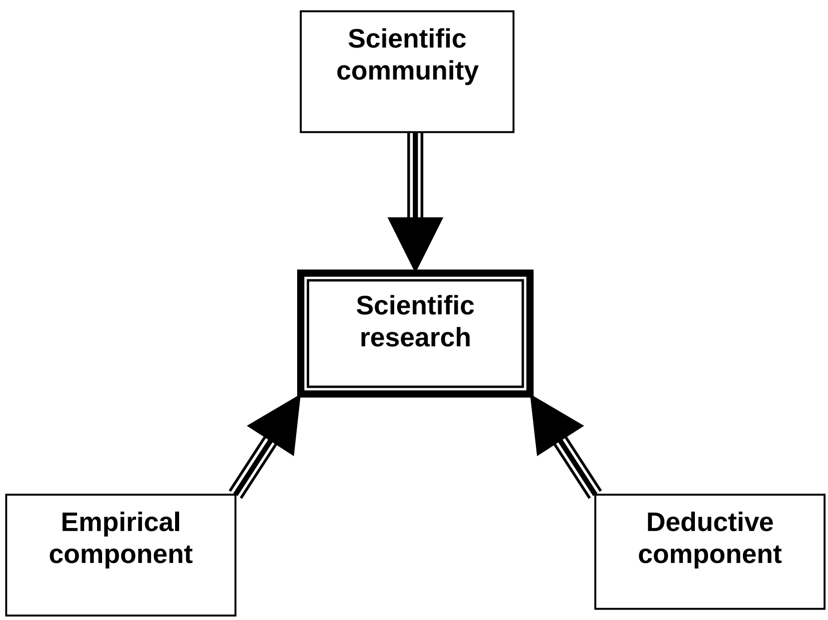
An obvious problem of inductivism is: when is empirical evidence sufficient? Another more fundamental critique is that observations are theory dependent. Observation statements can only be made with presupposed theoretical knowledge. These statements are therefore guided by theory, which contradicts the assumption of taking observation as starting point of science.

To overcome the problems of inductivism a new view developed mainly by Popper known as *falsificationism* (Popper, 1980). In his view a hypothesis can never be proven true, it can only be proven wrong (falsified). But the more falsification attempts fail, the more credible the hypothesis is. This also holds for a theory. Theory is considered to be a more general statement from which hypotheses can be deduced. Scientific knowledge therefore consists of theories that can be falsified and scientific research is the process to formulate theories / hypotheses and trying to falsify them. Falsificationism also has its limitations though. Observations can contain errors leading to an unjustified falsification of a theory. Furthermore, falsification can be problematic when test situations become so complex, that the test situation itself is responsible for an outcome not in line with the prediction.

Both inductivism and falsificationism fail to characterize how complex theories are developed over time. People like Lakatos (1970) and Kuhn (1970) argued that theories should be seen as structures. Only with structured theories statements and concepts used for these statements can be given a precise meaning. Studying the history this holds for all major sciences. According to Lakatos (1970) research programs provide this structure, giving guidance for future research in both a positive and negative way. Within this program a core of hypotheses and conditions are considered to be true and unfalsifiable (negative), but along the lines of the program research is developed and new phenomena are discovered (positive). A research method is only proper as long as the new hypotheses can be verified independently of the core assumptions. In this philosophy research is scientific if (1) a degree of coherence is available, which involves mapping out a program for further research and (2) the research program leads to the discovery of new phenomena at least occasionally.

Kuhn's ideas are more elaborate taking into account the revolutionary character of science and the sociological characteristics of scientific communities. The research program as Lakatos formulated them is only part of the evolution of scientific research. Kuhn (1970) calls it "normal" science based on a certain paradigm basically involving puzzlesolving activities both theoretically and practically. Research deals with working out the details, uncritical of the core of the paradigm. However there are always anomalies conflicting with the paradigm. When these conflicts become too serious a crisis will occur and rival paradigms solving the anomalies will emerge leading to a revolution. Eventually, one of the rivaling paradigms will be adopted and be considered the new basis of normal science, which closes the evolutionary circle. Thus, within normal science progress is made in a continuous way, but at times of revolution a discontinuous progress occurs. In this view mature science lacks disagreement about the fundamentals. Immature (or revolutionary) science has this debate, but it is a rather disorganized activity. Because of this in an immature science each researcher has to justify his or her approach making it impossible to develop a theory in more detail. Hence, both revolution and normal science serve their purpose. Without revolution researchers would stay trapped in their paradigm and without normal science complex theories would never be developed.

Figure 1.1: *Dimensions of scientific research*



In Kuhn's view in the accepted paradigm it is prescribed what method is considered to be scientific. However, there is no method describing how to arrive at rivaling paradigms. Feyerabend (1975) even suggested that methodological rules only give suggestions how to gain knowledge, but they fail to prescribe how to gain it. He argued that it is not realistic to expect a few simple rules to account for the process in which theories are created. It requires a complex analysis of sociological, psychological and historical factors. Therefore, there is no scientific method. In his view science is an ideology and it is institutionalized. Ways of research departing from the main stream are automatically labeled as unscientific. Feyerabend advocates methodological and theoretical pluralism. It is the discussion about and the interaction between different views that will lead to progress.

Summarizing the main views in the philosophy of science, they all agree that scientific research consists of an empirical and a deductive component. It is the dominant paradigm or structure of the scientific community that determines which method of doing empirical and / or deductive research is considered to be scientific. We will elaborate on these three dimensions: the structure of scientific communities, empirical and deductive research methods (see Figure 1.1).

1.3 Structure of scientific communities

Point of departure for discussing the structure of scientific communities is Whitley's framework. Whitley (1984) argued that "fields organized and controlled in different ways produce different organized knowledge and become established in different contextual circumstances (p.33)". In his view the two main variables determining the organizational structure are the *mutual dependence* between researchers and the *uncertainty in the task*.

Both variables have two components. *Mutual dependence* between researchers can be strategic and functional. Strategic dependence concerns the extent to which other researchers have to be convinced of the importance of the contribution. When the strategic dependence is high, it means research has to be more coordinated and research groups need to set common goals. Functional dependence has to do with the skills involved. A high functional dependence means research will only be accepted as a scientific contribution if it clearly fits with the existing knowledge base view and uses common methods and techniques.

Task uncertainty can be strategic and technical. Strategic uncertainty involves the uncertainty in setting research priorities and significance of the research. When the strategic uncertainty is high, the variety of research topics in the field is considerable and the importance of certain topics is perceived differently by different researchers. Technical uncertainty deals with the extent to which working procedures are well understood and produce reliable result. High technical uncertainty means results are more subject to different interpretations.

Combining the four components mentioned above with each component having a value "high" or "low" Whitley (1984) arrives at a 16-cell matrix. Nine cells he considers to be unstable, as interdependence between the components exists. The remaining seven cells describe seven stable types of research communities (see Table 1.1).

As stated above a scientific community, in which a researcher operates, determines the perceived value of a scientific research contribution. Therefore, a researcher who wants to make a scientific contribution, which is recognized as such in a particular field, has to be aware in what type of research field he operates.

Table 1.1: *Types of scientific fields (from Whitley, 1984, p.158).*

Type of scientific field	Mutual dependence		Task uncertainty		Example
	strategic	functional	strategic	technical	
Fragmented adhocracy	low	low	high	high	Management studies
Polycentric oligarchy	high	low	high	high	Continental European ecology
Partitioned bureaucracy	high	low	low	high	Anglo-Saxon economics
Professional adhocracy	low	high	high	low	Bio-medical science
Polycentric profession	high	high	high	low	Continental mathematics
Technologically integrated bureaucracy	low	high	low	low	Twentieth-century chemistry
Conceptually integrated bureaucracy	high	high	low	low	Post-1945 physics

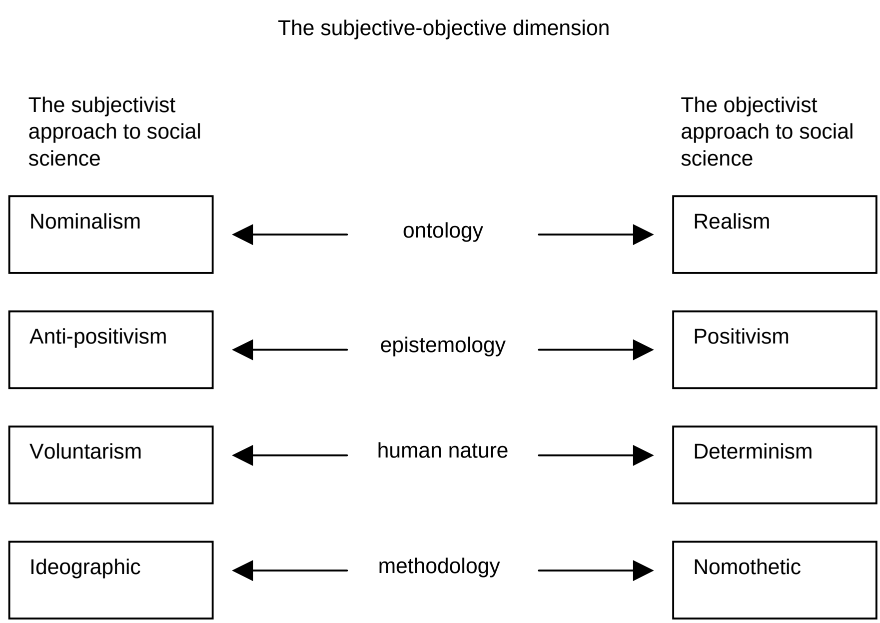
1.4 Empirical research

In the natural science it was assumed that observation could always be done objectively without interaction with the observed phenomenon. Within the natural sciences this assumption has been challenged in the 1930s with the developments of quantum mechanics. But especially the emerging research in social sciences has led to renewed debate.

Compared to the traditional natural sciences social sciences have a major drawback with respect to generalization. In the natural sciences phenomena are independent of time and space when the same experimental conditions are applied. This allows duplication of results by other researchers and generalization. Social sciences involve studying human and organizational behavior. Even if current relationships between observed variables are completely known, technological advances can change these relationships permanently (Ackoff, 1962). Also, assuming human behavior is not completely deterministic means generalization of statements is intrinsically limited.

This difficulty applies to all social sciences and has led to the philosophical debate on how scientific observations and therefore empirical research should be conducted. It revolves around the question whether observation can be conducted with or without interacting with the object and whether observations are independent of the observer. Can observation really be done in an objective way or is it always subjective? We will take the viewpoint of Burrell and Morgan (1979), who have given a good overview of this debate. In addition, they have provided a framework that fits all views within social sciences into four distinct paradigms. These paradigms are based on two dimensions: the "subjective – objective" dimension and the "nature of society" dimension.

Figure 1.2: *A scheme for analyzing assumptions about the nature of social science (from Burrell and Morgan, 1979, p.3)*



Burrell and Morgan (1979) split up the subjective - objective dimension into four underlying assumptions of researchers about: ontology, epistemology, human nature and methodology. In each case these assumptions can be subjective or objective. (see Figure 1.2). Regarding ontology the question is, whether reality is of an objective "nature" or reality is a product of individual consciousness. The same holds for epistemology. Is knowledge an independent "entity" or does it merely exist in the eye of the beholder? For the social sciences especially the assumption about human nature is important: whether humans have a "free will" or they respond deterministically to situations.

All assumptions just mentioned have their reflection on what methodology is considered to be a proper one. A subjectivist assumes knowledge can only be gained by getting close to and involved with one's subject and analyzing the background in great detail. In an extreme form this approach could be aimed at only trying to understand the individual study object rather than finding universal truths. According to an objectivist research should be based upon systematic protocol, like testing hypotheses using quantitative techniques. Obviously the latter relates directly to the approach used in the natural sciences.

The second dimension Burrell and Morgan (1979) consider is the nature of society. They distinguish between the assumption that emphasizes society as orderly, stable and cohesive and the assumption that emphasizes society as a set of conflicts and radically changing. This dimension mainly focuses on which aspects of society are important to study for the social sciences. So with respect to empirical research methods in general this dimension is less interesting.

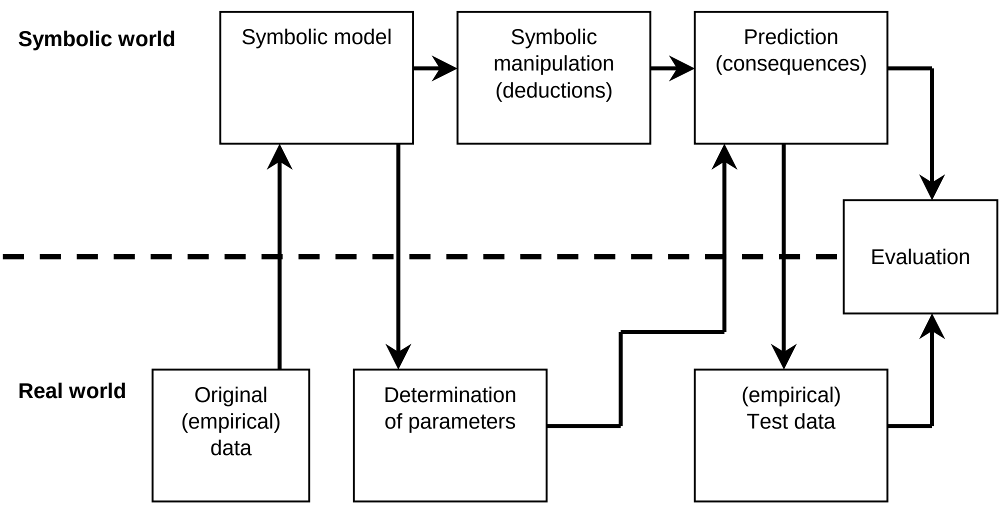
Focusing on empirical research methods the main distinction is between the ideograhic (subjective) and nomothetic (objective) approach. The subjective approach (also often referred to as interpretative or qualitative) advocates research like in-depth case studies. The objective approach (also often referred to as functionalist or quantitative) advocates research based on statistical analyses of surveys.

1.5 Deductive research: use of models

"Somewhat analogous to the way theorems are derived in geometry the physicist begins with a set of idealized assumptions from which using rigorous logical procedures, consequences are deduced (Beged-Dov et al, 1967)". From this quote it seems rather straightforward how to proceed when conducting deductive research. However, it does not say how to determine this set of idealized assumptions. It involves developing a model: a simplification of reality.

In order to be able to deduce anything models are used as a frame of reference and represents the theory behind it. Basically, models can be anything ranging from almost resembling reality to very abstract. We will mention four categories. First, there is the physical model such as a small airplane that can for instance be used in wind tunnel testing. Secondly, there is the verbal model describing the reality without making a physical representation of it. This verbal model can be made into an abstract model by translating descriptions used in the verbal model into general concepts. Finally, the concepts of the abstract model can be linked together in a formal way, leading to a formal or mathematical model. Similar to splitting empirical research in being quantitative and qualitative, in deductive research the formal modeling approach is referred to as quantitative, whereas verbal and abstract modeling are referred to as qualitative.

Figure 1.3: *Research using models (adapted from Levin and Lamone, 1969).*

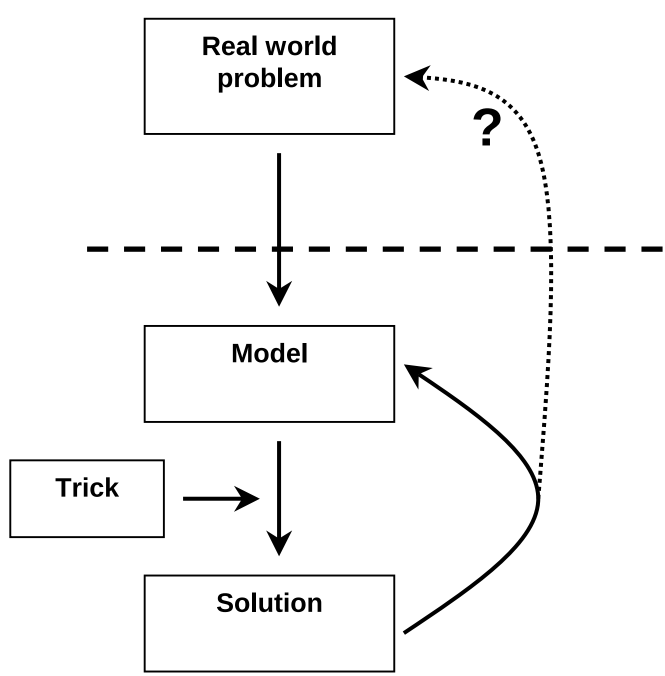


Developing a formal model has advantages over the other modeling approaches with regard to three aspects (Beged-Dov et al, 1967): conceptual clarity, conceptual relevance and identification of equivalent theories. Formalization of a model requires clear statements. In a verbal or abstract model the relationships between variables can be kept somewhat vague, because it is not necessary to make them very clear. Providing an unambiguous definition of a concept can be quite difficult, but for formal model this has to be done. In a formal model everything has to be made explicit, that is why it leads to conceptual clarity. Because of this conceptual clarity conceptual relevance can be shown in a more straightforward manner. It means showing which aspects of a theory are affected by an experimental result. The last aspect is the identification of equivalent theories and theorems. Formalization of theories gives a better possibility to identify to what extent theories differ from each other.

As for the purpose of models, no matter which model is used, the purpose is always the same. As said before, models are used as a frame of reference to be able to deduce consequences given an empirical (starting) situation. These consequences can be verified with empirical data. This verification may lead to confirmation of the model, adjustments of the model and its assumptions or even completely discarding the model, as illustrated in Figure 1.3.

Models can be seen as mediators between theory and observation as shown by Morgan and Morrison (1999). Furthermore, they argue there are no general agreed upon rules for model construction, a quote: "models are typically constructed by fitting together a set of bits, which come from disparate sources" (p. 15). Model building is the creative process of making the frame of reference or background on which the deductive reasoning takes place. Figure 1.4 provides insight how a model acts as mediator (based on Telgen, 1988). It is similar to Figure 1.3, but it emphasizes the fact that when a solution to a model is found it does not necessarily imply that the practical problem has also been solved. Finding a solution to the model always involves a trick, which can be relatively simply obvious or mathematically very sophisticated. But this will only solve the model not the real world problem. However, when the model has been constructed properly, the solution should also be helpful for the real world problem.

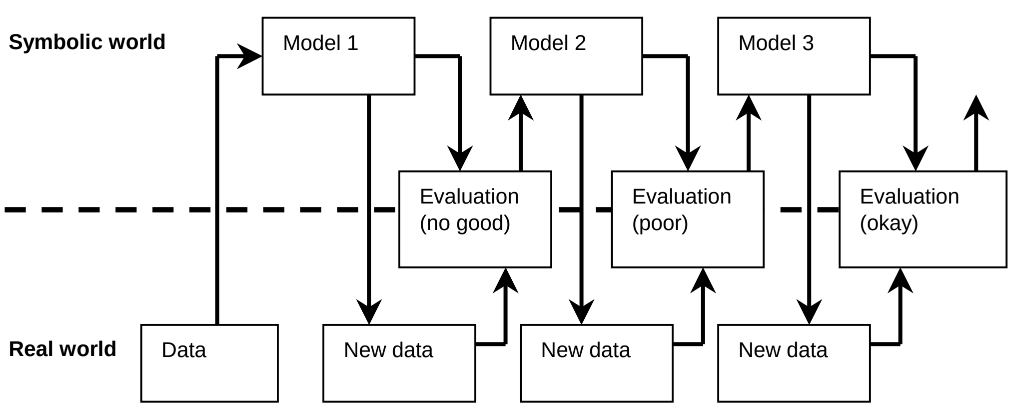
Figure 1.4: *Models act as a mediator (based on Telgen, 1988).*



Furthermore, model building is typically not a one-step process, but it involves several intermediate steps to come to a model that is considered satisfactory (see Figure 1.5). Satisfaction is based on two criteria: accuracy of prediction and applicability to practical situations. The more accurate the model predicts, but also the more widely it is applicable the more valuable is a model. The idea is that starting off with a simple model using very restrictive assumptions provides a good understanding of the basic properties. This allows for the researcher to learn and eventually develop a more complicated and satisfactory model.

Summarizing the last three sections, we identify four types of research: empirical and deductive research which both can be either qualitative or qualitative (see Figure 1.6). In principle all types of research add to the scientific body of knowledge. Therefore, in a particular research field the most scientific progress can be made by embracing all these research types. For a single researcher it means that he / she can focus on one research type, as long as in the research field as a whole all different research types are being conducted. Although this is in principle true, it is not always recognized as such due to the structure of the community in which the researcher operates. If a community has developed in such a way that only quantitative research is considered to be scientific (like in the natural sciences), a qualitative contribution will be labeled unscientific in this community. Of course, putting such a label on a type of research holds this type of research back. Hence, the role of the scientific community should not be neglected.

Figure 1.5: *Evolution of a model (adapted from Levin and Lamone, 1969).*



1.6 Scientific status of management research

Whereas the previous sections focused on aspects of scientific research in general, we will now narrow our focus to scientific management research. We will study the structure of this research field and the empirical and deductive research methods used.

First we consider in more detail the structure of scientific management research. Using the terminology of Whitley (see also Table 1.1) management research can be described as a fragmented adhocracy. In this field type there is a high task uncertainty both strategic and technical. In addition, there is low mutual dependence between researchers both strategically and functional. A quote from Whitley (1984, p. 159) gives a more detailed characterization a fragmented adhocracy: "Typically, these fields are open to the general 'educated' public and have some difficulties in excluding 'amateurs' from competent contributions and from affecting competence standards. The political system is therefore pluralistic and fluid with dominant coalitions being formed by temporary and unstable controllers of resources and charismatic reputational leaders." Therefore, in this field type certain research methods can be more fashionable than others, but this may change over time because of the unstable overall situation. Engwall (1995) gave some empirical evidence for Whitley’s assumption about management research as a fragmented adhocracy by looking at citations in the Scandinavian Journal of Management.

Figure 1.6: *Four types of research.*

	qualitative	**quantitative**
empirical	I	II
deductive	III	IV

In a fragmented adhocracy, because of its pluralistic nature, there is room for conducting all types of research. In this structure it would be best to have a combination of both quantitative and qualitative approaches in both empirical and deductive research, because each approach is accepted as scientific and can add to the body of knowledge.

Before looking at empirical and deductive research methods used in management research let us first focus on management as a research topic itself. Management is about managing organizational processes that involve human interference. Management research can be positioned in between natural and social sciences, as it takes into account human interaction, but it is not purely focused on these interactions.

When management research in general started to evolve in the nineteenth century as a scientific field the natural sciences were the established scientific fields. Only the objective approach was considered to be scientific. Logically this approach became dominant in empirical management research and in fact it still is. With the slow acceptance of the subjective approach to be scientific as well, case study research has gained popularity over the last decades, but it still is not as accepted as quantitative techniques.

Nowadays management research is an umbrella term for many separate established scientific fields such as: operations management, marketing, strategic management organizational behavior, finance & accounting, information management. Whether or not PM should be mentioned here, will be discussed in the next section. However, we would like to illustrate what has been described about management research in general terms above with the development of two management fields in particular: operations management (OM) and marketing.

Until about the 1950s OM research was highly descriptive in nature (Buffa, 1980). From the 1960s the mathematical approach known as operations research (OR) or management science became dominant in this field (for more background information see Eilon, 1995; Keys, 1991; Meredith et al, 2002). Despite the earlier mentioned drawbacks of solely using a quantitative approach, using this method proved to be very successful. With this formal approach in line with the natural sciences OM developed to an established field.

Until the 1970s OM almost only focused on quantitative deductive research: focusing on problems that could be solved with the OR techniques together with improving these techniques and very limited attention to empirical research. This led to a crisis, as the relevance was starting to be questioned. After this crisis the field awakened and tried to take a more practitioner oriented view: more empirical research and sometimes even a more qualitative approach. Nowadays, in the year 2002, this view is still encouraged (see also Telgen, 1988), but although the amount of empirical research is increasing, reality is that the majority of the research is still of a formal deductive nature. To provide some evidence for this statement Scudder and Hill (1998) found that the percentage of articles in OM journals presenting empirical research ranges from only 3% in 1985 to 11% in 1995. Pidd and Dunning-Lewis (2001) found that most OR papers focus on untested theory rather than application. This conclusion is shared by Pannirselvam et al (1999). It seems that a lack of empirical research slows down scientific development, as only incremental theoretical improvements are being made to existing models. However it is this theoretical approach which made OM an established scientific research field, which causes researchers to stick to it.

The development of marketing as an establish scientific field is very much in line with the development of OM. Similarly, during the 1960s marketing was transformed from a descriptive and qualitative nature into a highly quantitative one. Also, in the late 1970s a debate emerged about the philosophical basis of marketing: the objective versus the subjective approach (Easton, 2002). Again this seems similar to OM, but there is a major difference. In marketing research unlike OM empirical research always played an important role. So the debate was not about increasing the amount of empirical research, but about whether the objective approach both in empirical and deductive research was the right one. Although the subjective approach gained popularity, the main stream until now is still the objective approach. Looking at published articles from 1970 to 1997 Chung and Alagaratnam (2001) found there has only been a slight shift towards the interpretative paradigm.

Li and Cavusgil (1995) have given an indication of the amount of empirical research. They conducted a content analysis of several scientific marketing journals from 1982 to 1990 focusing on international marketing. Their analysis shows that 69% of the 757 investigated studies are empirical research and the other 31% are conceptual. From the empirical research 66% is classified as statistical (quantitative) and the rest as non-statistical (qualitative). The research by Leeflang and Wittink (2000) indicates that using formal models in quantitative deductive research has played an important role throughout the years.

What both OM and marketing management have in common is that they both focused on one type of research at some point in time. This nearly led to a dead end in the sense that the relevance of the research field was starting to be questioned and therefore its scientific status. Only by incorporating all types of research, both empirical and deductive, both quantitative and qualitative, these fields were able to elevate their declining status. However, it is clear that quantitative research is still the main stream for both fields.

Both fields can be seen as a good example of how a specific field in management research has developed into a mature field because of this focus on a greater variety of research. It prevents a field from getting stuck in too narrow a scope, a danger, which still lurks around the corner, especially in OM research.

1.7 Scientific status of PM research

Although Chandler (1962) showed that purchasing played an important role in the rise of American companies in the beginning of the 20th century, the recognition of purchasing having strategic value declined enormously in the 1950s and 1960s (Farmer, 1997). Farmer (1997) sees the vertical integration and diversification of companies leading to increased bureaucracy as a possible cause for this decline. At that time purchasing was merely seen as a clerical, administrative task.

New interest in PM only emerged in the 1970s. The main reason was the oil crises and the lack of raw materials it caused. This drew the attention to the importance of purchasing (Ellram and Carr, 1994). Another reason was emergence of Japanese companies together with their way of more actively managing their suppliers using concept like Just In Time (JIT) deliveries (Farmer, 1997). Also, from the marketing field some interest was shown in industrial buying behavior, as understanding this behavior could result in improved performance of marketers. A result was the foundation of the International Marketing and Purchasing (IMP) group in de middle 1970s by researchers from various European countries (Hakansson, 1982). These developments coincided with the changing view on corporations, namely focusing more on core competencies. This led to less vertical integration of business and more outsourcing. Nowadays it is fair to say that on average from each dollar received through sales, more than half a dollar is spent on purchases. Thus PM is interesting from a financial point of view as well.

With the recognition of its importance purchasing developed into a management research field. Researchers focusing on a new field have come from various related fields and apply theories and methods that are used in these fields. For purchasing these fields are: OM, marketing, economics, social sciences, organizational behavior and law. During the last decades a pluralistic body of purchasing knowledge has been built up. The fast increase in the number of dissertations shows that the amount of purchasing research has been increasing rapidly (Williams, 1986; Das and Handfield, 1997). Das and Handfield (1997) also classify the twelve key purchasing areas. They are worth mentioning here to give an idea of what purchasing research consists of:

- purchasing information systems
- early supplier involvement / new product development
- global sourcing
- purchasing planning, organization, policies and personnel
- purchasing performance measurement
- single / multiple sourcing
- supply chain integration
- supplier selection and development
- buyer-supplier relationships
- supplier quality
- legal, ethical and environmental issues
- cost, pricing and contracts

A similar list of topics can be found in Morlacchi et al (2002). They give an overview of the largest international purchasing research network called IPSERA

(International Purchasing & Supply Research & Education Association). Founded in 1991, it currently has about 300 members. The main event organized is the annual conference. Morlacchi et al (2002) evaluated all conference proceedings giving interesting insights in the topics and research methods used.

Das and Handfield (1997) find that no dominant paradigms and theories in PM research exist. Therefore, in Whitley's (1984) terminology, researchers seem to have a low strategic mutual dependence. Also the functional dependence is low, as researchers come from various backgrounds and apply different research methods. The wide variety of topics shown above indicates a high strategic task uncertainty. Finally the technical task uncertainty is also high, as PM is a young field and working procedures are still being developed and various methods are being applied. Taking the values of mutual dependence and task uncertainty together PM can be classified as a fragmented adhocracy, similar to management research in general.

Focusing on the type of PM research, Das and Handfield (1997) conclude that it is still largely exploratory and descriptive. They argue that in a new field research always starts off exploratory, but with the passing of time more normative research should be conducted. As normative research still lacks in PM, PM research can therefore still be considered an immature field.

With regard to empirical research both qualitative and quantitative research are present in PM. From purchasing dissertations investigated by Das and Handfield (1997) 62 employed surveys and 25 case studies. The investigation of the IPSERA conference proceedings by Morlacchi et al presents a slightly different outcome. About 70% of the papers present empirical research: about 40% case studies, about 20% surveys and the rest other methodologies such as action research, focus groups and multiple methods.

Ramsay (1998) discusses the problems of empirical research and their implications for PM research in more detail. He argues that both quantitative and qualitative empirical research have their merits for PM research, but they also have their limitations. He therefore favors triangulation of methods. He especially warns for embracing only quantitative methods, as in his view unfortunately many established disciplines have done.

In deductive research until now the focus has mainly been on qualitative models, i.e. conceptual models used as frameworks for putting ideas together. For quantitative deductive research Das and Handfield (1997) find "for instance the relative lack of simulation / mathematical approaches in most topic areas is noticeable (p. 113)." Olsen and Ellram (1997) investigated different research approaches on buyer-supplier relationships (one of the key areas mentioned above) and they come to a similar conclusion: "The authors believe that theoretically developed and tested normative research is greatly needed (p. 229)."

Analysis of all IPSERA proceedings by Morlacchi et al (2001) shows that 30% of the papers are of a conceptual nature (no empirical results). We conducted a little more in depth analysis of the proceedings looking at the number of papers that actually use quantitative deductive research in the last five years. In addition, we examined the articles published in the last five years in two leading PM journals: the European Journal of Purchasing & Supply Management and the Journal of Supply Chain Management.

Table 1.2 shows the results. A paper has been considered quantitative deductive, if anything of quantitative deductive nature was written in that paper. Hence, the paper could also contain other types of research. Both in the journals and the proceedings quantitative deductive research make up only a very small segment.

Our analysis of both the journals and proceedings confirms the statement that in PM a lack exists in quantitative deductive research. An explanation for this lack can be found in De Boer's thesis (1998). He links the fact that the 1960s and early 1970s were the eras in which (a) the quantitative deductive research approach (Operations Research) was booming and (b) purchasing management was not considered strategic. Hence, there was no attention for developing quantitative models for purchasing at that time. And by the time PM was gaining importance, the mathematical approach of management problems was under fire with respect to its relevance (see above).

Table 1.2: *Quantitative deductive (QD) research in PM literature.*

Year	**EJPSM***		**JSCM****		**IPSERA*****	
	Total	**QD**	**Total**	**QD**	**Total**	**QD**
2002					63	6
2001	23	1	23	2	76	3
2000	22	1	22	1	80	5
1999	19	2	24	1	76	3
1998	23	3	23	1	54	3
1997	23	2	23	0		
Total	**110**	**9 (8.2%)**	**115**	**5 (4.3%)**	**349**	**20 (5.7%)**

*European Journal of Purchasing & Supply Management

**Journal of Supply Chain Management (before 1999 International Journal of Purchasing & Materials Management)

***Proceedings of the annual IPSERA conference

1.8 Conclusions

The objective of this chapter has been to determine the status of PM research. We argue that scientifically PM theory and research is still in its infancy. The focus is mainly on inductive explanations of practice. The use of deductive reasoning has been limited until now. It often makes use of qualitative models only. In other management fields such as OM and marketing it has been shown that formal analysis of decision problems provides unique opportunities to establish these fields and to bring them forward scientifically. It provides fundamental new insights and predictions, although other types of research should not be neglected.

It seems that PM is not different from these fields in this respect. Therefore, attention should be paid to the current lack in quantitative deductive research. Increasing research efforts in that area will be of great help to increase the knowledge base of PM and will help improving the status of PM. Filling up this research gap gives the possibility for PM to develop along the lines of other management research such as marketing. Marketing is an established research field incorporating quantitative and qualitative approaches in empirical as well as deductive research. With extra effort in quantitative deductive research PM will have the same completeness. Continuing like this will without doubt establish PM as a mature scientific field in the near future.

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Chapter 2

The research setup

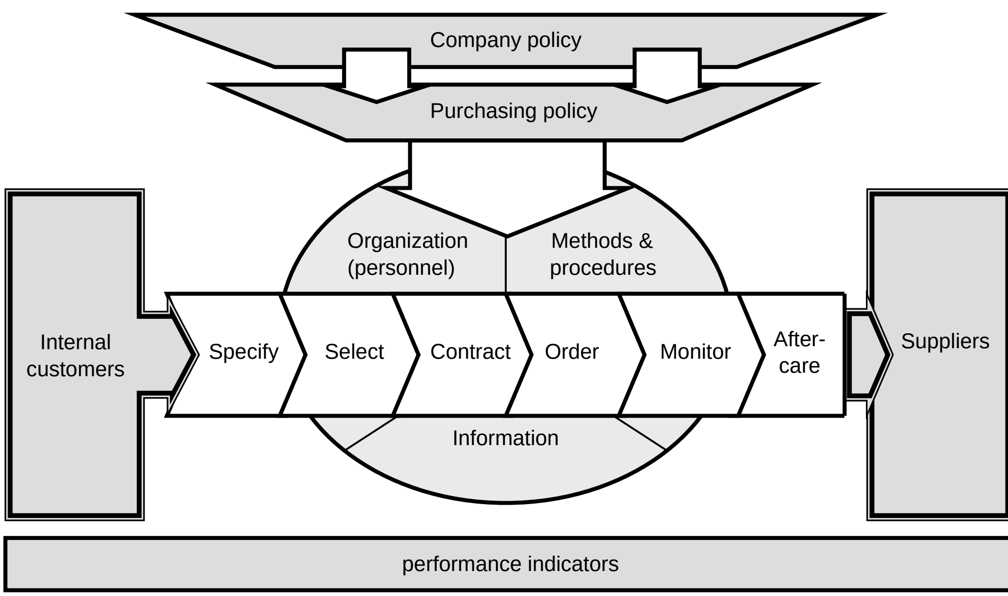
introducing the quantitative deductive approach in strategic and tactical purchasing problems

In the previous chapter we argued that there is a lack of attention for quantitative deductive (QD) research in the field of purchasing management. Furthermore, giving quantitative research the attention it deserves will help purchasing management to develop to an established field. This is the rationale behind our research project "Quantitative analysis of strategic and tactical purchasing decisions". Subsequently, this led to the following main goal for our project:

The goal of our project is to further develop purchasing theory by introducing a quantitative deductive approach to a selection of strategic and tactical purchasing decision problems.

Again, the motivation for the introduction of the QD approach is clear from the previous chapter. Below we will explain why we focus on a selection of strategic and tactical purchasing problems.

Figure 2.1: *The racing car model showing the components of the purchasing function (Gunning and Veeke, 1993; Harink, 1999; Lenselink and Telgen, 1999).*

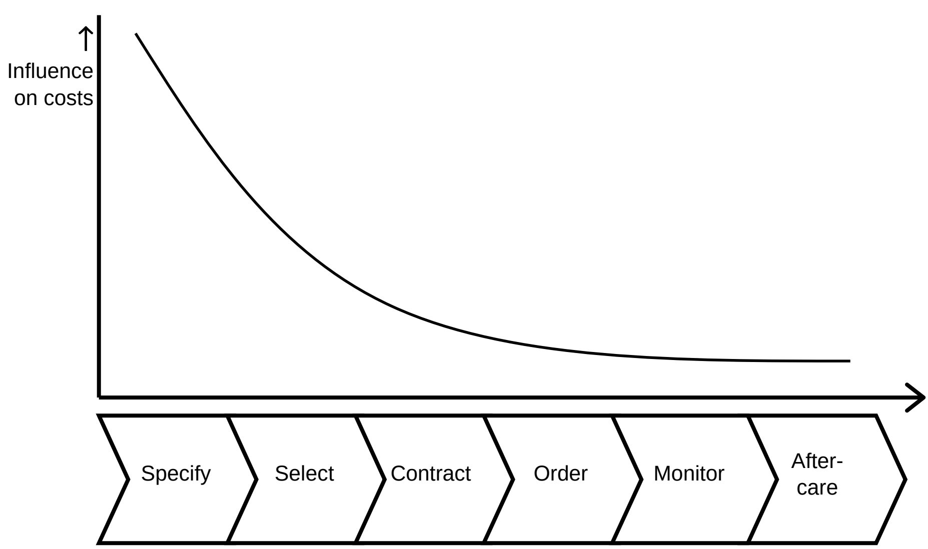


First we define strategic and tactical purchasing. Figure 2.1 provides an overview of all components of the purchasing function. An important part of the purchasing function is the purchasing process (from the internal customer to the supplier in Figure 2.1). The purchasing process consists of a tactical and an operational purchasing phase. Tactical or initial purchasing involves specifying the needs, selecting and contracting suppliers, while operational purchasing involves ordering, monitoring and after care. Strategic purchasing management does not involve decisions within the purchasing process, but about the purchasing process. It is about defining a general purchasing policy that determines the purchasing organization, the methods and procedures and information management. Finally, performance indicators are needed to verify what the results of the purchasing policy is and how well it is adhered to.

2.1 Focus on strategic and tactical purchasing

Most of the costs for a certain purchase are determined by the earliest stages in the purchasing process (see Figure 2.2). Let us explain this with an example. Suppose a purchaser has been ordered to buy a number of computers. Specifying the type of monitor, the processor, the amount of memory, the size of the hard disk, etc will determine the price to a very large extent. For instance, whether or not a flat screen monitor is required makes a huge difference on the total costs maybe 100% or more. After the specifications have been determined, of course selecting a good supplier and making a good contract can save more money, but the price difference will typically be in the order of 10-50%. After that, in the operational phase additional costs can be avoided by having a good ordering policy (bundling orders) and streamlining the logistics, but compared to the total costs these operational cost savings are very small. Clearly, the largest savings can be made in tactical purchasing. That is one reason to focus on tactical rather than on operational purchasing.

Figure 2.2: *Impact of purchasing steps on total costs (De Boer, 1998; Harink, 1999)*



Furthermore, strategic purchasing decisions create the environment in which the purchasing process takes place. Wrong decisions, i.e. implementing faulty methods, will affect the effectiveness of both tactical and operational purchasing. Hence, we also take strategic purchasing decisions into consideration for this project.

Another reason to focus on strategic and tactical purchasing is similar to the reason we focus on QD research. The amount of QD research is limited in purchasing management, but the same holds to a lesser extent for research on strategic and tactical issues in purchasing management in general. Purchasing management research only has started to focus on strategic and tactical issues since the middle of the 1970s, because purchasing management was not considered strategic until then (see chapter 1). Although nowadays a body of knowledge on these strategic and tactical issues exists, its size can not be compared with the vast body of knowledge of operational issues in purchasing, which were already being researched long before.

Finally, applicability of our research is also important. Strategic and tactical purchasing decisions are of a more generic nature. These decisions are by definition less organization specific, because they are taken at a higher level and they do not include the company specific details, like operational decisions do. Hence, research findings on strategic and tactical purchasing decisions can be beneficial for a wide range of organizations. In addition, if research helps to improve strategic and tactical purchasing decision making in practice, it contributes to the promotion of the importance of purchasing in organizations.

2.2 Selection of decision problems

But even with this preference for strategic and tactical purchasing decision problems, there are still many topics to be investigated. Therefore, we apply three additional criteria:

- *Originality*. We want to investigate decision problems which have not or have hardly been subject to a quantitative deductive approach. This rules out a topic like supplier selection. Actually, supplier selection is the topic within tactical purchasing which probably has been studied the most in a quantitative deductive way (see e.g. De Boer, 1998; De Boer et al, 2001).
- *Practical relevance.* Among the topics that we could investigate we want to focus on topics which are (the most) relevant to purchasing practitioners.
- *Manageability.* This means that we have to be able to handle the problem. For some decision problems we may not succeed in translating them into a quantitative model.

About practical relevance, although our focus is on theoretical development, we do not ignore the purchasing practice. Introducing a quantitative deductive approach implies developing new mathematical models. In order to make these new models available for the purchasing practitioners we aim to incorporate them in (prototype) decision support systems (DSS). An additional advantage of having a DSS available is that it makes it easier to test the practical applicability of the models. A DSS makes the underlying model more easily accessible and understandable for a purchaser.

Using the selection criteria above still leaves a large number of topics worth of investigation. Six of the topics have been investigated to such an extent that they can be presented in this thesis. The main reason for choosing these six topics is variety from two different viewpoints. First, we would like to have a large variety in the strategic and tactical decision problems addressed. So, we would like to address several components of the purchasing function (see Figure 2.1). For instance, we do not only want to address issues dealing with contracting, but also issues dealing with purchasing policy. Second, we would like to use a large variety of quantitative techniques. In this way we are able to demonstrate various different techniques available and how they can be applied successfully to purchasing decision problems.

Before presenting the topics addressed in this thesis one by one, we will first describe the research design.

2.3 Research design

The nature of this research project requires a modular approach. We investigate each purchasing problem in a separate module, but in a similar way, as described below.

First, an extensive literature study is conducted to make sure that we are familiar with all aspects of the problem. Second, assumptions have to be made, as a model can never be as complex as reality itself. Based upon these assumptions a quantitative model is developed. To find solutions for the model we apply existing techniques from mathematics, statistics and operations research.

A first model may be somewhat simple to test the general idea. After that new variables can be added and more and complex dependencies can be implemented to make it more realistic and applicable to more situations, analogous to Figure 1.5 in the previous chapter. The mathematical model allows us to prove theorems on the purchasing decision problem. This improves the theoretical understanding of the problem.

When the model is acceptable, we develop a (prototype) DSS. A model is acceptable if it can be applied in a large enough number of situations for which its predictions are reasonable enough. This requires validating the model internally (consistency) and externally. External validation means testing the practical applicability in the sense that the model assumptions have to be realistic enough for the practitioners to find it useful. Hence, the validation step acts as a feedback. This results in an iterative process of improvement.

Although the general approach to each problem is similar, in this thesis we notice the extent to which problems are investigated differs. This is especially true for the external validation of certain decision problems, as thorough empirical research is very time consuming. This can hardly be avoided in a modular research project that has to be finished within a certain time frame. However, for all presented decision problems we claim to have reached our main goal of developing purchasing theory by means of quantitative deductive research.

2.4 Layout of the thesis

In the rest of the thesis we present the selected topics one by one. Each chapter deals with one topic. Thus, these chapters have no overlap with each other, i.e. they can be read independently of each other. In line with this modular approach, instead of having one reference list at the end of the thesis, we present the references at the end of the chapter to which they belong. Below we give a brief overview of the topics in this thesis.

In chapter 3 we investigate the influence of purchasing on the Return On Investment (ROI) of companies. We present a mathematical model of the ROI as a function of several key figures, most of which can be found on a company's annual report. This model is an extension of the Du Pont chart to explicitly take into account the direct spend and non product related (NPR) purchasing spend. Analyzing this model we show in which theoretical situations direct and NPR purchasing are the main ROI improvement drivers and equally important in which situations they are not. Furthermore, we apply this model using data of several Dutch business sectors. This gives an overview of the ROI improvement drivers per sector depending on the characteristics of the companies within that sector. In addition, we developed a DSS that shows ROI improvement drivers for a company specific situation.

In chapter 4 we investigate the allocation of savings to members of a purchasing consortium using a game theoretic analysis. We model the allocation of cost savings in a purchasing consortium as a cooperative game. Using this cooperative game model we analyze how common approaches to this allocation problem fit with game theoretic concepts. We also analyze the implications of known allocation methods from game theory within the purchasing consortia setting. Furthermore the model can be used to calculate the minimum and maximum size of a consortium.

Chapter 5 deals with tendering procedures (competitive bidding). Purchasers are required to make a decision regarding the number of suppliers that are to be invited to submit a tender. For this decision a formal model has been developed by De Boer et al (2000) which specifies the economic tender quantity (ETQ). In this chapter we investigate the assumptions underlying this model. Moreover, we develop and test a DSS to verify the model's practical applicability. Finally, we investigate several extensions.

In chapter 6 we investigate purchasing policies for raw materials that are heavily traded on spot markets. In particular, we investigate the trade-off between buying on the spot market and establishing a fixed-price contract for a longer time period. Although raw material prices tend to fluctuate heavily over time, we show by means of a stylized mathematical model that simple decision making tools and strategies can be very effective when applied to buying raw materials.

The objective of chapter 7 is to give an answer to the question when it is worthwhile to change suppliers or to renegotiate the contract for a certain commodity group for which a single sourcing strategy is used. Single sourcing gives the selected supplier the opportunity to gradually increase prices, especially when the assortment of the commodity group is being renewed. We present a mathematical model to calculate the switching (or renegotiation) time based on parameters such as the spend and the replacement rate of products in a commodity group.

Chapter 8 deals with electronic ordering through catalog systems. Theoretically, the implementation of such a system can lead to huge cost savings, but it is a large and costly task. In addition, not much experience on good rollout strategies is available yet. We contribute to the solution of this problem, by presenting a mathematical model for determining the EP rollout strategy into an organization that maximizes the overall cost savings.

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Chapter 3

Where to focus for ROI improvement?

a purchasing perspective

3.1 Introduction

Nowadays measuring the performance of a company is unthinkable without making at least use of the Return on Investment (ROI) as a key performance indicator. The origin of the focus on ROI dates back to World War I. Around that time Donaldson Brown of the Du Pont Powder Company came up with the idea of what is now known as the Du Pont chart or formula. The Du Pont Powder Company was a pioneer in systematic management (Dale, 1957; Johnson and Kaplan, 1987). As Johnson and Kaplan (1987) put it: "Indeed, their intense desire to assess every aspect of the company's activities in terms of the price of capital led the founders of the Du Pont Powder Company to devise an ingenious return on investment formula that continues to serve accountants and financial analysts today (p.84)."

Furthermore, the Du Pont Powder Company already recognized the impact that purchasing could have on ROI (Johnson and Kaplan, 1987). Purchasing textbooks always refer to the Du Pont chart to show the importance of purchasing (e.g. Van Weele, 1994, p. 13; Leenders and Fearon, 1993, p.13). The impact of other factors on ROI have been examined as well, for instance productivity (Miller, 1987), investments (Östermark et al, 2000) and information technology (Dehning and Stratopoulos, 2002).

However, the impact of factors on ROI has always been considered separately, not in relation to each other. In this paper we focus on the relative importance of various factors, with a focus on purchasing. The research question is the relative importance of purchasing direct and non-product related goods and services on ROI improvement. In this respect purchasing competes with marketing (sales), operations management (productivity) and finance (investments). We take a global perspective, that is considering both large companies and SMEs.

First we present a mathematical model of the ROI as a function of several key figures, most of which can be found in a company's annual report. This model is an extension of the Du Pont chart. It explicitly takes into account the direct spend and non-product related (NPR) purchasing spend. Analyzing this model we can show in which theoretical situations direct and NPR purchasing are the main ROI improvement drivers and equally important in which situations they are not. Furthermore, we apply this model using data from several Dutch business sectors. This gives an overview of the ROI improvement drivers per sector depending on the characteristics of the companies within that sector. In addition, we developed a DSS that shows ROI improvement drivers for a company specific situation.

3.2 The ROI model

ROI is commonly defined as the net income divided by invested assets. As we focus on purchasing, we will focus on income of main business activities. Therefore, we will only consider the income from operations and we will not consider other financial income and taxes.

The income from operations equals turnover T minus all costs involved. We split these costs in personnel costs (salaries), direct purchasing spend and NPR purchasing spend. We assume the direct spend to be proportional to the turnover with factor p_{dir} and the NPR spend proportional to the number of employees with factor p_{npr}. Furthermore, we assume employees either to be directly involved in the production process (direct employees) or indirectly involved (indirect employees E_{ind}). The number of direct employees is again assumed to be proportional to the turnover, which is similar to assuming that the direct employees have a fixed productivity w. Hence the total number of employees E_{tot} can be written as:

$$E_{tot} = \frac{T}{w} + E_{ind} \tag{3.1}$$

Although we distinguish between direct and indirect employees, we do assume for both groups the same average salary per employee s and the same NPR spend per employee p_{npr}.

Table 3.1: *Parameters of the ROI model*

Parameter	**Explanation**
T	Turnover
p_{dir}	Direct purchasing spend as a percentage of turnover
p_{npr}	NPR purchasing spend per employee
s	Average salary per employee
w	Turnover per direct employee (productivity)
E_{ind}	Number of indirect employees
I_f	Fixed assets
i_v	Current assets as a percentage of turnover

For the investments (assets) we assume they can be split up into two parts: fixed investments I_f and variable investments. The variable investments such as stock, cash or equivalent, and trade receivables are assumed to be proportional to the turnover with factor i_v. Hence the total investments I_{tot} can be written as:

$$I_{tot} = I_f + i_v \cdot T \tag{3.2}$$

These assumptions lead to the following formula for the ROI:

$$ROI = \frac{T \cdot \left(1 - p_{dir} - \frac{p_{npr} + s}{w}\right) - E_{ind} \cdot \left(p_{npr} + s\right)}{I_f + i_v \cdot T} \tag{3.3}$$

An overview of the parameters has been given in Table 3.1. All parameters except for ROI itself are assumed to be greater than or equal to zero. Because the ROI depends on the parameters, each parameter itself is a ROI improvement driver; each parameter can be either increased or decreased to improve ROI.

3.3 A graphical interpretation: the ROI sector plot

For companies in a certain business sector several parameters of the ROI model usually are very similar. As the business processes of different companies within a sector have a high resemblance, investments, productivity, salaries and the purchasing parameters will typically be similar. Assuming I_f, i_v, w, s, p_{dir}, and p_{npr} to be constant, a plot can be constructed with the ROI as a function of the turnover per employee. For the remainder of this paper we will refer to such a plot as a ROI sector plot or simply sector plot.

A generic example of such a plot can be seen in Figure 3.1. We will explain a few aspects in more detail. First of all, in this plot different lines can be drawn for companies of different size. One can see that two companies with the same turnover per employee can have a different ROI, depending on the turnover itself and as a consequence the number of employees of the company. A second observation is that the (theoretical) maximum turnover per employee that can be achieved is *w*, which simply implies that the maximum is a situation in which there are no indirect employees, only direct employees.

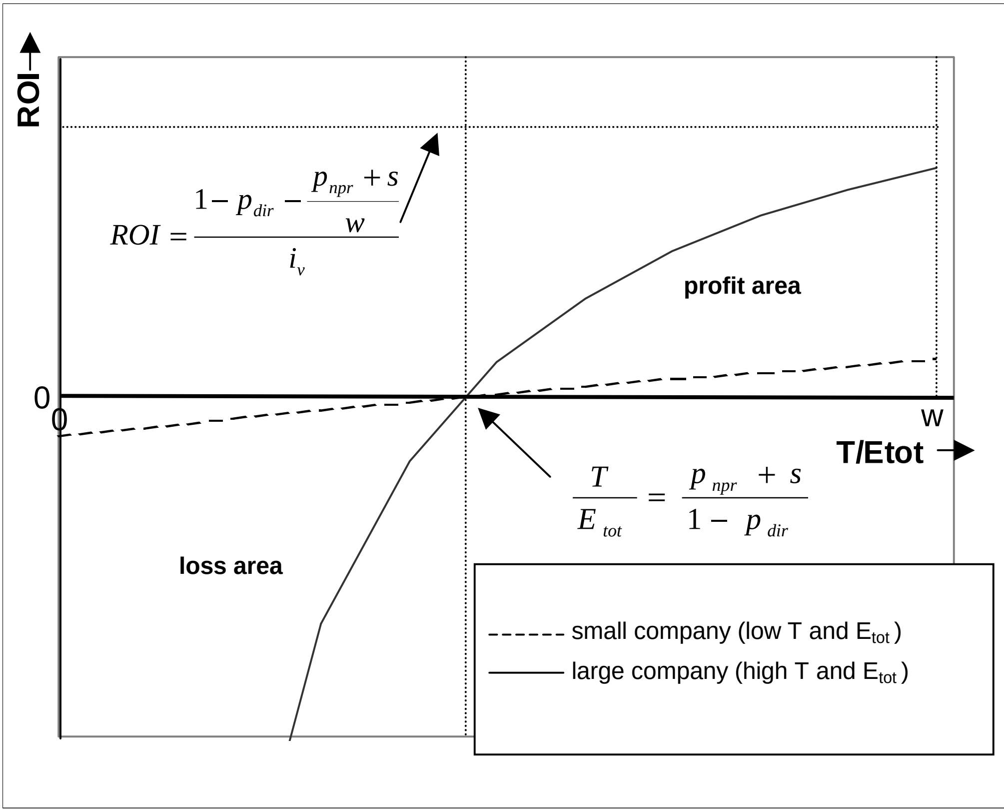
Looking at the point for which ROI equals zero one can see it is the same for all companies. It can easily be shown using (3.1) and (3.3) that:

$$\left(\frac{T}{E_{tot}}\right)_{ROI=0} = \frac{p_{npr} + s}{1 - p_{dir}} \tag{3.4}$$

The value of (3.4) only depends on parameters which have been assumed constants for a sector. Hence it applies to all companies within the sector Furthermore, assuming the value of (3.4) is smaller than w implies that:

$$\frac{p_{npr} + s}{1 - p_{dir}} < w \Leftrightarrow 1 - p_{dir} - \frac{p_{npr} + s}{w} > 0 \tag{3.5}$$

Figure 3.1: *Return on investment as a function of the turnover per employee for companies of different size (ROI sector plot).*



From (3.3) one can see that (3.5) implies having a positive margin on each unit of turnover, i.e. the price is higher than the direct purchasing costs and the costs related to the direct employees for each unit produced. If (3.5) does not hold, then the main business process is unprofitable even with zero indirect costs. Also, the profit area in Figure 3.1 does not exist in this case.

Furthermore, it is interesting to look at the minimum and maximum ROI possible for a company. The minimum ROI occurs when the turnover per employee is zero, meaning there is no turnover, hence there are no direct employees, only indirect ones:

$$ROI_{\min} = -\frac{(p_{npr} + s) \cdot E_{tot}}{I_f} \tag{3.6}$$

The maximum occurs when the turnover per employee equals *w*, meaning as mentioned above that there are no indirect employees:

$$ROI_{\max} = \frac{T \cdot \left(1 - p_{dir} - \dfrac{p_{npr} + s}{w}\right)}{I_f + i_v \cdot T} \tag{3.7}$$

Theoretically, when the turnover goes to infinity – having a very large company – the maximum ROI that can be achieved is:

$$\lim_{T \to +\infty} ROI_{\max} = \frac{1 - p_{dir} - \dfrac{p_{npr} + s}{w}}{i_v} \tag{3.8}$$

This upper bound has also been indicated in Figure 3.1. There is no lower bound for the ROI, because the ROI can basically go to minus infinity when the number of employees becomes infinitely large.

Finally, two specific areas can be defined in Figure 3.1: a profit area in the upper right corner and a loss area in the lower left corner. This is, because ROI is always increasing with increasing turnover per employee and all company lines have zero ROI at the same turnover per employee.

Companies within a sector can now position themselves in a ROI sector plot. But more importantly ROI improvement drivers can be related to this sector plot. For each position the dominant ROI improvement driver can be calculated. The next section analyses when the purchasing parameters p_{dir} and p_{npr} are relatively more important than the other parameters.

3.4 Analyzing the importance of purchasing on ROI improvement

As said earlier, ROI improvement can be achieved by changing the parameters in Table 3.1. In a short period it is unlikely that parameters can be changed very radically, but by focusing on one parameter it may be possible to change it a few percent. We will analyze small changes in parameters only.

How to relate changes of different parameters to each other? A change of one percent for each parameter in the right direction has a different effect on ROI for each parameter. At first it may seem the best thing to take the parameter that gives the most ROI improvement, when considering for each parameter a one percent change. However, when it takes a huge effort (costs) to achieve this change compared to the effort it takes to change other parameters, it may turn out not to be the best choice after all.

In this section we focus on comparing the ROI improvement for parameters when applying the same small relative changes to them. We assume such a change for each parameter takes equal effort, an assumption which as mentioned above does not always hold.

Because purchasing has our particular interest we will have a pair wise comparison of p_{dir} and p_{npr} with the other six parameters and with each other. We want to know under which conditions the same relative change in parameter A has a higher effect on the ROI than parameter B. We consider parameter changes to be conducted in the direction (either increase or decrease) that increases the ROI. We have to examine the following inequality:

$$\frac{\Delta ROI}{\Delta A / A} > \frac{\Delta ROI}{\Delta B / B} \tag{3.9}$$

Assuming these changes are small enough (3.9) can be approximated by using first derivatives:

$$\left|\frac{\partial ROI}{\partial A}\right| \cdot A > \left|\frac{\partial ROI}{\partial B}\right| \cdot B \tag{3.10}$$

The absolute value of the derivative is taken, because when the derivative is negative, a change in the opposite direction is considered in order to have a positive ROI change.

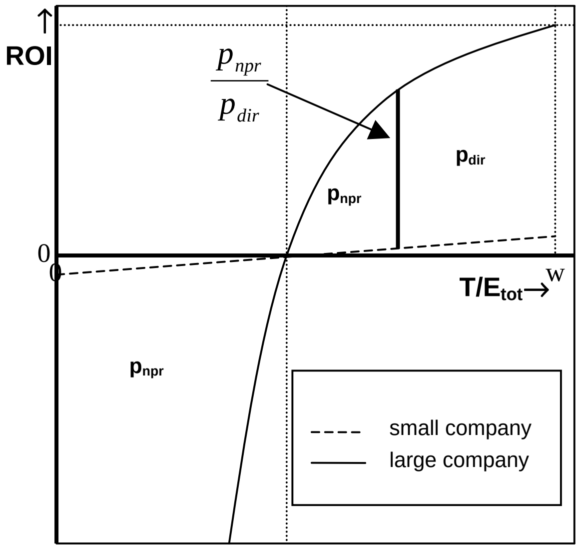
Below we give the results of the pair wise comparison. We discuss the analysis of the first comparison in more detail. For the other analyses we only state the results, because the analysis is very similar.

Comparing the purchasing parameters

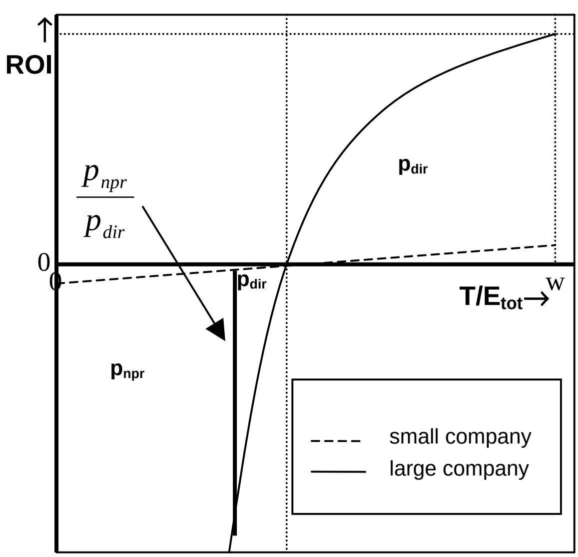
We will first examine when p_{dir} has a higher effect than p_{npr}. Using (3.10) we can derive the following:

$$\left|\frac{\partial ROI}{\partial p_{dir}}\right| \cdot p_{dir} > \left|\frac{\partial ROI}{\partial p_{npr}}\right| \cdot p_{npr} \Leftrightarrow$$

Figure 3.2: *Comparing p_{dir} and p_{npr}*



$$\boxed{p_{dir} < \frac{1}{2 + s/p_{npr}}}$$



$$\boxed{p_{dir} > \frac{1}{2 + s/p_{npr}}}$$

$$\frac{T}{I_f + i_v \cdot T} \cdot p_{dir} > \frac{E_{tot}}{I_f + i_v \cdot T} \cdot p_{npr} \Leftrightarrow \frac{T}{E_{tot}} > \frac{p_{npr}}{p_{dir}} \tag{3.11}$$

This condition can be used to indicate in the ROI sector plot where p_{dir} has the highest effect and similarly where p_{npr} has the highest effect (see Figure 3.2). Depending on the ratio of p_{dir} and p_{npr} the vertical division line between the p_{dir} and p_{npr} area could be in the profit or loss area (left or right side of Figure 3.2). When this line is located in the loss area (to the left side of the zero ROI point) the following holds:

$$\frac{p_{npr}}{p_{dir}} < \frac{p_{npr} + s}{1 - p_{dir}} \Leftrightarrow p_{dir} > \frac{1}{2 + {s}/{p_{npr}}} \tag{3.12}$$

In addition, the ratio of p_{dir} and p_{npr} has to be smaller than w; otherwise p_{npr} would always have a higher effect than p_{dir}.

What (3.12) also shows, is that for a profitable company (ROI > 0) it is *always* better to focus on p_{dir} than p_{npr}, if p_{dir} is larger than 50%. For smaller values of p_{dir} this could still be the case, but it depends on the ratio of the salary and NPR spend per employee. If p_{dir} is even smaller than the ratio of p_{npr} and w, then it is always better to focus on p_{npr}, even for a non-profitable company. Typically, p_{dir} will then be smaller than 10%.

Comparison with the average salary

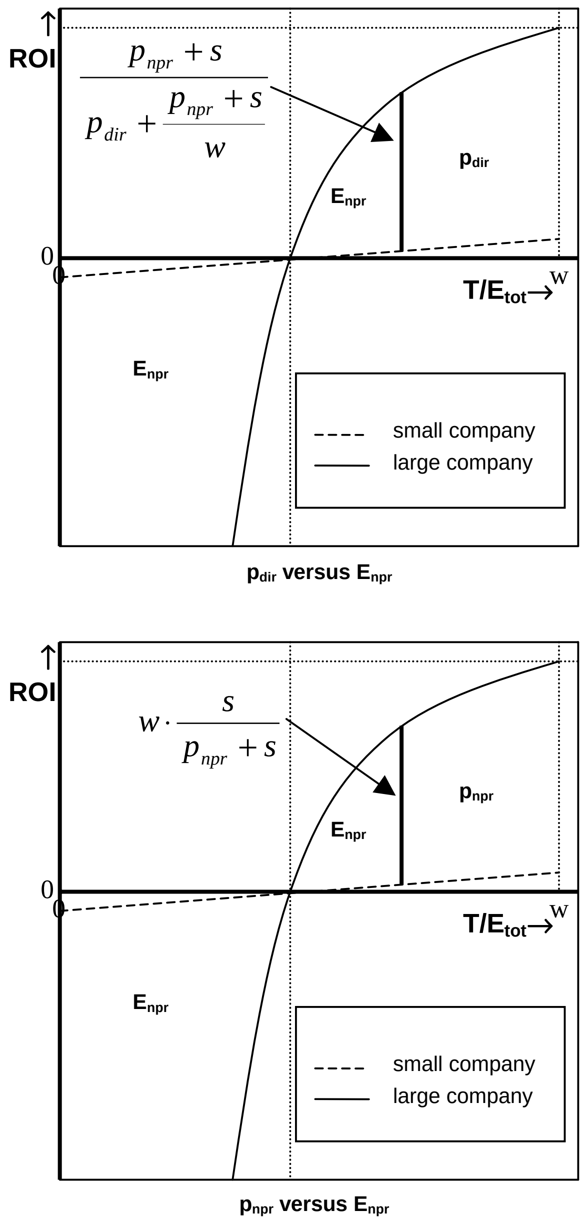
Because the average salary s and p_{npr} always appear as a sum in (3.3), the result for p_{dir} versus s is the same as above replacing p_{npr} with s and vice versa. Hence, Figure 3.2 holds here as well, but (3.11) changes to:

$$\frac{T}{E_{tot}} > \frac{s}{p_{dir}} \tag{3.13}$$

In addition, (3.12) changes to:

$$p_{dir} > \frac{1}{2 + {p_{npr}}/{s}} \tag{3.14}$$

Figure 3.3: *Comparing the purchasing parameters with E_{npr}*



When comparing p_{npr} with s, it simply boils down to comparing the values of both parameters, again because they appear as a sum in (3.3). The parameter with the highest value always has the highest impact on ROI for the entire ROI sector plot.

Similar to the previous comparison we can conclude that for a profitable company (ROI > 0) it is *always* better to focus on p_{dir} than s, if p_{dir} is larger than 50%. For smaller values of p_{dir} this could still be the case, but it depends on the ratio of the NPR spend and salary per employee. If p_{dir} is even smaller than the ratio of s and w then it is always better to focus on s. Again, p_{dir} will then typically be smaller than 10%.

Comparison with the number of indirect employees

Comparing p_{dir} to the number of indirect employees (E_{npr}) also turns out to be very similar to comparing p_{dir} to p_{npr}; p_{dir} has a larger impact on ROI than E_{npr} when:

$$\frac{T}{E_{tot}} > \frac{p_{npr} + s}{p_{dir} + \dfrac{p_{npr} + s}{w}} \tag{3.15}$$

For p_{npr} the impact on ROI is larger than for E_{npr} when:

$$\frac{T}{E_{tot}} > w \frac{s}{p_{npr} + s} \tag{3.16}$$

Figure 3.3 shows the effect in the sector plot. The vertical borderline can also be located in the loss area depending on the parameter values similar to Figure 3.2.

Again, if p_{dir} is larger than 50% it is *always* better for a profitable company to focus on p_{dir} than $E_{npr.}$ Clearly, when there are hardly any direct employees, it is always better to focus on E_{npr} than p_{npr}, because firing indirect employees also reduces the salary costs. Otherwise, the focus depends on the trade-off between the indirect spend of direct employees and the salaries of indirect employees.

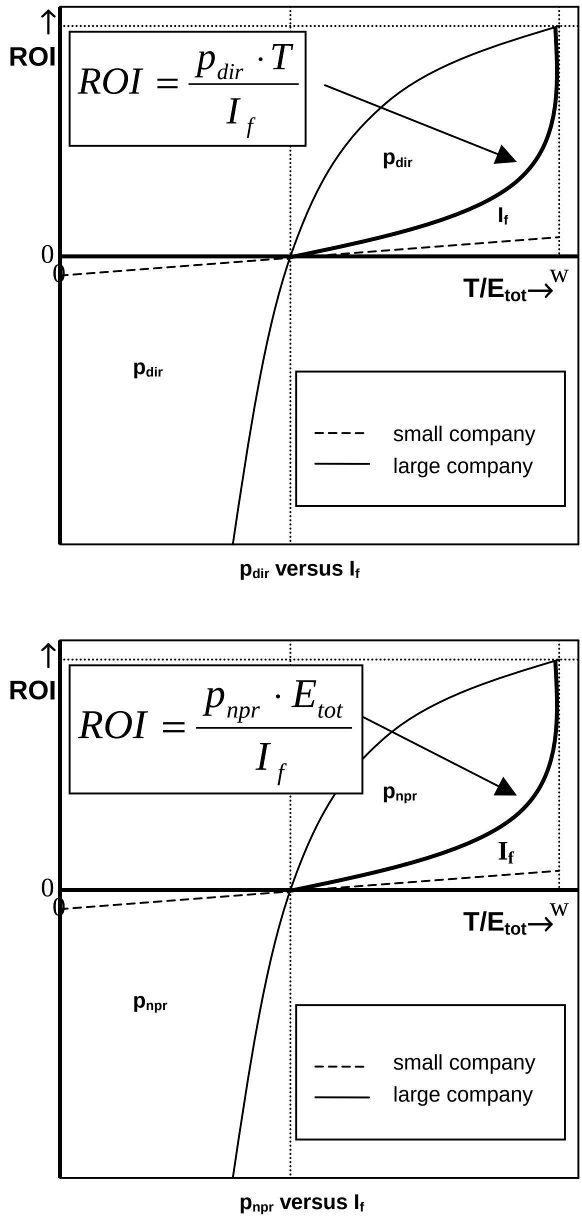
Comparison with the investment parameters

Now we will focus on the purchasing parameters versus the investment parameters. Before comparing it is important to notice the special character of the partial first derivatives of the investment parameters:

$$\frac{\partial ROI}{\partial I_f} = -\frac{ROI}{I_f + i_v \cdot T} \tag{3.17}$$

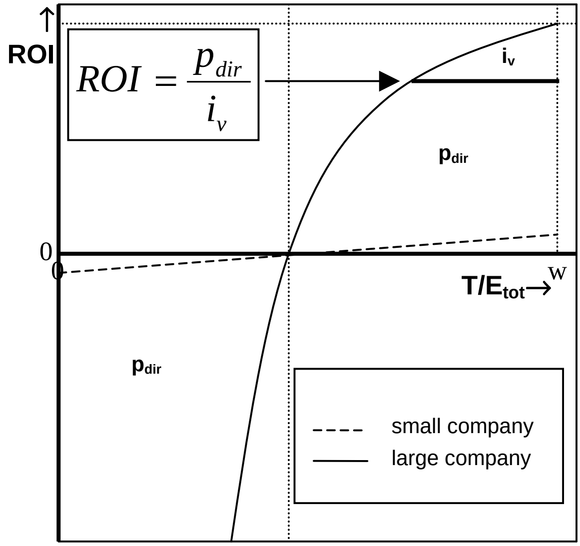
$$\frac{\partial ROI}{\partial i_v} = -\frac{ROI \cdot T}{I_f + i_v \cdot T} \tag{3.18}$$

Figure 3.4: *Comparing the purchasing and investment parameters*

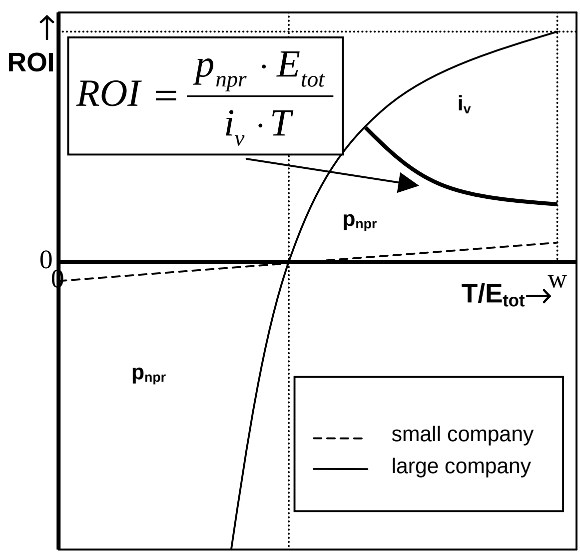


The derivatives are negative for positive ROI and positive for negative ROI. This implies decreasing assets to increase an already positive ROI. However, it also implies increasing assets to make ROI less negative. The last effect is clearly not

Figure 3.4: *(continued)*



p_{dir} versus i_v



p_{npr} versus i_v

desirable. It is like cutting your losses from 20% to 10% by doubling your investments. It may look nicer but the loss in absolute number does not change. It is only worthwhile to do so, when these investments cause a fundamental change in the business process, hence changing one or more of the parameters we assumed constant. These radical changes are outside of our scope of analysis. Therefore, we only look at the effect of the investment parameters for positive ROI.

Considering only positive ROI the results of the analysis are:

- p_{dir} dominates I_f if $ROI < \frac{p_{dir} \cdot T}{I_f}$ (3.19)
- p_{npr} dominates I_f if $ROI < \frac{p_{npr} \cdot E_{tot}}{I_f}$ (3.20)
- p_{dir} dominates i_v if $ROI < \frac{p_{dir}}{i_v}$ (3.21)
- p_{npr} dominates i_v if $ROI < \frac{p_{npr}}{i_v} \cdot \frac{E_{tot}}{T}$ (3.22)

The implications for the sector plot can be seen in Figure 3.4. As we saw in Figure 3.2 and Figure 3.3, the actual location of the borderline differs depending on the parameter values, but the shape remains similar.

As we will see later, it turns out that for realistic values I_f and i_v are always dominated by either p_{npr}, p_{dir} or w. For immediate ROI improvement the investment parameters do not play an important role. However, when investments are used for more fundamental changes in the business process as mentioned above, they too can have a major impact.

Comparison with the productivity per direct employee

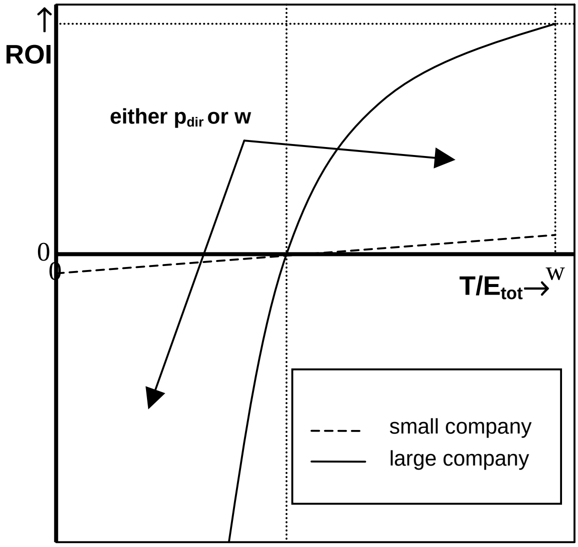
The next parameter we compare the purchasing parameters to is the productivity of the direct employees w. We find that p_{dir} has a higher impact on ROI than w when:

$$p_{dir} > \frac{p_{npr} + s}{w} \tag{3.23}$$

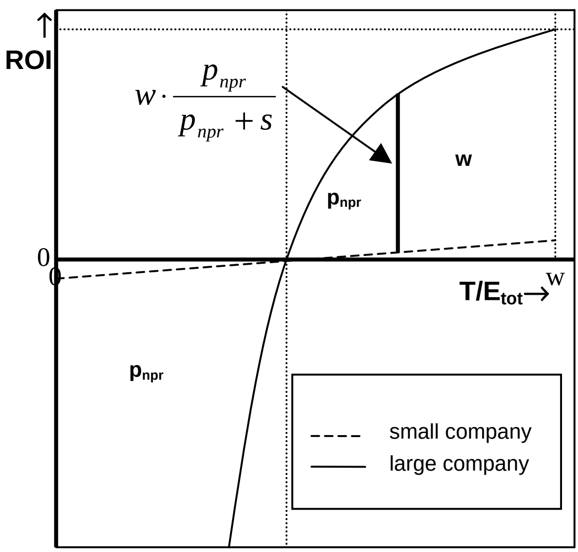
In this inequality ROI, T and E_{tot} do not play a role. Therefore, for the entire sector plot it is either w or p_{dir} that has the highest impact on ROI. For p_{npr} versus w an inequality similar to (3.16) arises:

$$\frac{T}{E_{tot}} < w \frac{p_{npr}}{p_{npr} + s} \tag{3.24}$$

Figure 3.5: *Comparing the purchasing parameters with productivity*



p_{dir} versus w



p_{npr} versus w

Figure 3.5 visualizes the results in the sector plot. The higher the salaries are compared to the indirect spend, the more important the productivity will be.

Comparison with turnover

Last but not least is the comparison of the purchasing parameters with turnover T. The calculation is somewhat more complicated than the previous ones. Therefore, we will elaborate a bit more on it. p_{dir} has a higher impact on ROI than T when:

$$\frac{T}{E_{tot}} > \frac{I_f}{i_v \cdot E_{tot}} \cdot \frac{1 - 2p_{dir} - \frac{p_{npr} + s}{w}}{p_{dir} + \frac{p_{npr} + s}{w}} + \frac{p_{npr} + s}{p_{dir} + \frac{p_{npr} + s}{w}} \tag{3.25}$$

The first term in (3.25) can be either positive or negative. This term is positive when:

$$1 - 2p_{dir} - \frac{p_{npr} + s}{w} > 0 \Leftrightarrow p_{dir} > \frac{1}{2} - \frac{p_{npr} + s}{2w} \tag{3.26}$$

Otherwise the term is negative (or zero). When E_{tot} becomes very large the first term becomes negligible. Then (3.25) is approximately:

$$\frac{T}{E_{tot}} > \frac{p_{npr} + s}{p_{dir} + \frac{p_{npr} + s}{w}} \tag{3.27}$$

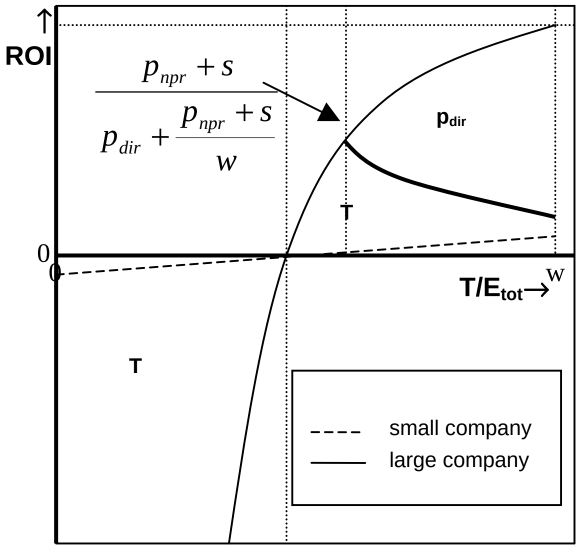
The rhs of (3.27) can be either in the profit or loss area. For it to be in the profit area the following must hold:

$$\frac{p_{npr} + s}{1 - p_{dir}} < \frac{p_{npr} + s}{p_{dir} + \frac{p_{npr} + s}{w}} \Leftrightarrow p_{dir} < \frac{1}{2} - \frac{p_{npr} + s}{2w} \tag{3.28}$$

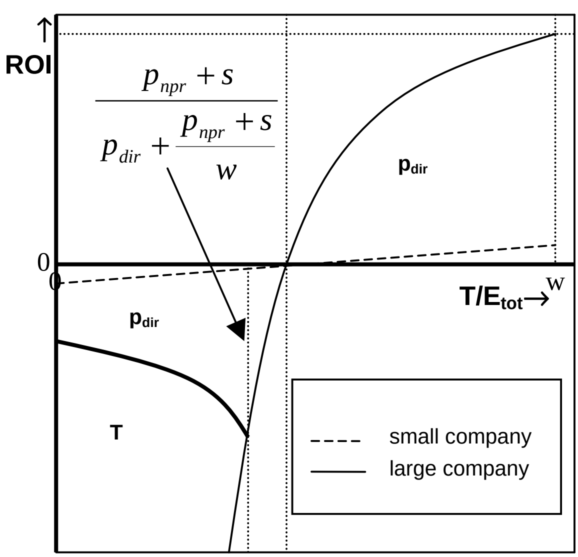
This is the same inequality as (3.26). Summarizing, if (23.6) holds then the rhs of (3.27) is in the profit area and the first term of (3.25) is positive. Otherwise the rhs of (3.27) is in the loss area and the first term of (3.25) is negative. The implications for the sector plot can be seen in Figure 3.6. It is clear that p_{dir} will always have a higher impact for a profitable company when its value exceeds 50%. Otherwise, it depends on other parameters as shown in the formulas above.

Calculating the condition under which p_{npr} has a higher impact on ROI gives:

Figure 3.6: *Comparing p_{dir} and T*



$$p_{dir} < \frac{1}{2} - \frac{p_{npr}+s}{2w}$$



$$p_{dir} > \frac{1}{2} - \frac{p_{npr}+s}{2w}$$

$$\frac{i_v \cdot (p_{npr} + s)}{w}\left(\frac{T}{E_{tot}}\right)^2 - \left(\frac{I_f}{E_{tot}}\left(1 - p_{dir} - \frac{p_{npr} + s}{w}\right) + i_v \cdot s\right)\frac{T}{E_{tot}} + \frac{I_f \cdot p_{npr}}{E_{tot}} > 0 \tag{3.29}$$

Replacing a few parameters which are taken constant in the sector plot we have an inequality of the type:

$$a\left(\frac{T}{E_{tot}}\right)^2 - \left(\frac{b_1}{E_{tot}} + b_2\right)\frac{T}{E_{tot}} + \frac{c}{E_{tot}} > 0 \tag{3.30}$$

The lhs is quadratic and if (3.30) has two zero values, p_{npr} dominates on the left side of the smallest zero value and on the right side of the largest one.
The lhs is quadratic and has two zero values only when:

$$\left(\frac{b_1}{E_{tot}} + b_2\right)^2 - 4\frac{a \cdot c}{E_{tot}} > 0 \tag{3.31}$$

This is true for each E_{tot} when the minimum of the lhs of (3.31) is positive. The minimum occurs when:

$$E_{tot} = \frac{b_1^{\ 2}}{2ac - b_1 b_2} \tag{3.32}$$

Using (3.32) in (3.31) lead to a strictly positive lhs for all E_{tot} when:

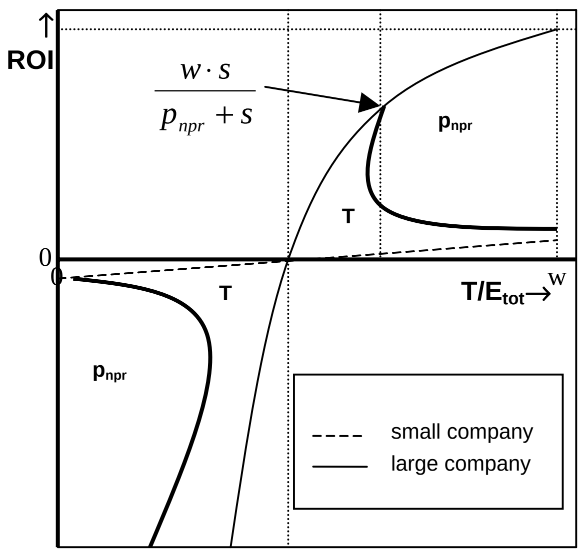
$$b_1 b_2 > ac \Leftrightarrow p_{dir} < 1 - \frac{(p_{npr} + s)^2}{s \cdot w} \tag{3.33}$$

Furthermore, if E_{tot} is very small, (3.29) is approximately:

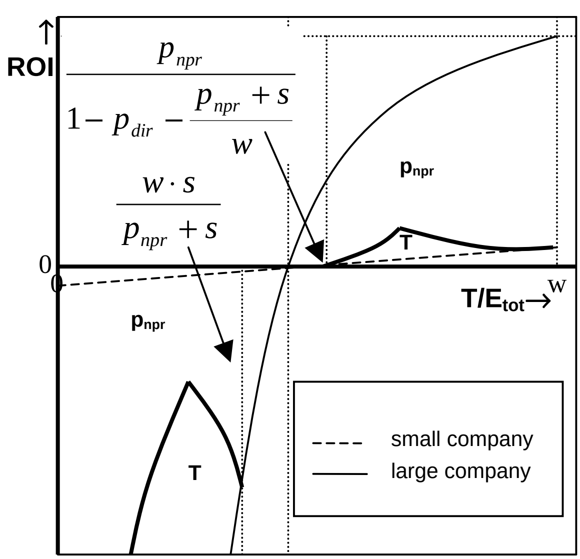
$$\frac{T}{E_{tot}} < \frac{p_{npr}}{1 - p_{dir} - \dfrac{p_{npr} + s}{w}} \tag{3.34}$$

Similarly, if E_{tot} is very large, (3.29) is approximately:

Figure 3.7: *Comparing p_{npr} and T*



$$p_{dir} < 1 - \frac{\left(p_{npr} + s\right)^2}{s \cdot w}$$



$$p_{dir} > 1 - \frac{\left(p_{npr} + s\right)^2}{s \cdot w}$$

$$\frac{i_v \cdot (p_{npr} + s)}{w}\left(\frac{T}{E_{tot}}\right)^2 - (i_v \cdot s)\frac{T}{E_{tot}} > 0 \Leftrightarrow \frac{T}{E_{tot}} < 0 \vee \frac{T}{E_{tot}} > \frac{w \cdot s}{p_{npr} + s} \tag{3.35}$$

Checking when the last inequality of (3.35) is in the profit area leads to:

$$\frac{p_{npr} + s}{1 - p_{dir}} < \frac{w \cdot s}{p_{npr} + s} \Leftrightarrow p_{dir} < 1 - \frac{(p_{npr} + s)^2}{s \cdot w} \tag{3.36}$$

Plotting this in these results in the sector chart results in Figure 3.7. In general it appears that focusing on p_{npr} worthwhile when the ROI is either very negative or very positive. This can be explained as follows. Naturally when the ROI is getting higher and higher, the effect of increasing turnover is decreasing. The indirect spend is increasing with turnover (because of the extra employees needed) and at a certain point it will become more important to focus on the indirect spend than turnover. For very negative ROI the turnover is minimal and hence it will remain minimal when increased by a few percent. Reducing the indirect spend by a few percent immediately cuts down costs and therefore it has a higher effect. In between these "extreme" areas turnover has the largest effect on ROI.

Using the pair wise comparison we will now be able to analyze entire business sectors. We can now produce a sector plot of each one of them and we illustrate this in the next section.

3.5 Sector analysis

As mentioned in section 3.3, we assume that companies have similar I_f, i_v, w, s, p_{dir}, and p_{npr} in a particular sector. Hence, a sector can be characterized by the real values of these six parameters. To know where to focus for ROI improvement, an overlay of the different pair-wise comparisons of parameters can be made. This leads to a sector plot with areas for which one parameter is most important.

To illustrate the approach we have calculated sector plots for a number of sectors in the Netherlands. We have used real data from the CBS (Central Statistics Office Netherlands). The CBS gathers information about Dutch society among which profit and loss statements and balance sheets of Dutch companies for most sectors. We have used data from the most recent available year, 1999. The following available average values per sector have been used:

- turnover per company
- number of full time employees per company
- salary per full time employee
- tangible and intangible fixed assets

- current assets split up in stock, cash or equivalent and trade receivables
- direct spend
- amortization and other costs

The six parameters were calculated from the CBS. For the fixed investments the sum of the tangible and intangible assets were taken. The i_v was calculated by dividing the current assets by the turnover. The average salary needed no calculation. For p_{dir} the direct spend was divided by the turnover. The p_{npr} was calculated by dividing the amortization and other costs by the number of employees. Calculating the productivity proved to be the most difficult, because no data is available on which percentage of the total number of employees are indirect employees. For the purpose of the illustration we took this percentage to be 25%, a realistic value in our opinion.

Table 3.2 shows the six parameter values for a number of business sectors. From Table 3.2 we have chosen four sectors to illustrate the sector plot: paper industry, construction, restaurants and consultancy firms. The other sectors have sector plots similar to one of the four chosen sectors.

Table 3.2: *CBS data from several Dutch sectors (sector averages from 1999)*

Sector	**I_f**	**i_v**	**p_{dir}**	**p_{npr}**	**s**	**w**
	mln €		**%**	**1000 €**	**1000 €**	**1000 €**
Industry						
Chemical industry	14.53	0.41	59.9	100.2	52.1	591
Food producers	6.65	0.40	69.5	45.8	37.6	421
Paper industry	9.84	0.33	52.1	43.6	41.6	274
Publishers	1.33	0.32	41.3	33.1	42.7	230
Metal (basic)	1.76	0.38	41.1	63.1	44.0	256
Metal products	1.56	0.36	49.5	21.6	35.0	172
Machinery	1.13	0.45	54.0	24.7	39.2	211
Construction	0.50	0.30	58.0	18.4	33.0	179
Textile industry	0.72	0.45	54.8	27.8	33.6	214
Transportation manufacturers	2.87	0.26	66.1	30.5	40.5	313
Retail						
Gas stations	0.96	0.24	89.7	38.8	27.6	1015
Supermarkets	0.64	0.21	76.8	17.8	19.9	239
Restaurants	0.92	0.30	34.4	26.6	20.5	115
Services						
Consultancy firms	0.27	0.38	13.0	34.4	51.7	176
Cleaning services	0.54	0.38	11.5	4.6	20.3	42

Figure 3.8: *ROI sector plot for the paper industry*

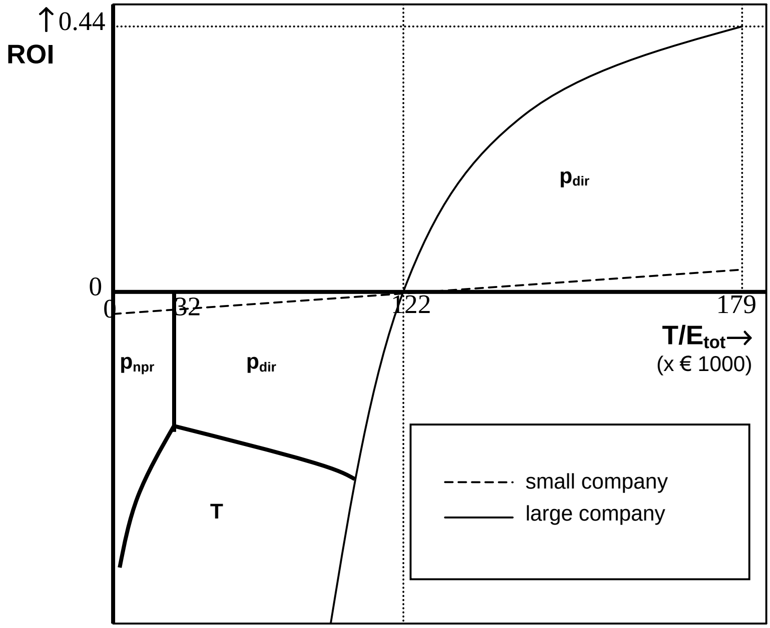


Figure 3.9: *ROI sector plot for the construction sector*

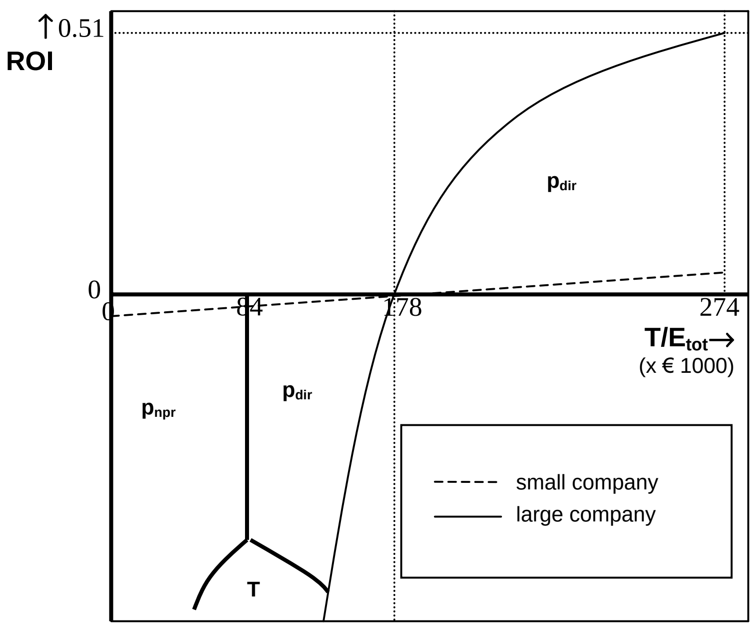


Figure 3.10: *ROI sector plot for restaurants*

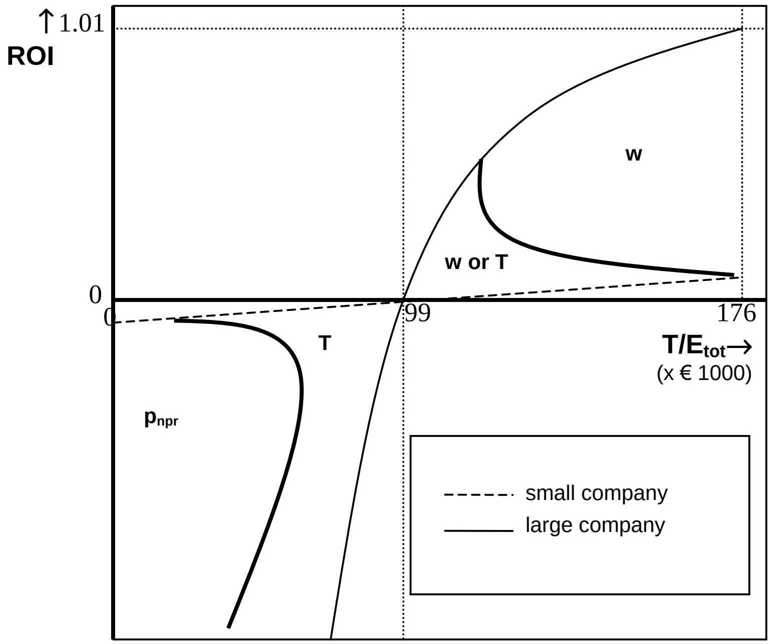
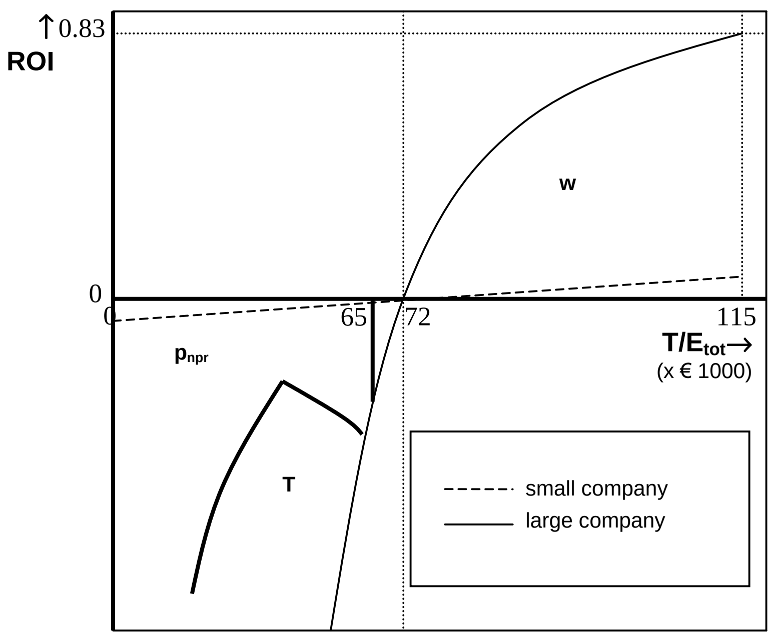


Figure 3.11: *ROI sector plot for consultancy firms*



The factors E_{npr} and s have been excluded as parameters in the sector plot. From a practical point of view, it is not so easy to decrease salaries and to fire people (reducing s and E_{npr}). Stated analytically, the effort to change these parameters will be very high compared to the other parameters. Hence, improving ROI through these parameters will not emerge from models that take this into account.

The four illustrative sector plots can be viewed in Figures 3.8 to 3.11. The paper industry (Figure 3.8) and the construction sector (Figure 3.9) serve as an example for the entire industrial sector. Naturally with a direct spend of more than 50% of turnover, it seems an important factor. As it turns out, for profitable companies in the industrial sector direct purchasing is indeed the most important profit improvement driver. Only when a company has heavy losses the turnover and the NPR purchasing should be focused upon.

The restaurants and consultancy firms represent sectors in which the direct purchasing spend is much lower. As indicated in Figure 3.10 and 3.11 for profitable companies the focus should be mainly on productivity and partly on turnover for consultancy firms. Similar to the industrial sector when a company has losses, focusing on turnover and NPR spend is most important for improving ROI.

In the four sector plots no areas have been indicated in which investment parameters are most important. Although they were taken into consideration, for I_f the area was negligible and for i_v in all figures no area exists in which it is the most important ROI driver. This is not necessarily the case, but using the real values of Table 3.2 it is. This led to the earlier remark in section 3.4 regarding the investment parameters that apparently they are not very important for immediate ROI improvement.

Finally, we go back to an assumption we made earlier. We assumed for each parameter that changing it by a certain (small) percentage takes equal effort. This assumption determines the borderlines of each area in the sector plot. This can easily be generalized. For example, perhaps it is reasonable to assume that changing one parameter by one percent takes an equal effort as changing another parameter by two. This of course changes the segmentation of the sector plot. Parameters that require more effort are less interesting to focus and those areas are reduced in favor of other parameters that require less effort.

We have taken this into account when just considering an individual company.

3.6 A DSS for individual companies

How can the pair wise comparisons and the sector plot be used for an individual company? The goal of both the comparisons and the sector plots was to show an individual company where it should focus on for ROI improvement.

To get an idea of this focus taking a look at the sector plot for the sector in which the company resides can be very useful. Naturally, for more in-depth insights a company has to perform calculations based on its own key figures. As shown in the previous section, these calculations may take some effort. Hence, to facilitate this investigation for an individual company we developed a decision support system called ROImprove.

Figure 3.12: *Screenshots of the DSS ROImprove*

Input variables (in yellow) and calculated variables (in green)	Current situation		Changes in %	Changes in absolute figures	Results		Changes in %
Currency	Euro						
Turnover	8,000,000	Euro			8,000,000	Euro	0.00%
Fixed assets	10,000,000	Euro			10,000,000	Euro	0.00%
Current assets per unit turnover	0.1000				0.1000		0.00%
Current assets (invested)	800,000	Euro			800,000	Euro	0.00%
Total assets (invested)	10,800,000	Euro			10,800,000	Euro	0.00%
Non Product Related purchase spend per employee	30,000	Euro	-5		28,500	Euro	-5.00%
Total Non Product Related purchase spend	780,000	Euro			741,000	Euro	-5.00%
Direct purchase spend as a % of turnover	50.00				50.00		0.00%
Total direct purchase spend	4,000,000	Euro			4,000,000	Euro	0.00%
Total purchase spend	4,780,000	Euro			4,741,000	Euro	-0.82%
Turnover per direct employee (productivity)	500,000				500,000		0.00%
Number of direct employees	16.00				16.00		0.00%
Number of indirect employees	10.00				10.00		0.00%
Number of employees	26.00				26.00		0.00%
Average salary per employee	35,000	Euro			35,000	Euro	0.00%
Total personnel costs	910,000	Euro			910,000	Euro	0.00%
Total expenses	5,690,000	Euro			5,651,000	Euro	-0.69%
Profit	2,310,000	Euro			2,349,000	Euro	1.69%
Return on investment	0.21				0.22		1.69%

ROI Improvement drivers	First derivative	Percent change	Increase / decrease	New ROI	ROI change in %
Turnover	3.23E-08	1.00	Increase	0.2165	1.21
Fixed assets	-1.98E-08	1.00	Decrease	0.2159	0.93
Current assets per unit turnover	-1.58E-01	1.00	Decrease	0.2140	0.07
Non Product Related purchase spend per employee	-2.41E-06	3.00	Decrease	0.2161	1.01
Direct purchase spend as a % of turnover	-7.41E-01	1.00	Decrease	0.2176	1.73
Turnover per direct employee (productivity)	1.93E-07	1.00	Increase	0.2149	0.45
Number of indirect employees	-6.02E-03	1.00	Decrease	0.2145	0.28
Average salary per employee	-2.41E-06	1.00	Decrease	0.2147	0.39

ROImprove is a spreadsheet that shows the impact of all key parameters on ROI using these company specific key parameters as input. Figure 3.12 shows a screenshot. Not only does ROImprove perform the calculations, but it also provides some extra advantages:

- calculation of the effect when applying multiple changes in different parameters at once
- allows for the input of expected difference in effort for changing various parameters

The upper screenshot of Figure 3.12 shows a sheet with the current situation in the second column with the input in yellow and the calculated parameters in green. With this input, scenarios can be investigated such as reducing the NPR spend per employee by five percent, leading to an increase in ROI by 1.69% as indicated in the screenshot. But also the effect of multiple parameter changes calculated automatically, like including also a three percent change in turnover at the same time for instance.

The lower screenshot shows the relative importance of the key parameters on ROI based on the current situation. It shows (and calculates) based on the input of the upper screenshot what effect a one percent change in the "right" direction has on ROI. Hence, here it would be best to focus on p_{dir}.

In addition the expected difference in effort can be included here. If one feels changing one parameter requires less effort than another then the percent change that is being compared can be changed. In the screenshot a three percent change in the NPR spend per employee is being compared to one percent changes in the other parameters. Hence, it is assumed that changing the NPR spend takes three times less effort.

In this way ROImprove can be used as a management tool for setting priorities for an individual company.

3.7 Conclusions

In this paper we aimed to shed more light on the relative importance of major parameters that influence ROI with a particular focus on purchasing. We aimed to shed light both from a theoretical and a practical perspective.

From the theoretical perspective, we analyzed the Du Pont formula, which we extended to incorporate direct and indirect purchasing in more detail. Using pair wise comparison of the key parameters conditions have been derived for which one parameter has a higher effect on ROI than the other.

From the practical perspective, we developed the ROI sector plot to visualize sector characteristics including the relative importance of parameters affecting ROI. Using the knowledge gained from the theoretical analysis and real data from the CBS database we have been able to show what realistic sector plots would look like. For individual companies we incorporated the extended Du Pont model into a DSS called ROImprove. We think that this contributes to the decision making of managers in companies for setting priorities for ROI improvement.

Obviously, the complete analysis has been limited to the specific Du Pont model that we have considered. A company's cost structure could be somewhat different, like having NPR spend not proportional to the number of employees, heaving different average salaries for direct and indirect employees, splitting up costs in more detail, etc. However, even with all these changes and additions in the model still a similar analysis can be conducted.

An interesting subject for further investigation would be the relative effort of making changes in the key parameters. Empirical research could provide valuable knowledge on this subject. This could be researched by means of interviews with top managers or surveys.

However, assuming equal effort for all parameters, evidence from Dutch sectors shows that for companies nowadays the focus should be either on reducing their direct spend or on increasing productivity of their employees.

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Chapter 4

Allocating savings in purchasing consortia

a game theoretic analysis

This chapter is partly based on:

Heijboer, G.J., 2002. Allocating savings in purchasing consortia; analysing solutions from a game theoretic perspective. Proceedings of the 11th International Annual IPSERA Conference, 275-287.

While economies of scale are an obvious advantage for a purchasing consortium as a whole, the benefits for one member are not always clear. The allocation of the benefits of joint leverage to the individual members may cause lack of commitment and hesitation to join a consortium. This paper presents an instrument that provides clarity in the allocation of cost savings by modelling a purchasing consortium as a cooperative game. Using this model we analyse how common approaches to this allocation problem fit with game theoretical concepts. As it turns out, all members paying the same price per item is not a fair policy in general. This policy may allocate the largest share of consortium savings to members with the least leverage. Game theoretical concepts like the compromise value overcome this problem.

4.1 Purchasing consortia: common practice, a neglected research topic?

Joining a purchasing consortium (also known as Group Purchasing Organisation or GPO) has obvious advantages. By purchasing goods together lower prices or better service can be obtained from suppliers (economies of scale). In addition, transaction costs can be lowered by bundling orders. Ideally, these cost savings have to outweigh the expenses of setting up and maintaining the consortium for all parties involved (Pye, 1996).

Doucette (1997) showed that for a purchasing consortium to be successful commitment of its members is very important. He showed that this commitment (apart from financial benefits) is mainly influenced by: the perceived commitment of other members, the degree of information exchange and trust. Hence, if from a financial point of view joining a consortium is worthwhile, there may still be hesitation to join. Reasons for this hesitation mentioned by Hendrick (1997) are: anti-trust (legal) issues, disclosure of sensitive information, supplier resistance and the "fear of parasites". The last reason means that a firm does not see the advantage of joining a consortium as it believes it already has a good leverage. Therefore, the (perceived) result of joining would be that the rest of the consortium would benefit parasitically on its leverage. Clarity is the key issue here.

Bearing in mind the pros and cons, what is the occurrence of purchasing consortia in practice? In public sector areas such as health care and education, purchasing consortia are well established (Doucette, 1997). This is also true for the retail sector in Europe (Zentes and Swoboda, 2000), but certainly not for the private sector in general. A recent study of CAPS (Hendrick, 1997) shows that only about one fifth of US companies are members of a purchasing consortium. However, Hendrick's research and other sources (Macie, 1995; Sickinger, 1996; Major 1997) indicate that this percentage is increasing. A survey among small firms in the UK has shown that although hardly any firm now participates in a consortium 74% has a strong interest in joining one (Quayle, 2002).

In the past few decades purchasing consortia received only minor attention in purchasing management research. Analyzing many sources, Essig (1998, 2000) concludes that compared to the interest in vertical (buyer-supplier) relationships, the interest in horizontal relationships (cooperation) between buyers has been neglected. This lack of attention of researchers seems unjustified because of the growing interest by practitioners in the private sector and the existing interest in the public sector. Essig (1998, 2000) also introduces the concept of "consortium sourcing" as an important part of supply strategy and as a framework for further research. He envisages the development of instruments that help supply managers to establish purchasing consortia as a next step.

This paper presents such an instrument. It has been developed by modeling the allocation of cost savings in a purchasing consortium as a cooperative game. Using this cooperative game model we analyze how common approaches to this allocation problem fit with game theoretic concepts. These common approaches include: fixed price per item, allocation proportional to the quantity ordered, equal split. We also analyze the implications of known allocation methods from game theory within the purchasing consortia setting. The model can be used as an instrument with which allocation methods can be chosen, based on underlying properties like purchasing power and added value of participants, coalition stability, etc. The purpose of developing this instrument has been (1) to contribute to the (theoretical) development of purchasing consortia research and (2) to provide clarity in practice for participants, hence increasing commitment and decreasing reluctance to join a purchasing consortium.

The setup of the rest of the paper is as follows. In the next section, a brief introduction to cooperative game theory is given. Section three describes the problem of allocating cost savings in purchasing consortia by modeling it as a cooperative game. In section four, we analyze possible solutions (allocation methods) to the model and their properties. For practical application an example will be given in this section. Applicability issues are discussed in section five. Finally, together with the conclusions we will give some suggestions for further research.

4.2 Introduction to cooperative game theory

Game theory is a mathematical research field that deals with multilateral decision making. Each decision-maker (player) has his own interests and has a number of possible actions open to him. By his actions, each player affects the outcomes for the other players. The foundation of this theory and its application to economic behavior can be found in the book by Von Neumann and Morgenstern (1944). Other areas of application include social sciences (Shubik, 1982), politics (Ordeshook, 1986) and operations research (Curiel, 1997). Game theory can be divided into two fields: non-cooperative (conflicts) and cooperative game theory.

We will restrict ourselves to cooperative game theory (for theoretical background see e.g. Peyton Young, 1985; Driessen, 1988; Shubik, 1992). In cooperative game theory it is assumed that cost savings / profit can be made when all players cooperate. The main problem that is addressed in this theory is how to divide these savings in a "fair" way among all players.

We will introduce some mathematical details. Let us assume a game v with a player set N, consisting of n players. Each subset S that can be formed out of N is called a coalition. We will restrict ourselves to TU (transferable utility) games. In a TU game a real value $v(S)$ is assigned to each coalition S with $v(\emptyset) = 0$ (the empty coalition). This value depends only on the players in S. This value of the coalition $v(S)$ can be interpreted as the savings that can be achieved when only the players in S cooperate. So $v(N)$ are the savings for the grand coalition N.

An example: consider three players each having one painting of Rembrandt in their possession with different value. They want to sell their paintings. The three paintings belong to the same series and it is therefore more profitable to sell them together as a set. For each coalition S, the value $v(S)$ can be seen in Table 4.1. The question arises how can we divide the 17 Million Dollars (= $v(N)$) in a fair way among the three players?

Table 4.1: *Example of a 3-person cooperative game.*

Selling coalition *S*	***v*(*S*)**
{1}	2
{2}	3
{3}	7
{1,2}	10
{1,3}	12
{2,3}	12
{1,2,3} = N	17

Let x_i be the amount allocated to player i. Then x is the allocation vector. Now we introduce the notion of a solution concept f. A solution concept f prescribes just one allocation vector $f(v)$ for each game. Which solution concept to use depends on the agreement the players can reach on what they consider to be "fair". This involves the values of the subcoalitions S. A list of properties that f can have, is given below:

- EFF: efficiency. All savings are allocated back to the players: $\sum_{i \in N} f_i(v) = v(N)$
- SYM: symmetry. If for two players i and j can be interchanged without changing any $v(S)$ then $f_i(v) = f_j(v)$. It means that equal players should get equal pay-offs.

- DUM: dummy: If $v(S \cup \{i\}) - v(S) = v(\{i\})$ for all $S \subset N \setminus \{i\}$ then $f_i(v) = v(\{i\})$. It means that a player, who does not contribute anything, should not get anything.
- INV: invariance. For a game *w* with $w = k \cdot v + a$ (with *k* a real value and *a* a real vector) it holds that $f(w) = k \cdot f(v) + a$.
- ADD: additivity. For two independent games *v* and *w* with solutions *f*(*v*) and *f*(*w*) it holds that $f(v + w) = f(v) + f(w)$. This means that in case of two games it should make no difference in the payoffs whether each game is considered separately or both games are considered together as one game.
- IND: individual rationality. Not only EFF is satisfied, but also for all players *i* it holds that $f_i(v) \geq v(\{i\})$. It means that for each player the pay-off of cooperation is higher than the pay-off of working alone.
- STA: stability. EFF is satisfied and for all coalitions *S* it holds that $\sum_{i \in S} f_i(v) \geq v(S)$. It means that for each player the pay-off of cooperation in the grand coalition is higher than the pay-off of working alone or in any other coalition.

Three common solution concepts from cooperative game theory are the Shapley value $\Phi(v)$, the compromise value $\tau(v)$ and the nucleolus *n*(*v*). Below we briefly discuss the definitions and interpretations of these three concepts, because we will use them later.

The Shapley value $\Phi(v)$ is the unique solution concept that satisfies EFF, SYM, DUM and ADD (Shapley, 1953). The Shapley value is defined as:

$$\Phi(v) = \frac{1}{|N|!} \sum_{\sigma \in \Pi(N)} m^{\sigma}(v) \tag{4.1}$$

Here $m^{\sigma}(v)$ is called the marginal vector of a game *v* for a permutation σ and it is defined as:

$$m^{\sigma}_{\sigma(k)} = v(\{\sigma(1), \dots, \sigma(k)\}) - v(\{\sigma(1), \dots, \sigma(k-1)\}) \text{ with}$$
$$\sigma \in \Pi(N),\ \Pi(N) = \{\sigma : \{1, \dots, |N|\} \to N \mid \sigma \quad bijective\} \tag{4.2}$$

Note that for a game there are |*N*|! marginal vectors. The marginal vector can be interpreted as follows: assume the players enter the game one by one in the order σ(1),σ(2), etc and assign each player the marginal contribution (added value) he creates by joining the group of players already present. The Shapley value is simply the weighted average of all possible marginal vectors.

The compromise value $\tau(v)$ is based on the maximum $M_i(v)$ and minimum $m_i(v)$ amount that each player i can reasonably claim (Driessen, 1985). This maximum amount $M_i(v)$ equals the total value of the game minus the value the other players can establish without him:

$$M_i(v) = v(N) - v(N \setminus \{i\}) \tag{4.3}$$

The minimum amount $m_i(v)$ can be determined by looking at each coalition that player i belongs to. In each of these coalitions he will give to the other players in that coalition their maximum claims and see what is left for him. Then the maximum leftover is the minimum claim:

$$m_i(v) = \max_{S:i\in S}\left\{ v(S) - \sum_{j\in S, i\neq j} M_j(v) \right\} \tag{4.4}$$

As indicated in its name, the compromise value lies in between the maximum and minimum claims in such a way that the allocation is efficient:

$$\tau(v) = \alpha M(v) + (1-\alpha)m(v) \tag{4.5}$$

with $\alpha \in [0,1]$ unique such that $\sum_{i\in N} \tau_i(v) = v(N)$.

The nucleolus $n(v)$ is a concept which minimizes the maximum dissatisfaction level of all coalitions. As a measure for the dissatisfaction level, the excess $E(S,x)$ of coalition S with respect to allocation x is introduced:

$$E(S,x) = v(S) - \sum_{i\in S} x_i \tag{4.6}$$

Furthermore, $\theta(x)$ is the excess vector consisting of the excesses of all coalitions in a decreasing order. The nucleolus $n(v)$ is defined as the unique solution that satisfies IND and:

$$\theta(n(v)) \leq_L \theta(x) \text{ for all x satisfying IND} \tag{4.7}$$

The general properties of the three solution concepts are listed in Table 4.2.

For the example above (Table 4.1) the actual values of these solutions are given in Table 4.3. Note that in this case the compromise value and nucleolus are equal, but in general this need not be true.

Table 4.2: *Properties of solution concepts (Y = satisfied, - = not satisfied in general, * = if existent).*

	EFF	SYM	DUM	INV	ADD	IND*	STA*
Shapley value	Y	Y	Y	Y	Y	-	-
Compromise value*	Y	Y	Y	Y	-	Y	-
Nucleolus*	Y	Y	Y	Y	-	Y	Y

Table 4.3: *Values of solution concepts for the example in Table 4.1.*

	Player 1	Player 2	Player 3
Shapley value	4.33	4.83	7.83
Compromise value	5.00	5.00	7.00
Nucleolus	5.00	5.00	7.00

4.3 Modeling a purchasing consortium as a cooperative game

Managing purchasing consortia can be a complex task (see e.g. Laing and Cotton, 1997). In modeling purchasing consortia as a cooperative game we only consider two aspects: price reduction due to economies of scale and costs for setting up / maintaining a consortium. First we will focus on price reduction only; costs will be added later (we assume negligible costs for the time being).

Figure 4.1: *Price per item as a function of the quantity of the items to be purchased.*

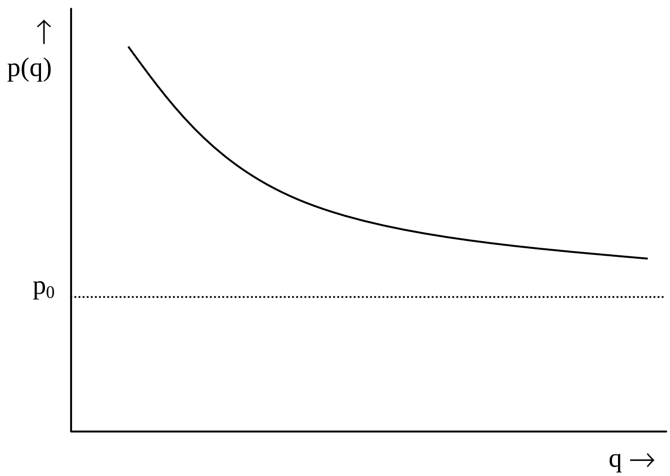
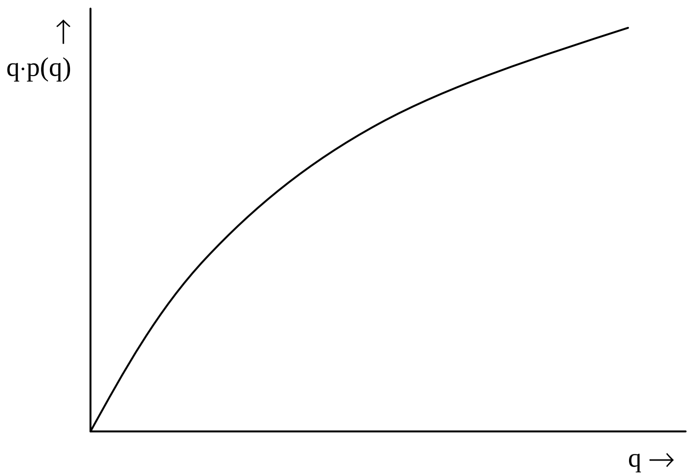


Figure 4.2: *The total price for buying a quantity of q items.*



For the price per item $p(q)$ we assume a decreasing discount is given, with more items being purchased. However, there is a minimum price p_0. So $p(q)$ is a convex function as in Figure 4.1. In addition, we assume the total price $q \cdot p(q)$ always to be increasing with the number of items (see Figure 4.2). These assumptions hold for most practical situations (for more about quantity discounts see e.g. Dolan, 1987).

For the remainder of this chapter, we will refer to the game model for a purchasing consortium as a cooperative purchasing game or CP-game (N,q,p). N is the number of players, q the number of items each player wants to purchase and p the price per item (as a function of the quantity). Together they completely define the CP-game. Then the reward function $v(S)$ of each coalition S is defined as the savings it generates by buying items together compared to the situation where each of the players in the coalition has to buy the items on his own. Thus:

$$v(S) = \sum_{i \in S} \left(q_i \cdot p(q_i)\right) - \sum_{i \in S} q_i \cdot p\left(\sum_{i \in S} q_i\right) \tag{4.8}$$

With this definition, all coalitions of just one player $\{i\}$ have value zero:

$$v(\{i\}) = 0 \tag{4.9}$$

For all other coalitions, $v(S)$ will always be positive (or zero).

The game represented above resembles a surplus sharing game, which together with its equivalent, the cost sharing game, have been extensively studied, although the emphasis has been mainly on cost sharing (see e.g. Moulin and Shenker, 1992 and recently Angeles de Frutos, 1998; Friedman, 1999; Friedman and Moulin, 1999; Watts, 2002). In a cost or surplus sharing game a group of players share a common technology that transforms a given input into a given output. For a surplus sharing game the input is a certain effort by each player and the output is the surplus. This leads to the question how this surplus should be divided. For a cost sharing game the input is costs and the output is certain products or services. Each player gets a part of output, but the question remains what part of the input each player should contribute. The CP-game is a special example of a surplus sharing game, an application that has not been discussed before. Therefore, the focus here is on the practical implications for purchasing consortia of applying existing game theoretical concepts, not on developing new theoretical concepts.

A CP-game is a convex game (for proof see text box on the next page). This is relevant because as for convex games the following statements hold:

- The game is superadditive. This means $v(S)$ increases as the coalition consists of more players:

$$v(S \cup T) \geq v(S) + v(T) \text{ for all } S, T \in 2^N \text{ with } S \cap T = \varnothing \quad (4.10)$$

- There always exist allocations satisfying IND and STA, which implies the compromise value $\tau(v)$ and the nucleolus $n(v)$ always exist.
- For all players the minimum claim $m_i(v)$ equals zero, reducing the formula for the compromise value to:

$$\tau(v) = \frac{v(N)}{\sum_{i \in N} M_i(v)} M(v) \quad (4.11)$$

Assuming the n players in the CP-game want to cooperate, the question remains: how can the total savings of the purchasing consortium $v(N)$ be allocated to the players in a "fair" way?

4.4 Solutions to cooperative purchasing games

Before going into detail about the solution concepts, we will first introduce another property that these solutions concepts could have: the purchasing power property (POW). This is a property specifically dealing with the CP-game, because it involves the quantities q_i. Satisfying this property means that a player with a larger quantity of items to be purchased through the consortium (higher leverage) should receive a larger share of the savings. More formally stated: if for two players i and j $q_i \geq q_j$ then $f_i(v) \geq f_j(v)$. Note that POW implies SYM.

Theorem

Every CP-game (without costs) is *convex*, i.e.

$$v(S \cup \{i\}) - v(S) \le v(T \cup \{i\}) - v(T)$$

for all $S, T \in 2^N$; $i \in N$ such that $S \subset T \subset N \setminus i$

Proof

Looking at the lhs of the inequality first, using the definition of $v(S)$:

$$v(S \cup \{i\}) - v(S) =$$

$$\sum_{j \in S \cup i} \left(q_j \cdot p(q_j)\right) - \sum_{j \in S \cup i} q_j \cdot p\left(\sum_{j \in S \cup i} q_j\right) - \sum_{j \in S} \left(q_j \cdot p(q_j)\right) + \sum_{j \in S} q_j \cdot p\left(\sum_{j \in S} q_j\right) =$$

$$q_i \cdot p(q_i) - \sum_{j \in S \cup i} q_j \cdot p\left(\sum_{j \in S \cup i} q_j\right) + \sum_{j \in S} q_j \cdot p\left(\sum_{j \in S} q_j\right)$$

Similarly,

$$v(T \cup \{i\}) - v(T) = q_i \cdot p(q_i) - \sum_{j \in T \cup i} q_j \cdot p\left(\sum_{j \in T \cup i} q_j\right) + \sum_{j \in T} q_j \cdot p\left(\sum_{j \in T} q_j\right)$$

Back to the inequality we get:

$$\sum_{j \in S \cup i} q_j \cdot p\left(\sum_{j \in S \cup i} q_j\right) - \sum_{j \in S} q_j \cdot p\left(\sum_{j \in S} q_j\right) \ge \sum_{j \in T \cup i} q_j \cdot p\left(\sum_{j \in T \cup i} q_j\right) - \sum_{j \in T} q_j \cdot p\left(\sum_{j \in T} q_j\right)$$

And this is true as q·p(q) is a concave function and it is clear that $\sum_{i \in S} q_i \le \sum_{i \in T} q_i$ as $S \subset T$. This is a general result and therefore holds for all $S, T \in 2^N$; $i \in N$ such that $S \subset T \subset N \setminus i$. q.e.d.

In practice, often simple rules are used when dividing the savings among the members of a consortium, rules such as: equal, proportional, same price per item, etc. Sometimes costs and cost savings are dealt with in a different way, each with their separate allocation method. Four of these common allocation methods will be considered and compared to the three solution concepts from game theory. These four methods are:

- *equal*(v). All players are considered equal, hence they obtain the same amount:

$$equal_i(v) = \frac{v(N)}{n} \tag{4.12}$$

- *prop*(v). The amount allocated to a player is proportional to the number of items he purchased:

$$prop_i(v) = \frac{q_i}{\sum_{i \in N} q_i} v(N) \tag{4.13}$$

  As can be easily verified, with *prop*(v) the savings are allocated on equal (absolute) savings per item.

- *equalperc*(v). The amount allocated to a player is based on an equal savings percentage per item:

$$equalperc_i(v) = \frac{q_i \cdot p_i}{\sum_{i \in N} (q_i \cdot p_i)} v(N) \tag{4.14}$$

- *sameprice*(v). All players pay the same price per item (the price that can be obtained with the volume of the grand coalition N):

$$sameprice_i(v) = q_i \cdot \left(p(q_i) - p\left(\sum_{i \in N} q_i \right) \right) \tag{4.15}$$

With the definitions of these methods we can find out which methods satisfy which properties. An overview is given in Table 4.4 (proven statements, but proofs have been omitted here). The first three practical methods satisfy the POW property. It is therefore guaranteed for any solution that these methods will allocate more savings to a participant who is buying more products through the consortium. However, these three methods do not satisfy STA in general. So in a particular example STA could be satisfied coincidentally, but it is not guaranteed for all situations. Hence, if one of these methods is used, it may be worthwhile not to cooperate in the grand coalition N.

As for paying the same price per item it is the other way around. STA is satisfied, but in general the player who purchases the most items does not always get the largest share of the savings. For the solutions from game theory both properties are satisfied. ADD is only satisfied for the equal split and the Shapley value. From

Table 4.4 we can conclude that game theoretic solution concepts are preferable over practical methods, because they satisfy more properties associated with "fairness".

Table 4.4: *Properties of solution concepts for CP-games (Y = satisfied, - = not satisfied in general)*

Properties→ ↓Solutions	**EFF**	**SYM**	**DUM**	**ADD**	**IND**	**STA**	**POW**
equal	Y	Y	-	Y	Y	-	Y
prop	Y	Y	Y	-	Y	-	Y
equalperc	Y	Y	Y	-	Y	-	Y
sameprice	Y	Y	Y	-	Y	Y	-
Shapley	Y	Y	Y	Y	Y	Y	Y
Compromise	Y	Y	Y	-	Y	Y	Y
Nucleolus	Y	Y	Y	-	Y	Y	Y

To illustrate the CP-game model, the allocation methods and its solutions, we give an example. We assume a situation in which three companies want to purchase laptops. Each company needs a different quantity: 20 for company 1, 40 for company 2 and 50 for company 3. Furthermore, the price p for the laptops as a function of the quantity q that will be ordered, is known (in Euro):

$$p(q) = 2000 \cdot \left(1 + \frac{1}{\sqrt{q}}\right) \tag{4.16}$$

Table 4.5: *A CP-game for buying laptops by three companies*

Buying party S	**Number of laptops**	**Price per laptop**	**Total**	***v*(*S*)**
{1}	20	2,447	48,940	0
{2}	40	2,316	92,640	0
{3}	50	2,283	114,150	0
{1,2}	60	2,258	135,480	6,100
{1,3}	70	2,239	156,730	6,360
{2,3}	90	2,211	198,990	7,800
{1,2,3} = N	110	2,191	241,010	14,720

The companies want to buy the laptops together, but they still have to decide how to allocate the savings. We assume no costs. This situation can be modeled into a CP-game as has been done in Table 4.5. When the three companies cooperate, 14,720 Euro can be saved.

Table 4.6 gives an overview of possible allocations for this example based on each of the seven solutions that were introduced earlier. These solutions have been plotted in Figure 4.3, in which a triangular plane of all allocations satisfying IND and EFF is shown (for more than three companies / players, this picture becomes multi-dimensional). In this case all seven solutions satisfy STA and all, except the allocation based on the same price per item, satisfy POW. For this allocation we see company 1 receives the largest share of the savings, while purchasing the fewest laptops. Of course, because of the same price per item, the savings per item are the highest for company 1, but in this case even the total allocated savings are the highest.

Except for paying the same price per item all solutions seem reasonable, as they all satisfy POW and STA for this example. Although, for the practical methods satisfying these properties was not guaranteed beforehand, as mentioned above. Looking at these solutions, one can see that the three game theoretical solutions are less "extreme" than the other three.

Which solution will be chosen depends on which allocation method companies can agree after negotiations. However, reaching agreement is likely to be easier when the actual figures are not yet known. It is easier to decide on the concept to use, while not having the bias of the actual figures. Knowing these figures will cause companies to prefer the allocation that maximizes their share regardless of the concept behind it.

4.5 Costs of cooperating

The costs of setting up and maintaining a consortium can not be neglected. Hendrick (1997) reported that for the consortia he investigated the average annual costs were $ 300,000. For modeling we assume a cost function *C(S)* with fixed costs C_o and variable costs c depending on the number of players in the consortium $|S|$ (only for a coalition of at least two players):

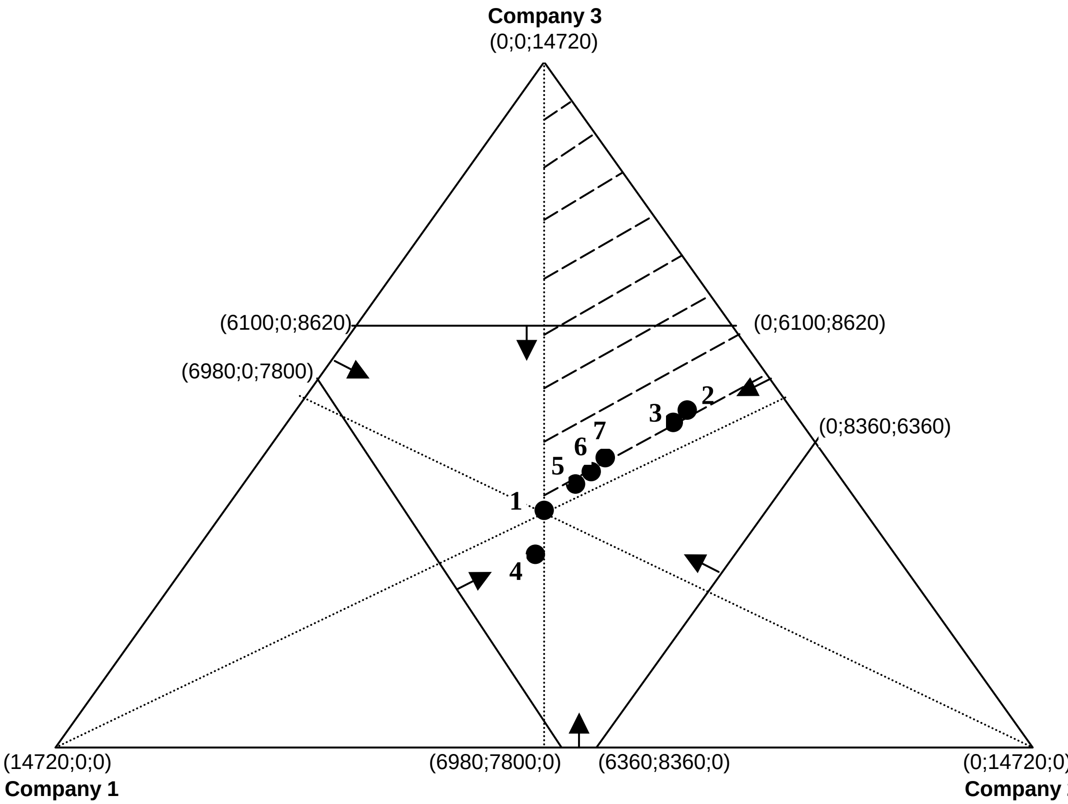
$$C(S) = \begin{cases} C_0 + c \cdot |S|^{\alpha} & |S| \geq 2 \\ 0 & |S| = 1 \end{cases} \tag{4.17}$$

Here α determines whether the variable costs are less than proportional (α < 1), proportional (α = 1) or more than proportional (α > 1) to $|S|$. In practice, the costs are likely to increase more than proportional with the number of participants.

Table 4.6: *Allocation of the savings for each solution of the example in Table 4.5.*

Allocation method	**Company 1**	**Company 2**	**Company 3**
1 equal	4,907	4,907	4,907
2 prop	2,676	5,353	6,691
3 equalperc	2,817	5,332	6,571
4 sameprice	5,120	5,000	4,600
5 Shapley	4,383	5,103	5,233
6 Compromise	4,262	5,149	5,309
7 Nucleolus	3,860	5,300	5,560

Figure 4.3: *Graphical overview of the solutions from the example. The numbers next to the dots correspond to the allocation methods in Table 4.6. The coordinates (1;2;3) refer to the amount given to company 1, 2 and 3. Within the triangle all allocations satisfy IND and EFF. Within the area indicated by the arrows STA is satisfied; within the triangle indicated by the dashed lines POW is satisfied.*



If we assume there have to be bilateral agreements between all N participants, it means $\frac{1}{2}(N-1)N$ agreements are necessary. Hence, if the variable costs are proportional to the number of agreements, the total costs will increase more than proportionally with the number of participants.

Costs and benefits can be dealt with separately using a different allocation method for both of them. This cost function can also simply be included in the expression for $v(S)$. However, we assume $v(S)$ can not become negative. If the costs of cooperating would be larger than the benefits for a coalition S, cooperation would simply not occur and therefore in that case $v(S) = 0$, so:

$$v(S) = \max\left(\sum_{i\in S}(q_i \cdot p(q_i)) - \sum_{i\in S} q_i \cdot p\left(\sum_{i\in S} q_i\right) - C(S), 0\right) \qquad (4.18)$$

When introducing costs, in general the CP-game is no longer convex. This is caused by the marginal costs c, The added value of a player could become negative and this contradicts superadditivity (see above). However, if we require only players being allowed in the game such that superadditivity holds then convexity is satisfied. This basically means the marginal contribution (added value) of a player to any coalition must be larger than the marginal costs c. In the next section we will restrict ourselves to situations where this requirement is met.

4.6 Determining the optimal consortium

Without including costs it is always profitable to join a consortium. In addition, the larger the size of the consortium the better, because each extra participant increases the economies of scale.

Only when costs are taken into consideration the profitable size of a consortium becomes limited. Including costs allows us to determine the maximum and minimum size of a consortium. We will first consider the situation of equal participants. Consider N players all needing the same quantity Q. Consider *p(q)* a differentiable function as in Figure 4.1 and 4.2 and a cost function as in (4.17). The total savings $v(N)$ per participant of the consortium is then calculated as follows (assuming at least two participants):

$$\frac{v(N)}{N} = Q \cdot (p(Q) - p(NQ)) - \frac{C_0}{N} - c \cdot N^{\alpha-1} \qquad (4.19)$$

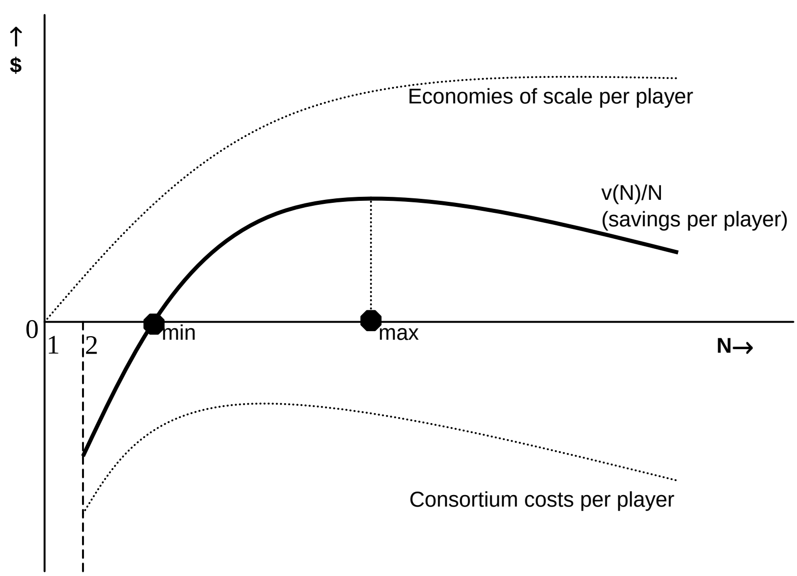
To start a consortium a minimum number of participants is needed. As long as there are not enough participants such that (4.19) has a negative value cooperation will not occur. This minimum number is the first integer N larger than the smallest positive zero value of (4.19).

Figure 4.4 shows the total savings per player as a function of the number of players for the case of $\alpha > 1$. The maximum consortium size is reached when the savings per player start to decline. Logically, the players already in the consortium do not want to make it larger in that situation. This maximum size is also the economic size. It is reached when:

$$\frac{d}{dN}\left(\frac{v(N)}{N}\right) = 0 \Leftrightarrow Q^2 \left.\frac{dp}{dq}\right|_{q=Q} - \frac{C_0}{N^2} - (\alpha - 1)\cdot c \cdot N^{\alpha-2} = 0 \qquad (\alpha \neq 1) \tag{4.20}$$

From (4.20) the maximum number of players can be calculated. Note that (4.20) can only be solved for values of $\alpha > 1$. Hence, only for more than proportional variable costs a maximum consortium size exists as indicated in Figure 4.4. This could already be seen in (4.19) as well, because for $\alpha < 1$ the costs become negligible for large N.

Figure 4.4: *Optimal consortium size with equal players and more than proportional variable costs of cooperation.*



In case of unequal participants whose quantities are known, a similar analysis can be conducted by considering all consortia sizes and combinations of these participants. Furthermore, a problem related to the consortium size is with which type of participants a company should try to form a consortium. Is it more beneficial to have larger companies in the consortium or is it better for the allocated savings to have the other companies in the consortium of similar size? Of course, it depends on the allocation method that is used.

To shed more light on this problem we consider two situations. In situation I there is a consortium of N equal players buying a quantity Q in total, thus Q/N per player. In this case $v(N)$ equals:

$$v(N) = Q\left(p\left(Q/N\right) - p(Q)\right) \tag{4.21}$$

For all methods discussed each player will get an equal share, as they are indistinguishable. In situation II there is a consortium of N-K (K = 2,...,N-1) equal players each buying a quantity Q/N and one (large) player buying a quantity KQ/N. Hence, in total still a quantity Q is purchased. In this case $v(N)$ equals:

$$v(N) = Q\left(\frac{N-K}{N} \cdot p\left(Q/N\right) + \frac{K}{N} \cdot p\left(Q/N\right) - p(Q)\right) \tag{4.22}$$

Using (4.21) and (4.22) we can calculate the savings allocated to each player who is buying a quantity Q/N. This amount is:

- larger for situation II when using the equal split rule
- larger for situation I when using the proportional, equal percentage rules as well as the compromise value
- equal for both situations when using the same price per item rule

In addition, if for the equal player situation I is favorable for particular allocation methods, it implies for a large player it is beneficial to cooperate with smaller players for these methods. Thus, when a game theoretic solution concept such as the compromise value is used, a company would be better off to cooperate with equal or smaller companies. Although, enough small companies have to be available in order to obtain similar economies of scale. Also, this example does not include costs and, as has been shown for more than proportional costs, the amount of companies to cooperate with should be limited.

4.7 Applicability issues

In the previous two sections the CP-game model and possible solutions were described from a more theoretical point of view. In this section we will focus on issues regarding applicability in practice.

From among the possible solutions, it seems that the game-theoretic solutions are the best to use, as they satisfy most properties mentioned in Table 4.4. However, calculating these solutions becomes more complex for larger coalitions. Compared to the Shapley value and the nucleolus, the compromise value is the easiest to calculate. Only the values for the grand coalition N and the coalitions consisting of n-1 players are used for the compromise value, while for the others all coalition values need to be known and larger number of calculations need to be done with those values (the marginal vectors for the Shapley value, constructing the least excess vector for the nucleolus).

Although the compromise value is easy to calculate, applying it to the combination of different items has one major drawback. A purchasing consortium could of course be used for multiple (types of) items at the same time. Each item could be treated as a separate game with a separate allocation of the savings. The cost savings from all items could also be added together and then these total savings could be allocated all at once. It seems "fair" that when the same allocation method is used for each item separately or for all of them together, the total amount allocated to each player should be the same. This is just another way of saying that ADD has to hold. But for the compromise value ADD does not hold (Table 4.4). Hence, for the compromise value considering different items separately or together will give different solutions.

Another applicability issue for the CP-game model is the different forms in which purchasing consortia occur. Consortia can consist of members purchasing more or less equal quantities, members purchasing very different quantities or even have one main buyer (who has by far the highest leverage of the members). Another possibility is a third party that in exchange for a fee is specialized in negotiating leverage and arranging a consortium setting on behalf of other companies. The third party does not purchase items for itself; it uses the purchasing volume of the companies on whose behalf it operates. The third party bears the actual costs (effort) of setting up and maintaining the consortium. A slightly different but similar setting would be to have one company in the consortium doing all the work, but also needing a quantity of the product itself.

All these situations can be modeled as a CP-game. Except for the third party option, the CP-game model as described above can be used. The model is particularly useful when the quantities of each member differ a lot. When consortium members order (nearly) equal quantities the extensive analysis of solution concepts is not necessary. In this case all solutions discussed converge to an equal split of the savings, a solution to which no member is likely to object.

A consortium with one main buyer is an extreme case of unequal quantities of members. The following example gives an interesting insight. Consider a main buyer m whose quantity is much larger than the quantities of all n-1 small indistinguishable buyers together (similar to situation II from the previous section). Using the leverage of the main buyer *m*, cost savings *k* can be obtained for one small buyer. We will only calculate the compromise value; hence only the values for the following coalitions are relevant:

$$\begin{aligned} &v(N) = (n-1)\cdot k \\ &v(N \setminus \{i\}) = (n-2)\cdot k \qquad i \neq m \\ &v(N \setminus \{m\}) = 0 \end{aligned} \tag{4.23}$$

In this case the compromise value for the main buyer is equal to $\tau_m(v) = 0.5\cdot(n-1)\cdot k$ and for the small buyers $\tau_i(v) = 0.5\cdot k$. So with this allocation each small buyer shares the savings fifty-fifty with the main buyer.

When a third party is responsible for the consortium, the CP-model has to be extended. Basically, there will be two cost functions $C(S)$ depending on whether or not the third party is involved in coalition *S*. The third party will only have added value if its involvement can lower the costs. But it may be possible that the third party can negotiate a better price, which also means that two price functions could be involved. With these functions $v(S)$ can be calculated for all coalitions *S* similar to the basic CP-model. Analysis of the allocation method can also be done similarly. The third party will normally be the decision-maker. The allocation method determines the contract arrangements that are offered to possible participants. The extended CP-model can help the third party in providing insights into more and less profitable or "fair" arrangements, which can affect the continuity of the consortium over time, commitment of the participants and persuasion of new participants to join. Note that a similar analysis can be applied when one company in the consortium is responsible for the consortium setup and maintenance.

Until now we assumed the marginal contribution of a player to a coalition always to be positive. As mentioned in section three, with this assumption the marginal contribution can be negative. At first it may seem unlikely that this player would (be allowed to) join the consortium. However, in practice this situation may occur more often than one would think. When companies decide to join together in a consortium the exact quantities to be purchased may not always be known in advance. Early indications of the quantities may turn out to be quite off the mark. When the quantity purchased through the consortium turns out to be much less than expected for a company, a negative marginal contribution can occur. The CP-model can incorporate this, but in general it will not be convex anymore. Solutions such as the compromise value and the nucleolus may then no longer exist and certain properties of Table 4.4 may not hold. If a certain "fair" allocation method was decided upon at the start-up of the consortium, it may turn out not to be so "fair" anymore. To prevent this, penalties could be included for not meeting the quantities that were indicated at the start-up. Another way would be to split up costs and cost savings. The CP-model without costs is always convex and different quantities will not change the properties of the solutions discussed. Naturally this still leaves the allocation problem of the costs. But with equal marginal costs for all participants equally splitting the costs may be agreed upon.

4.8 Conclusions

Only limited research has been conducted on purchasing consortia. Linking cooperative game theory to purchasing consortia is a new approach. In this paper we have shown the CP-game model provides new insights into the problem of allocating the costs and cost savings to the consortium members. Several allocation methods have been analyzed for their properties. The analysis shows that practical methods are not good policies in general. When all members pay the same price per item the largest share of consortium savings may be allocated to members with the least leverage (POW is not satisfied). When all members get a share of the savings proportional to the quantities purchased, it could be worthwhile for some members to form smaller subcoalitions (STA is not satisfied). Instead game theoretic concepts like the compromise value should be preferred, as they always satisfy POW and STA, therefore giving "fairer" solutions to this problem for all instances. In addition, the CP-game model allows us to calculate the optimal size for purchasing consortia.

Furthermore, the CP-game model with possible solutions and their properties can be used as an instrument to provide clarity to participants in a purchasing consortium. It can help in negotiations, by reducing the fear of other members benefiting parasitically. By enhancing trust commitment to the consortium can improve, which is very important for the purchasing consortium to be successful (Doucette, 1997).

The paper already showed that the CP model provides the opportunity for calculating the maximum size of a consortium in a specific setting. In addition, future research could include theoretical extensions of the game theoretic approach such as considering non-homogeneous items: each company could have slightly different requirements regarding the item to be purchased through the consortium. Some companies would therefore have to change their requirements in order to obtain the volume discount, for which they could receive compensation. Another extension could be to include volume discounts that are stochastic or unknown and perhaps depend on negotiation efforts. Furthermore, in the CP-game model only volume discounts are taken into account as benefit of cooperation. However, cooperation is also possible on other purchasing activities such as making specifications and searching and selecting suppliers.

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Chapter 5

The economic way of tendering

applications, tests and extensions of the ETQ model

This chapter is partly based on:

Heijboer, G.J., 2000. The economic tender set. Poster presentation at the 9th International Annual IPSERA conference.

Heijboer, G.J., 2001. Pre-selection in tender procedures. In: Purchasing and supply topics at the turn of the Millenium, IFPMM Publications 3, 29-41.

Heijboer, G.J. and De Boer, L., 2001. Optimal number of tenders in practice. Proceedings of the 10th International Annual IPSERA conference, 473-484.

Heijboer, G.J. and De Boer, L., 2002. ETQ-DSS: a decision support system for deciding on the number of tenders. Working paper.

Heijboer, G.J. and Telgen, J., 2002. Choosing the open or restricted procedure: a *big* deal or a big *deal*? Journal of Public Procurement 2(2), 187-215.

Competitive bidding (or tendering) remains an important purchasing practice, both in the private and public sector (Bensaou, 1999). Competitive bidding requires the purchaser to make a decision regarding the number of suppliers that are to be invited to submit a tender. For this decision a formal model has been developed by De Boer et al (2000) which specifies the optimal number of tenders or economic tender quantity (ETQ). In this chapter we investigate the assumptions underlying this model as well as some extensions.

5.1 Introduction: why use tendering procedures / competitive bidding?

The two main reasons for using tender procedures (competitive bidding) are to provide public accountability and to obtain the best value for money (Holmes, 1995). The public accountability is especially important for purchasers from public agencies, as in principle all work done by civil servants has to be publicly accountable. In many countries law requires the use of prescribed tender procedures for governmental purchases (Smyth, 1997), like the European Union (EU) with its Directives and the GPA (Agreement on Government Procurement of the World Trade Organization). The EU Directives aim to provide transparency in general and more particular on the following aspects (Netherlands Ministry of Economic Affairs, 1999): (a) contracts notifications and contract awards, (b) more objective specifications, (c) rules of conduct for awarding contracts and (d) rules of conduct about what can be demanded from suppliers. In addition the Directives have been put into place to improve the effectiveness of purchasing and fair trade within the EU and other marketplaces.

It is good to note the difference in tendering procedures between the public and private sector, due to public accountability. In private firms often negotiations follow after the tender procedure to determine the final price (Leenders and Fearon, 1993), a practice that is usually forbidden for governmental purchases. This makes it even more important for the public sector to arrange the tendering procedure as good as possible as no "damage control" can be exercised by means of additional negotiations afterwards.

From an economic point of view using tender procedures is a good way of achieving best value for money. In a tender procedure suppliers need to act competitively. The market mechanism is used to ensure the best price. However, if a situation exists that frustrates the market mechanism in some way, the outcome of a tendering procedure may not be optimal, making it therefore less applicable. This is the case when few to no suppliers are available. Also collusion between some of the bidders destroys (some of) the competition. Knowing that this will occur, just negotiating with a few suppliers would probably lead to the same outcome, but without the effort of setting up the whole tendering procedure (Holmes, 1995). Competitive bidding is also difficult when the specification of the product is not clear, making the comparison of tenders a difficult job and therefore more costly.

Negotiations in this case can be more flexible and it could be better for developing trust between companies. From this it can be concluded that competitive bidding is especially useful for so-called leverage purchases and to some extent for routine purchases in terms of the purchasing portfolio of Kraljic (Kraljic,1983).

Basically, a tender procedure is equivalent to an auction, more specifically a standard sealed-price auction where the lowest bid wins (Beattie and Fearnley, 1998). Much of the literature on auction theory focuses mainly on the bidder's side: the optimal bidding strategy under certain conditions, for instance, the independence of bids (for a good overview see Milgrom, 1989). However, we want two mention two important phenomena in bidding from auction literature here.

The first phenomenon that has emerged from auction theory is the "winner's curse". It is a situation in which the supplier with a bid that is much lower than the rest is awarded the contract. However, suppose the supplier has estimated the costs of the contract inaccurately. From his point of view the bid turns out to be too low, leaving him with a non-profitable contract. This gives an incentive for compromising on performance and therefore this situation has to be avoided by the buyer (Beattie and Fearnley, 1998; Cripps and Ireland, 1994). This phenomenon is yet another reason for having a tender procedure (and particularly, specifications) with high transparency.

The second phenomenon is the submission of non-competitive bids. For example, suppliers perhaps do not really want a specific contract, because they do not have any capacity available at the moment. However, they may still want to show their interest, because it can give them a higher chance of similar contracts in the future. Or, suppliers may fear that if they do not submit a bid, the buyer will not consider them again. In this case, suppliers may submit a higher, less competitive, bid.

What should the design of a tender procedure look like to ensure the best bid? Free entry of bidders (open bidding) would naturally give the highest competition. Also, the level of the lowest bid price will be lower on average as the number of bidders increases (Holt, 1979). However free entry of bidders has its disadvantages:

- *Evaluation costs.* The most important factor is the costs involved with a tender procedure for the purchasing organization (McMillan, 1998). These costs can be substantial and consist of fixed costs and costs varying with the number of companies that are invited to tender. Fixed costs consist mainly of setting up the procedure, writing the request for quotations with the specifications and defining an evaluation procedure. The variable costs related to each bid are the costs associated with handling queries, filing, reading and evaluating the tenders and informing the supplier of the outcome. Given the high complexity of some tenders the time spent on evaluation can be huge. In addition, each tender often has to be evaluated equally (compulsory for public agencies). Finally, with free entry of bidders the number of tenders is not known beforehand, so the time that needs to be spent is uncertain.

- *Non-competitive bids.* Supplier companies compete more seriously when the number of bidders is restricted as the perceived chance of winning the contract might be very low with free entry of bidders (Hallwood, 1996). Especially if the costs of making the tender for firms are considerable, serious participation could be limited even more. Note that in this case suppliers submit a non-competitive bid for a different reason than the one in the previous paragraph.
- *Low quality bids*. As the quality level cannot always be demanded clearly in the contract (terms of reference), with high competition suppliers could take the opportunity to put in a (lower) bid with a lower quality standard in mind (Kim, 1998). In other words by having competition that is mainly price driven, having competition that is mainly price driven could compromise the quality.

To deal with these disadvantages invited bidding can be used instead. A number of suppliers is selected first (creating a shortlist) and only these suppliers are invited to tender. In order to ensure a competitive bid the selection of possible suppliers must be numerous, qualified and reliable enough, but not more than necessary in view of the tendering costs involved with each additional bid (Leenders and Fearon, 1993). A trade off must be made between the best bid that can be expected and the tendering costs that are necessary to obtain it. Hence, there will be an optimal number of tenders, which minimizes the total costs of the tendering process, i.e. the sum of tendering costs and the expected price that will be paid for the contract. Graphically this trade off is shown in Figure 5.1. A purchaser can influence these expected total costs by deciding at the beginning of the process on the number of tenders he wants to receive.

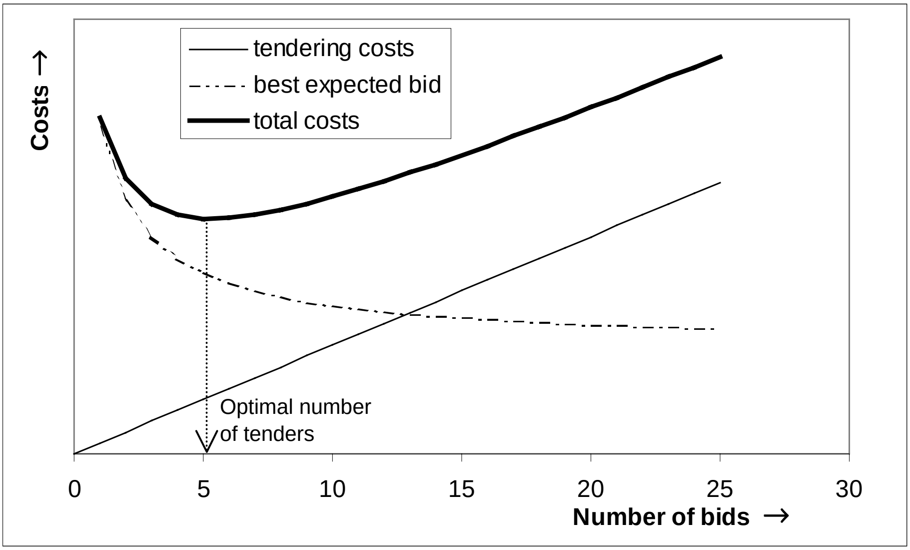
This trade-off has been quantified in a formal decision model by De Boer et al. (2000, and earlier work by Lansdowne, 1996). This model can be classified under the heading of research in bounded rationality as initiated by Simon (1978). More in particular, Conlisk's discussion of bounded rationality in terms of explicitly modeling deliberation costs reflects our approach (Conlisk, 1996).

The rationale behind developing the ETQ (economic tender quantity) model lies in the significance of competitive tendering on the one hand and the (at most only partial) guidance practitioners receive from corporate guidelines in deciding on the tender quantity (De Boer et al, 2000). In this chapter we investigate the assumptions underlying this model as well as some extensions.

In subsection 5.2, we first discuss the ETQ-model and its assumptions as presented by De Boer et al (2000), as the ETQ model is the basis of the research presented in this chapter.

In subsection 5.3 we consider the current practice of purchasers deciding on the number of bids they wish to receive in a tender procedure. More specifically, we study to what extent the ETQ-model can be useful in facilitating and improving that decision. For this purpose we developed a prototype DSS incorporating the ETQ model. The validity of the model assumptions is analyzed using empirical evidence from thirty cases. Furthermore, four semi-structured interviews were conducted with tactical purchasers to gain insight into the practical applicability of the model and the DSS and to identify specific directions for further improvement.

Figure 5.1: *Trade off between tendering costs and the expected bids.*



In subsection 5.4 we investigate an extension of the ETQ model: choosing between the open and restricted tendering procedure in the EU. The legislation in the EU regarding contracts to be awarded to third parties allows for a free choice by public agencies between the open and restricted procedure. Empirical evidence shows a high variance in the preference for one of the procedures between countries. This preference may be based on cultural phenomena only. We extend the ETQ model to calculate which procedure is the most economic. With insights from this model guidelines are given for an efficient policy regarding the choice for the open or the restricted award procedure.

In subsection 5.5 we investigate another extension: the economic tender set (ETS). The difference between ETS and ETQ lies in the assumption regarding the individual behavior of suppliers. For ETQ suppliers are assumed indistinguishable, whereas for ETS the are assumed not to be.

A final extension we consider is to include multiple criteria in the ETQ model. Subsection 5.6 presents a model on how to achieve this. Also the model is illustrated by means of a numerical example.

5.2 The ETQ-model: assumptions and parameters

In the ETQ model assumptions are made in three areas: the bid evaluation, the suppliers and the tendering costs. First, considering the bid evaluation it is assumed that there is only one quantifiable criterion. Here we refer to that criterion as the price, hence the bid with the lowest price will be awarded the contract. All other criteria that can be translated into a price, e.g. the delivery time may be expressed as costs, can be included easily. Using only the price as a criterion allows us to easily compare the bids with the tendering costs. Quantifying the ETQ in a kind of multi-criteria setting is also possible, but is more complicated. Therefore we chose to first gain experience in the price oriented setting.

Each supplier is assumed to give an independent bid (no collusion). Also, all suppliers are assumed to make a bid from the same probability distribution $f(x)$ (with cumulative distribution $F(x)$), from now on referred to as the "bid distribution". So each bid is a random pick from the bid distribution. The mean of this distribution is the average bid to be expected and variance can be used as an indicator for spread in the bids. Hence, we assume suppliers are indistinguishable. For instance, when the bid is uniformly distributed between 10 and 15, all suppliers bid randomly between those boundaries and of course the lowest one will be awarded the contract. In practical terms a purchaser needs to have enough knowledge of the supply market to be able to estimate what bid prices can be expected.

The cumulative distribution $F_{min}(x)$ of the lowest bid X_{min} out of n bids can be derived as follows:

$$F_{\min}(x) = P\{X_{\min} \le x\} = 1 - P\{X_{\min} > x\} = 1 - (1 - F(x))^n \tag{5.1}$$

The expected value of the lowest bid $E\{X_{min}\}$ is given by:

$$E[X_{\min}] = \int_0^\infty (1 - F_{\min}(x))dx = \int_0^\infty (1 - F(x))^n \, dx \tag{5.2}$$

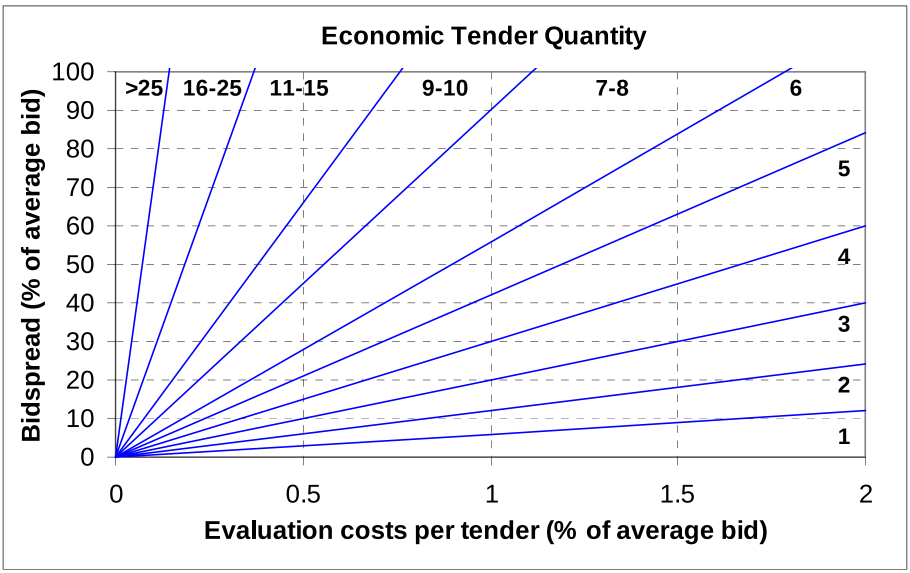
Looking at the tendering costs the fixed costs are not relevant for determining the ETQ. Having decided to start a tendering procedure the fixed costs are independent of the number of bids and can therefore be omitted. The variable costs are assumed to be proportional to the number of bids n with costs K for each bid, so every bid will take the same amount of time to evaluate.

The economic tender quantity (ETQ) can now be calculated by minimizing the expected total costs:

$$ETQ = \arg\min_{n>0}\left\{K \cdot n + \int_0^\infty (1 - F(x))^n \, dx\right\} \tag{5.3}$$

The ETQ is a unique solution to the minimization problem as the expected total cost function is convex (De Boer et al, 2000). The ETQ is uniquely determined by the characteristics of the bid distribution and the costs per tender. However, the calculation itself is not straightforward for an arbitrary bid distribution, as it requires the use of order statistics. De Boer et al (2000) considered the uniform, triangular and normal distribution. Figure 5.2 shows an example with a normal distribution (mean μ, standard deviation σ). The bid spread used on the vertical axis in Figure 5.2 is defined as the 2σ value on both sides, hence 4σ in total, which means about 95% of the bids will be within the bid spread defined in this way.

Figure 5.2: *Determining the ETQ with a normal bid distribution (the bold numbers in the graph denote the ETQ in that area of the graph).*



Based on estimates of the evaluation costs per tender and the two parameters of the normal distribution the ETQ can be obtained using Figure 5.2. Note that actually the ETQ only depends on the bid spread, i.e. σ and the costs per tender and not on the mean μ of the normal distribution. De Boer et al. (2000) showed that this holds for all investigated distributions. In other words the optimal number of bids to be requested is not dependent on the average market price, but only on the expected spread in the market and on the evaluation costs. From this perspective company rules like inviting at least X suppliers to tender above a certain threshold for the contract value have no rationality.

5.3 ETQ-DSS: a decision support system for deciding on the number of tenders (based on Heijboer and De Boer, 2002 and 2001)

The ETQ model described in 5.2 rests on certain assumptions, which until now have not been validated in practice. Apart from accurate estimates of the bid distribution and the evaluation costs, the validity of the result also depends on the validity of the underlying assumptions of the ETQ model itself. First of all, the suppliers each have to submit a bid independently. This assumption is of course very hard to check as no supplier will easily admit this not to be true taking into account the legal implications and anti-trust laws. Secondly, which probability distributions for the bids actually occur in practice? From literature a few phenomena in bidding practices such as the "winner's curse" (see above) are known, but hardly any empirical data is available on the distributions. Third, the evaluation costs are assumed to be proportional to the number of tenders. These costs mainly consist of the working hours spent by purchasers and therefore the number of these working hours must be estimated. In practice not much data on these working hours may be readily available.

As a purchasing practitioner can not use the formal ETQ-model in a straightforward manner, we developed a prototype DSS that incorporates the ETQ-model.

The goal of the research presented in this subsection is to test the practical applicability of the ETQ-model in general and more specifically when embedded in our DSS. Regarding the general applicability of the ETQ-model we first tested the validity of its underlying assumptions. In order to do this we analyzed 30 cases of competitive bidding in practice. In addition, four semi-structured in-depth interviews were conducted with tactical purchasers to obtain more in-depth expert knowledge. The interviews also served the specific goal of testing the practical applicability of the ETQ-DSS. During these interviews we used and evaluated the DSS in an experimental setting.

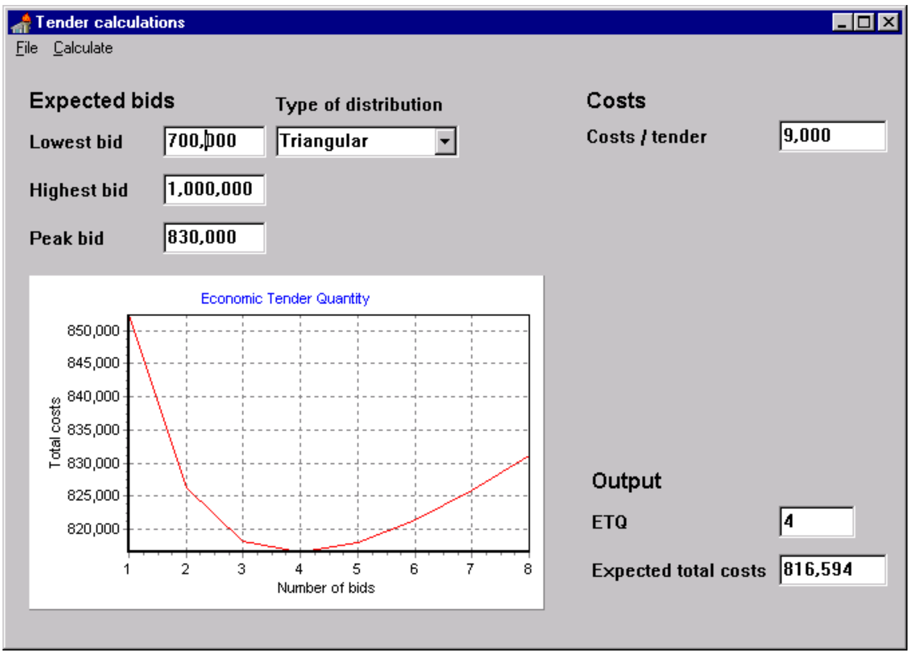
This subsection is organized as follows. First, we describe development of the prototype DSS. Subsection 5.3.2 gives the methodology we used in the empirical research. The results of the empirical work follow in subsection 5.3.3 Subsection 5.3.4. Finally, we draw general conclusions and lines for further research in section 5.3.5.

5.3.1 Developing the prototype ETQ-DSS

Following the development of the theoretical ETQ-model, a subsequent need arises to develop a viable DSS-environment for using the ETQ in practice. The few existing DSS's for supplier selection (see e.g. Cook, 1997; Ghodsypou and O'Brien, 1998; Haavegen and Sena, 1996) do not support the decision how many suppliers to invite for the bidding process. We developed a prototype DSS of the ETQ-model. A screenshot of this DSS can be seen in Figure 5.3. The DSS is an MS Windows application developed in Borland Delphi 4.0.

The aim of the DSS is to aid the user of the ETQ-model by presenting the input parameters in a clear way, performing all necessary calculations automatically and presenting the results graphically. To be able to use the DSS a purchaser will need to have enough information about the market to be able to estimate what bid prices can be expected and thus what kind of distribution is appropriate. Furthermore he needs to have an idea of the time (costs) that will be involved with each tender. Based on this input the ETQ as well as the total costs involved are calculated. Naturally the better the input can be estimated the more accurate the predicted outcome will be.

Figure 5.3: *A screenshot of the DSS for calculating the ETQ.*



5.3.2 Research methodology

To gather empirical data for validating the assumptions in the ETQ-model we made use of two information sources.

First we sent out a request for information about tender procedures, particular information about the number of bidders and their bids. This request was sent to various companies and public agencies in the Netherlands, all member of the NEVI (Dutch Association for Purchasing Management). We specifically asked for cases with at least five bids in order to be able to at least estimate to a certain extent which bid probability distribution is applicable. The other condition was that the price had to be the dominant criterion in the tender procedure, as other criteria are not taken into account in the ETQ model. We received 30 cases that met these conditions. The results of these cases are given in the next subsection.

Secondly, we conducted interviews with four tactical purchasers from a few large companies and public organizations. The purchasers are full-time professionals and decision-makers with regard to inviting suppliers. As they are field experts, they were asked their opinion on the ETQ-model, its underlying assumptions and its possible limitations. However, the interviews also served our second goal. With the ETQ-DSS available the second and as least as important objective of the interviews was to test to what extent the tool was indeed considered useful and how it could be improved.

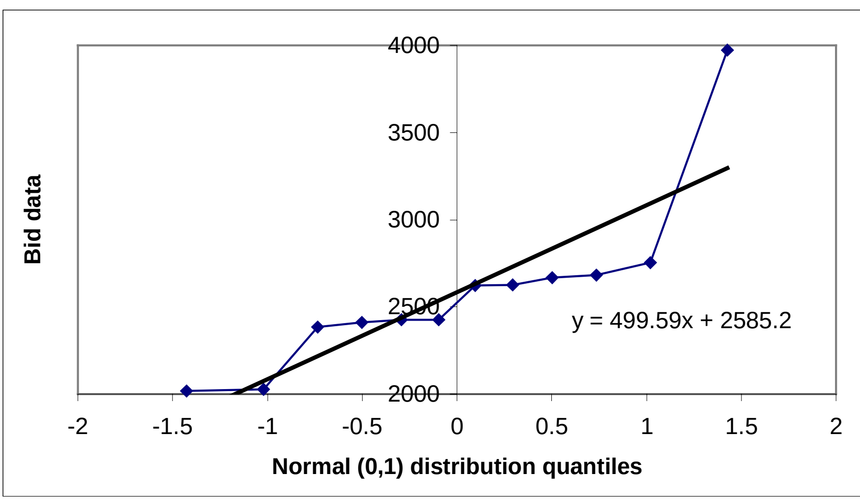
These interviews were conducted in a semi-structured way. We formulated a testing protocol in order to cover all aspects in an organized way within an hour. This way, it did not take too much time of the purchasers, increasing the number of people willing / able to cooperate. The testing protocol consisted of five items: (1) asking for a brief overview of the company, the role of the purchasing department and the position of the interviewee, (2) explanation of the ETQ-model, (3) illustration of the DSS with an example, (4) experimentation with the DSS together with the person interviewed using cases from his / her practice and (5) an evaluation by means of a small questionnaire. The results of the four interviews are presented in subsection 5.3.4.

5.3.3 Bid distributions in practice

Before going into detail about the results we received from the cases, we discuss the influence of two phenomena that we mentioned earlier on the bid distributions: the winner's curse and the submission of non-competitive bids. When looking at the distribution of bids for a particular tender the winner's curse may cause a few extra low bids (compared to the rest). The submission of non-competitive bids leads to a few extra high bids. Taking these effects together into consideration the bid distribution could have relatively fat tails with low and high prices.

Now we turn to the results from the cases we received. The majority of these cases (about 70%) comes from public agencies, e.g. municipalities, provinces, universities. The number of bids per case varies from 5 to 12. The price of the contracts varies from about 30,000 Euro to 50 Million Euro as far as the prices were given. As we are only interested in the spread, companies could also index the actual prices for confidentiality reasons. The variety in terms of the objects purchased is also high ranging from supplies like nitrogen gas, cars, chairs and PCs to services like cleaning and works like road construction and tunneling. Depending on the products and the different markets, the standard deviation in the bids (as a percentage) is also very different for each case, ranging from 2 % to 40 %. Another observation from the cases is that the spread of the bids can be characterized similarly for most cases: most bids are quite close to each other, whereas the highest and/or the lowest are very different from the rest.

Figure 5.4: *Q-Q plot for a case of supplying PCs.*



Unfortunately even the highest number of bids per case we received, namely 12, is still a very small number to make a good fit of a probability distribution. For this case which concerned purchasing PCs we made a so-called Q-Q plot, i.e. quantile-quantile graph, in order to assess to what extent a normal distribution was applicable, see Figure 5.4. When a normal distribution applies to the bid data the points in the figure should fit in a straight line $y = A \cdot x + B$ where the slope A is equal to the standard deviation σ of the normal distribution and B is equal to the mean μ. The linear fit in Figure 5.4 shows that the actual data deviate a bit. Apparently, the number of points is too small to fit any distribution with high confidence. No reliable chi-squared test can be made.

Therefore, we have taken a more global view on the bid data. In order to be able to compare all cases we indexed them all similarly, dividing each bid value with the average of the case it belongs to making the average bid 1 for all cases. After that we subtracted the value of 1 from each bid, making the average 0 instead of 1.

Figure 5.5: *Symmetry plot of all bid data.*

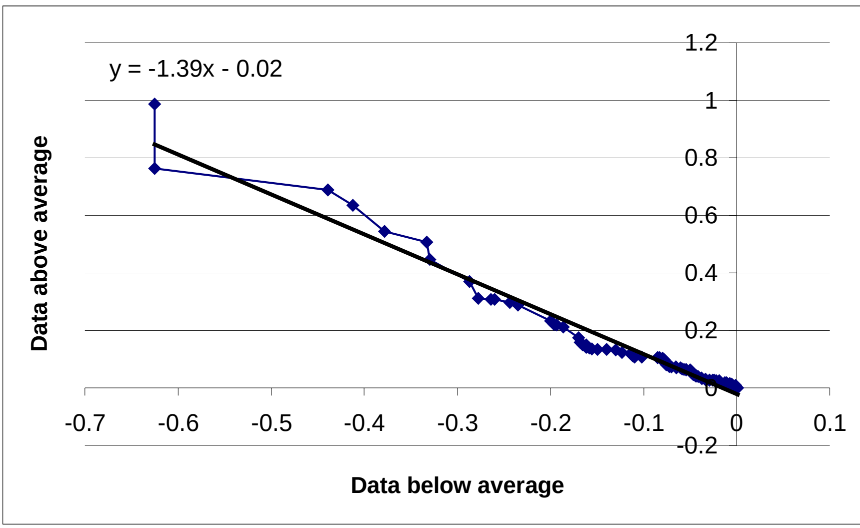
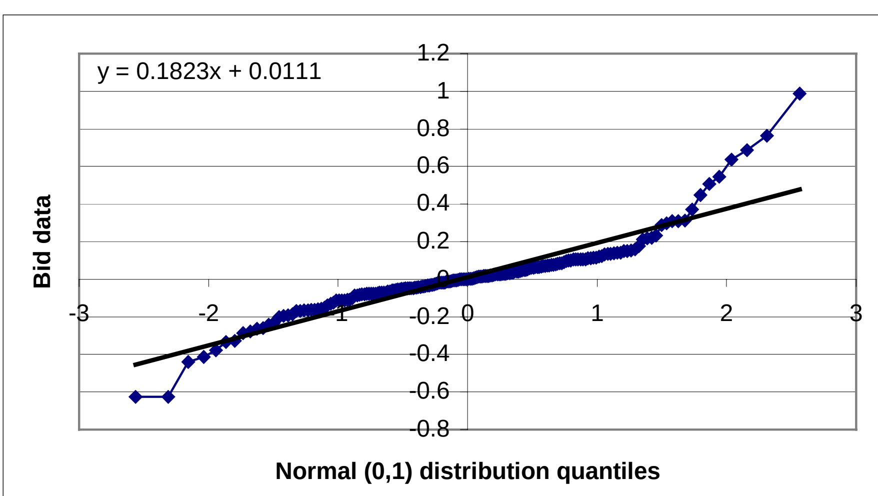


Figure 5.6: *Q-Q plot of all bid data.*



Assuming that a normal distribution is applicable for each case also the sum of all cases can be considered, as the sum of normal distributions with the same mean is itself a normal distribution again. In this way we have almost 200 data points. With these points we performed a symmetry check, see Figure 5.5. In addition, we made a Q-Q plot in order to check whether the aggregation of all bid data could be fit with a normal distribution, see Figure 5.6.

In Figure 5.5 the bid data were divided into two, comparing the lowest with the highest value, the next lowest with the next highest and so on. Having a symmetric distribution and applying linear fitting would lead to a slope of that fit equal to –1. In this case the slope is more negative, indicating the upper tail of the distribution is wider than the lower tail, i.e. there is more excess in very high bids than in very low bids.

Furthermore, the Q-Q plot in Figure 5.6 indicates that the bid data can not be fit with a normal distribution. The right tail is clearly above the linear fit, whereas the left tail is below. This indicates a probability distribution with a bigger probability density for the tails would give a better fit. Note that for the triangular and uniform distribution this probability density of the tails is even less than for the normal distribution, making them therefore even less applicable compared to the normal distribution. Distributions that assign a bigger probability distribution to the tails are Student t-distributions. Referring to the beginning of this section, the evidence we found for fat tailed distributions seems to support the suspected presence of the winner's curse and non competitive high bids.

5.3.4 Using the ETQ model in practice: testing the DSS

In this section we discuss the application and evaluation of the ETQ model and the prototype DSS in four semi-structured interviews.

As discussed in the methodology section, the interviews included experiments with the DSS, carried out jointly with purchasing professionals using empirical data from actual supplier selection cases from the professionals' own practice. This enabled us to (1) compare the outcome of using the DSS with the actual number of tenders requested and (2) assess various aspects of the DSS's practical applicability. Table 1 shows some basic and contextual information about the experiments as well as the outcome of the experiments in terms of the actual number of tenders requested by the professionals and the result of using the DSS for each case.

As follows from Table 5.1, the application of the DSS results in values of the ETQ that except for the service provider case closely resemble the actual number of tenders requested. In that respect, the DSS seems to follow the intuitive decisions of the professionals. It is clear that the corporate policies in the companies, insofar as such policies exist, provide a lower bound or range for the number of tenders to be

Table 5.1: *Relevant information about the four experiments.*

Company	**International service provider**	**Retail wholesale company in the sports industry**	**Bank A**	**Bank B**
Product / service purchased	A construction project	Printing business cards	Printing a large scale mailing	Market research services (outsourcing of previously in-house activities)
Tender Process	Restricted EU tender procedure was used: - open call for interested parties - 9 responses received - 3 discarded on knock-out criteria - remaining 6 were asked to quote - final selection from 6 bids received	- identification of 6 possible suppliers - visits by 5 of these candidates - 3 candidates invited to bid - final selection based on bid analysis and visits	- 9 potentially interested suppliers invited to bid - one supplier did not respond and two apologies were received - remaining 6 suppliers submitted a bid - final selection from these 6	- explorative talks with several suppliers - 8 suppliers invited to bid - 3 bids discarded immediately - final selection from remaining bids
Formal bidding policy	No specific rule for the tender quantity in the restricted EU tender procedure	None	- 3-5 bids if the expected price (EP) is under X Euro - more than 5 bids if X < EP < 16X. - in all other cases the EU tender procedures apply	At least 2 bids if the expected purchasing value exceeds Y Euro
Estimated working hours per tender	12 hours	20 hours	10 hours	4 hours
Estimated bid distribution	- (due to confidentiality)	Triangular distr. with 45,000 Euro bid spread	Normal distr. with 35,000 Euro bid spread	Normal distr. with 5,500 Euro bid spread
Result of the DSS	ETQ = 25	ETQ = 4	ETQ = 3	ETQ = 4

requested which still requires substantial reliance on judgement. The large difference in the service provider-case can most likely be traced back to the purchaser's estimate of the size of the supplier market in this case.

After each experiment, we continued the interview with the purchasing professional with an evaluation regarding three main aspects: (1) the descriptive adequacy of the basic ETQ-model, (2) aspects of using the DSS as such in practice and (3) the usefulness of its outcomes and possible extensions. Tables 5.2, 5.3 and 5.4 summarize some of the more insightful responses from the interviewees.

Table 5.2: *Comments on the descriptive adequacy of the ETQ-model.*

	Does the ETQ-model adequately describe practice?
-	This trade-off is not made explicitly; we rather ask ourselves what it will mean for the suppliers: should they invest too much or conversely is there enough incentive? (ISP)
-	It does not take into account the number of suppliers you want to work with (Retail)
-	You don't necessarily get lower bids by inviting more suppliers but rather through negotiations (Retail)
-	Not all tenders are compared in similar ways: tenders that immediately appear inferior are discarded before reading them entirely (Bank A)
-	Suppliers differ in terms of their queries regarding the Request for Proposal (Bank A)
-	This is how one instinctively does this (Bank B)
-	Time pressure, experience and the expected size of the market also play a role (Bank B)

Based on the data shown in Tables 5.2, 5.3 and 5.4 we now aim to extract underlying hypotheses about the three main aspects. Regarding the descriptive adequacy we hold forth that:

- the basic trade-off between opportunity loss and the cost of evaluating tenders may at least partly resemble the actual human thinking process
- the current ETQ model disregards certain restrictions that may be relevant in practice such as (1) the available time for making the decision and (2) the expected size of the supplier market
- the current ETQ model works with certain assumptions that may not hold in practice such as (1) the independence of the suppliers' bids (2) the passive status of suppliers and (3) equal costs of evaluation for each supplier

Regarding the practical use of the ETQ-DSS we argue that the applicability may depend on four categories of factors:

- the individual experience as a purchaser of various products and/or services and the knowledge of the relevant supply markets
- the available internal resources that may supplement a lack of individual knowledge or experience, for example (1) other people in the organization and (2) documents, archives, files and project plans of previous purchases
- the available external information coming from pre-selection – explorative – market research
- the novelty of the specific purchasing situation

Table 5.3: *Comments on working with the DSS***.**

Can the bid spread and the cost of evaluating a tender be adequately assessed in practice?
- In case of repeat buys one is quite experienced (Bank A)
- To a reasonable extent as we file all our tenders (Bank A)
- We estimate the number of hours required for each tender project (Bank A)
- Making estimates can be difficult, one has to distinguish between products and services (Bank B)
- Some of our internal units already conducted this kind of research so there already was some idea of what the bid spread was (Bank B)
- Initial talks with some suppliers had indicated potentially large differences between suppliers (Bank B)
- The spread and evaluation cost are difficult to estimate; purchasers are responsible for a wide range of items and services and consequently lack resources for extensive market research. In fact, market knowledge is gained during the tender project itself. (Retail)
- Everything depends on experience (Retail)
- The degree to which the Request for Proposal is univocal is also important (Retail)
- It will primarily be suitable for commodities (Retail)
- The type of distribution cannot be adequately assessed by users of the DSS (ISP)
- It should be possible to estimate the spread because there already is a budget and the peaks up as well as downwards can be estimated relatively easy (ISP)
- It should be possible to estimate the cost of evaluation because you know what you ask so therefore you know what you will receive from your suppliers (ISP)

Finally, we argue that factors determining the supportive value and useful extensions can be interpreted and classified as follows:

- issues regarding the user-interface, for example the requirement that there should be a low-effort threshold

- issues regarding extensions of the underlying model, for example (1) including other dimensions of supplier performance in addition to price and (2) simulate more actively the suppliers' possible behavior
- the urgency of the decision, which is likely to depend on (1) the corporate policy in that respect and (2) the need for purchasing professionals to convince internal customers in the organization
- the expectation level of the user, as the DSS can at most provide a sense of direction. The latter may be more or less useful depending on the support the decision-maker finds in his/her own experience or elsewhere in the organization

Table 5.4: *Comments on the usefulness and possible extensions of the DSS.*

Will the DSS make decision-making easier and will it be useful in communicating / justifying the decision to others? Which extensions would seem useful?
- It will lead to lower costs provided that the ETQ-DSS is sufficiently convenient (Bank B)
- In new situations it will be nice to use this model (Bank B)
- This DSS is not relevant for us; The number of suppliers to invite is usually already constrained by the characteristics of the market and the number of available suppliers (Retail)
- On the user-interface it should read 'evaluation costs' rather than 'cost/supplier' (Retail)
- It is a tool (Bank A)
- It provides direction (Bank A)
- It may make communication and justification towards internal decision-makers easier; they usually at least want their 'own' suppliers to be invited (Bank A)
- It would be useful to also accommodate the use of other criteria like quality and delivery (Bank A)
- Also take into account the suppliers' behavior and the longer term effects (ISP)
- Include a stage in the application process in which the total size of the supplier market in the EU is estimated (ISP)

5.3.5 General conclusions on ETQ use

We return to the main question with which this section is concerned: to what extent can the ETQ-model – embedded in a DSS – be useful in facilitating and improving purchasing decision-making, in particular decisions regarding the scope of supplier selection.

Overall, based on the tender cases we received and the four semi-structured interviews we conclude that as competitive bidding is a widely used practice, the ETQ model potentially has a substantial practical value.

First of all, our empirical analysis has yielded no evidence that the ETQ-model is in fundamental conflict with the experts' intuition. On the contrary, it seems to closely follow their intuitive reasoning. Despite some evident descriptive inadequacies and perhaps naïve model assumptions, application of the DSS in the four empirical experiments – using the actual bid spreads – yields outcomes that are quite similar to decisions made without the DSS. Furthermore, the analysis clearly showed the DSS's potential in guiding the decision-maker and facilitating communication and justification of the decisions. Existing purchasing knowledge, coming from tangible documents as well as subjective judgements can easily be combined in a flexible decision tool. Also, regarding the user interface – still in a prototype stage – no serious obstacles were identified.

Secondly, some of the limits to the model's applicability and descriptive inadequacies can be removed quite easily in the development of a final DSS. As suggested by our survey of tenders, incorporating Student t-distributions into the DSS is likely to produce more realistic descriptions of suppliers' bids. The basic ETQ-model is not limited to any particular distribution (De Boer et al, 2000), so Student t-distributions should pose no problems. Incorporating the available time for selecting suppliers could already be included without any basic alteration of the model as such and with only minor extensions of the user-interface. Estimating the expected tender evaluation costs is usually based on estimating the required lead-time for a tender. The DSS could simply multiply the tentative value of the ETQ – disregarding time restrictions – with this lead-time and instantaneously point out possible violations of the time restrictions. The time required by suppliers to prepare their tenders is not relevant here, as it is common practice that a request for quotation already specifies the deadline for submission. If the tentative ETQ would result in excessive violations of the time restrictions, the decision-maker could easily consider lower values of the tender quantity – in a 'what if' manner – and immediately assess the resulting opportunity loss.

As was shown in our empirical experiments, estimating the expected bid spread may be difficult in case of relatively inexperienced purchasers and/or lack of internal or external sources of knowledge. Incorporating a simple and easily accessible database of past tenders in the DSS – or linking the DSS to such a database – could substantially reduce this limitation. Simply filing the values of the received bids for each tender project allows for easy calculation of the bid spread, which can be used in future cases. In that way, an average bid spread can be calculated, in general as well as for specific categories of purchased items and services, or even per supplier. After all, this information will by definition become available, whether any DSS is used or not. Even inexperienced purchasers will after some tenders have collected some data to work with. Similarly, a purchaser could simply take some rough measures of how much time it takes to evaluate tenders for basic types of purchases they are involved in.

Finally, we briefly discuss some extensions resulting from the empirical analysis, which may require more substantial research and development effort. Following up on the suggestion to collect data from tender projects, the DSS could be extended in such a way that each supplier is characterized by a separate bid distribution rather than applying the same bid distribution to all. This leads to the so-called Economic Tender Set. We elaborate on this in section 5.5.

Another extension that was also indicated in one of the interviews concerns incorporating a two-step selection of suppliers using a pre-selection phase. This extension has already been investigated (Heijboer, 2001). Probably a very important improvement would be to include multiple criteria, in addition to price, in the decision process. This would considerably increase the number of situations, to which the model is applicable, because in most situations other criteria such as quality, reliability, delivery time, etc are as least as important. This multi criteria setting is discussed in section 5.6.

5.4. Choosing the open or the restricted procedure: a ***big*** deal or a big ***deal*****?** (based on Heijboer and Telgen, 2002; Heijboer 2001)

In the European Union (EU), Directives (legislation) exist for public procurement (European Parliament and Council 1989, 1992a, 1992b, 1993a, 1993b, 1993c, 1997, 1998). When public agencies want to award a contract with a value above a certain threshold to a third party these Directives have to be followed. These Directives prescribe rules for the award procedures of these contracts. Two award procedures can be followed: the open and the restricted procedure (and in certain specific cases there is the option of the negotiated procedure). The public agency is free to choose one of these two procedures. This section deals with the question: given a case that has to comply with the EU Directives, which award procedure, the open or the restricted procedure, should be chosen?

To answer this question this section is divided into a number of subsections each addressing a sub-question. Subsection 5.4.1 deals with the question: what is it exactly that a public agency has to choose between? The EU directives will be described in more detail focusing on the open and restricted procedures, to whom it applies and to what type of purchases it is restricted. Subsection 5.4.2 deals with the current practice in the EU. Results of research done by the authors on the usage of the two procedures are presented in this section. The difference between countries, the change over time and other relations are investigated. In subsection 5.4.3 we investigate what criteria the choice between the open and the restricted procedure can be based upon theoretically.

With the background of the previous sections, an answer to the main question will be given in subsection 5.4.4. A quantitative approach was developed for the decision on which procedure to choose. Here the total costs are the estimated costs of the contract (the actual contract price) together with the estimated costs of the procedure itself. A model is presented with which the total costs of both procedures can be estimated, making it possible to choose the most economic procedure.

The model, its validity and implications, as well as possible extensions, are discussed in subsection 5.4.5. Finally, conclusions are drawn and recommendations are given.

5.4.1 Description of the EU Directives for public procurement

The idea of the EU Directives originated from the White Paper by the European Commission on the internal market (European Commission, 1985) as one of the main issues. The aim was to create a single transparent internal market. However there were two common practices in the EU preventing this (Erridge, Fee and McIlroy, 1998; Uttley and Hartley, 1994): preferential purchasing (preferring certain suppliers not based on economic reasons, discrimination) and protectionism by governments ("buying national" policies). Both practices prevent market competition to a certain extent or even completely. Lack of competition leads to higher prices and less investment in innovation. In other words, the taxpayer's money is not spent efficiently. The potential on public procurement in the EU savings because of this was huge, estimated at up to 0.5 % of the EU GDP (Cecchini, 1988), while the expenditure of public agencies was about 11 per cent of the EU GDP (European Commission, 1996).

The new legislation framework was finished in 1993 (European Parliament and Council 1989, 1992a, 1992b, 1993a, 1993b, 1993c), and EU Directives on Public Procurement were introduced. The Directives are regulated ultimately by the European Court of Justice. The function of the directives is to provide transparency and to give rules of conduct for the whole procurement process: objective specifications, types of award procedures and time limits. To ensure transparency and also enough publicity, all notices about public contracts (the announcement of the contract to be awarded and to whom it is eventually awarded) have to be published in the Supplement to the Official Journal of the European Community and the TED (Tenders Electronic Daily) database. This database can be found at http://www.ted.eur-op.eu.int.

After 1993 two developments led to a few changes in the legislation. First, in 1996 the existing Directives were evaluated (European Commission, 1996) and it was concluded that compliance with the Directives could and should be improved. This has led to a proposal for new directives with the following improvements (European Commission, 2000): "The main theme to emerge from the Green Paper (referring to European Commission, 1996) debate is the need to simplify the legal framework and adapt it to the new electronic age while maintaining the stability of its basic structure." This is still being discussed in the EU. Secondly, the EU signed the

Agreement on Government Procurement (GPA) of the World Trade Organization (WTO) together with 10 other countries one of which was the USA. The GPA is similar to the EU Directives, but less strict and less detailed. From 1998, on the EU Directives were changed in such a way that they were in agreement with the GPA (European Parliament and Council, 1997 & 1998).

Note that for the utilities sector (energy, water, transport and telecommunications) a separate set of directives exists (similar to the general Directives though), but those will not be discussed here.

The Directives apply to public agencies that plan to award to a third party a contract above a certain financial threshold. The following agencies are defined as public agencies: (a) the State including governmental bodies such as central government (ministries), regional and local authorities (provinces, municipalities, etc); and (b) bodies governed by public law (or associations/cooperations of those bodies), that satisfy all of the following criteria:

- being established for the specific purpose of meeting needs in the general interest, not having an industrial or commercial character
- being a legal entity
- being either financed, for the most part by the State (defined as above) or other bodies governed by public law, or subject to management supervision by those bodies or having an administrative, managerial or supervisory board, more than half of whose members are appointed by the State or by other bodies governed by public law.

In the Directives, distinction is made between three types of purchases (contracts): (a) Works contracts for construction (buildings, roads, etc), (b) Supplies: contracts for physical products and (c) Services: the rest. For each type, a different Directive applies. The Directives only need to be applied when the value of the contract exceeds a certain threshold, which is different for each contract type. Furthermore, since the implementation of the GPA, there are new thresholds for those contracts to which the GPA applies. For the contracts to which only the Directives apply and not the GPA, the old thresholds are still used. The thresholds are shown in Table 5.5.

When the Directives apply, the public agency can choose freely from two award procedures: the open and the restricted procedure. In exceptional circumstances three more procedures are available: the accelerated restricted procedure and the negotiated procedure with and without publication of a contract notice. These special circumstances can be among others: lack of tenders (bids) in the open and/or restricted procedure, extreme urgency, and additional services to a contract that is already awarded.

Also, it is possible for the public agency to publish an annual notice indicating certain purchases for the coming year. In both procedures no negotiations with suppliers are allowed. Information has to be shared with all potential suppliers equally. Furthermore the specifications need to be written in such a way that they are non-discriminatory for all suppliers (for details see the Directives).

Table 5.5: *Contract thresholds** of the Directives.*

Type of contract	Public agency	New Thresholds in SDR*	New thresholds in Euro	Old thresholds in Euro
Works	all	5,000,000	6,242,028	5,000,000
Supplies	central govt.	130,000	162,293	200,000
	other	200,000	249,681	200,000
Services	central govt.	130,000	162,293	200,000
	other	200,000	249,681	200,000

*SDR: Special Drawing Right issued by the International Monetary Fund (IMF)

** Value Added Tax is excluded from the threshold amount

Source: TED Database

In an open procedure any interested supplier may submit a quotation in response to the publication of the invitation to tender (contract notice). With that publication the public agency needs to have all contract and supporting documents (specifications) ready and available. The minimum deadline for the receipt of tenders is 52 days after the publication of the notice. When the purchase is indicated in the annual notice, this minimum deadline is reduced to 36 days. After the deadline the contract is awarded to the supplier with the best bid based on the award criteria.

In a restricted procedure there are two stages. In the first stage any interested supplier may submit a request to participate in response to the publication of the contract notice and will then be considered as a candidate. The minimum deadline for the receipt of requests to participate is 37 days after the publication date. After this stage candidates are selected based on objective criteria (decided upon before the start of the restricted procedure) regarding the supplier such as: grounds on which candidates can be excluded (bankruptcy), financial standing, ability and technical capability, registration in a trade register. The number of candidates to be selected is open for the public agency (but should be decided before the start of the procedure), however the minimum is five. If there are fewer than five candidates, then all candidates who meet the criteria have to be selected. In the second stage the contracting authority sends an invitation to tender to the selected candidates and therefore needs to have all contract and supporting documents ready and available at this point. The minimum deadline for the receipt of tenders is 40 days after sending the invitation. After that the contract is awarded to the supplier with the best bid based on the award criteria. A restricted procedure can be accelerated in exceptional cases when objectively proven urgency renders it impossible to respect the normal deadlines (reducing the 37 and 40 days to 15 and 10 days respectively).

In the two negotiated procedures, contracting authorities consult the suppliers of their choice and negotiate with one or more of them the contract conditions. Similar rules on minimum deadlines and notifications apply. Discussing these rules in detail is outside the scope of this section, because a public agency is not free to choose for a negotiated procedure. Negotiated procedures are therefore not often used as can be seen in the next section.

The contracts in the open and restricted procedure are awarded on one of the two award criteria: (a) lowest price and (b) economically most advantageous. The latter award criterion may be composed of several objective criteria that have to be mentioned in the invitation to tender: quality, technical assistance and service, delivery period, price, etc.

5.4.2 Usage of the award procedures in practice

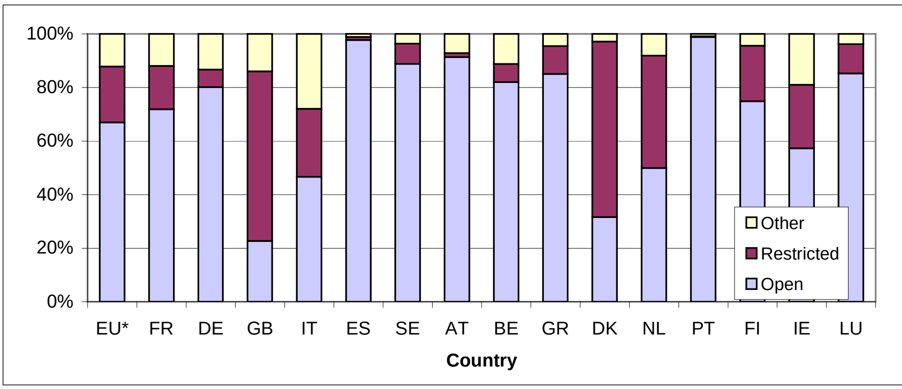
As stated in the previous section, public agencies have a free choice between the open and restricted procedure. Now it is interesting to know which procedure is preferred in practice. To check this, we conducted a study using the TED database. In this online database all data of contract and contract award notices from 1995 onward is available.

With this data different parameters were investigated that could be of influence on the preference for one award procedure above the other: (a) the country to which the public agency belongs, (b) the contract type (Works, Supplies or Services), (c) development over time and (d) contract price.

First, the difference in preference within each country was checked. This was done by looking only at all award procedures (contract notices) that were announced by EU countries in the year 2000 (also award procedures of some other countries are published in the TED database). Furthermore, we excluded the utilities sector, as the EU Directives are somewhat different. Even with these restrictions the number of awards procedure was 79,163, a number that has been steadily growing in the last few years from 53,368 in 1996. Figure 5.7 shows the award procedures used in percentages for each EU country. They are ordered from the left to the right in the decreasing number of contract notices (from France, 28,734 notices were published, from the Netherlands, only 1,390 notices). Note that the "other" procedures consist of the accelerated restricted procedure and the negotiated procedures. They were grouped together as all these procedures can be chosen only under specific conditions.

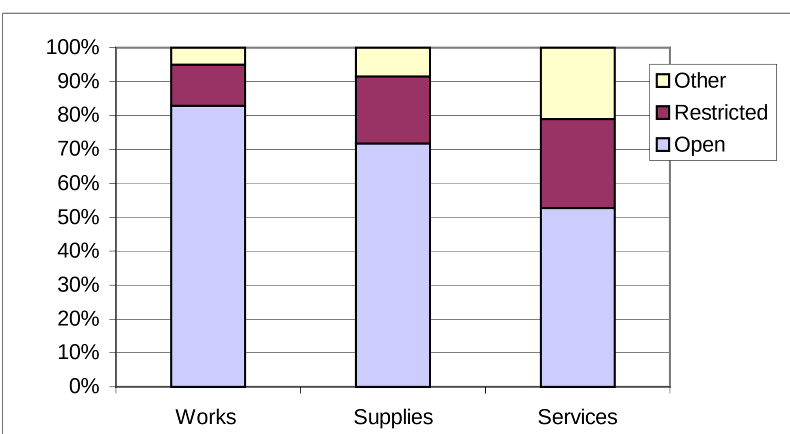
There is a noticeable difference between the countries. Although most countries prefer the open procedure, countries like Great Britain and Denmark mostly use restricted procedures. An obvious explanation for these differences could be national legislation, which of course public agencies have to comply with. It could be that only one type of procedure is allowed, explaining why some countries prefer the open procedure in 90% of the cases or more. This issue will be addressed in the discussion section.

Figure 5.7: *Use of award procedures in the countries of the EU in 2000.*



*Sum of all EU countries

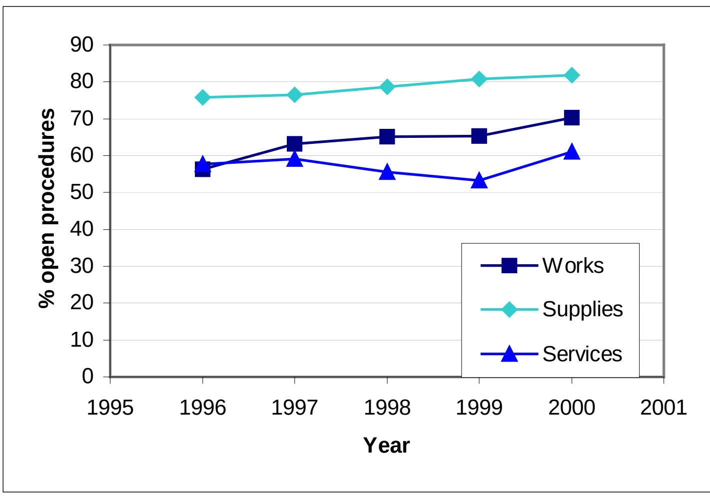
Figure 5.8: *Award procedures used for different contract types in 2000.*



Secondly, interesting insights emerge by distinguishing the award procedures used for different categories of contracts (works, supplies, services). Figure 5.8 shows that difference for the three categories in the year 2000. Again the open procedure is the most common one, but especially for services the restricted procedure is still used in more than 25% of the cases. A reason could be that, on average, specifications for certain contract types are easier to make. Specifying services can be very complex and public agencies may want to focus more on the qualities of the supplier by using a restricted procedure (only selecting a few suppliers with good quality).

Furthermore, the picture as shown in Figure 5.8 has not changed much from the picture of the years before. However, from 1996 on a slight trend is toward the use of open procedures; the percentage of open procedures used was 78%, 64% and 41% for Works, Supplies and Services, respectively, compared to 83%, 72% and 53% in 2000.

Figure 5.9: *Development in the preference for open procedures in France.*



Thirdly, the development of a few countries over time is taken into consideration: France, United Kingdom and the Netherlands. These three countries are particularly interesting as the first one has a high percentage of open procedures (as most EU countries), the second one a high percentage of restricted procedures and the last one is in between (see Figure 5.7). Figure 5.9 shows that for France the percentage of open procedures has been increasing gradually for all types of award procedures. A comparison of Figure 5.9 with Figure 5.8 indicates that even more open procedures are used for supplies and services in France than in the EU, but French procedures for public works are equal to those of the EU. The trend for France is typical for most EU countries that have a high percentage of open procedures (like Germany, Sweden, etc). The United Kingdom is the country that deviates most from the EU average. Note that Figure 5.10 shows the preference for the restricted and not the open procedures. Although the preference for restricted procedures for

Figure 5.10: *Development in the preference for restricted procedures in the UK.*

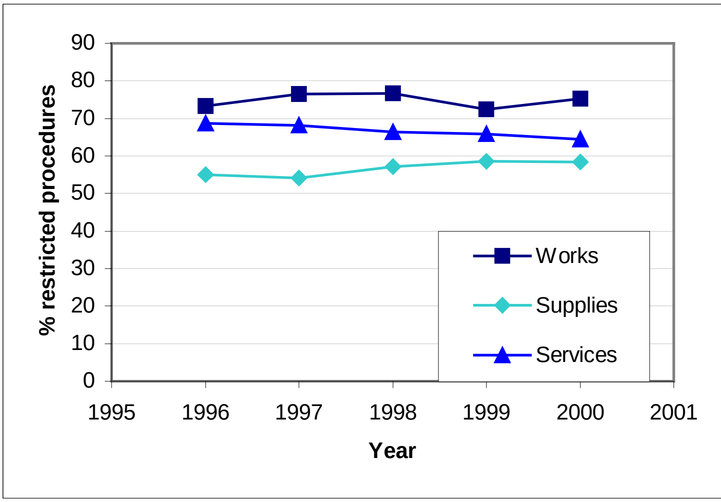
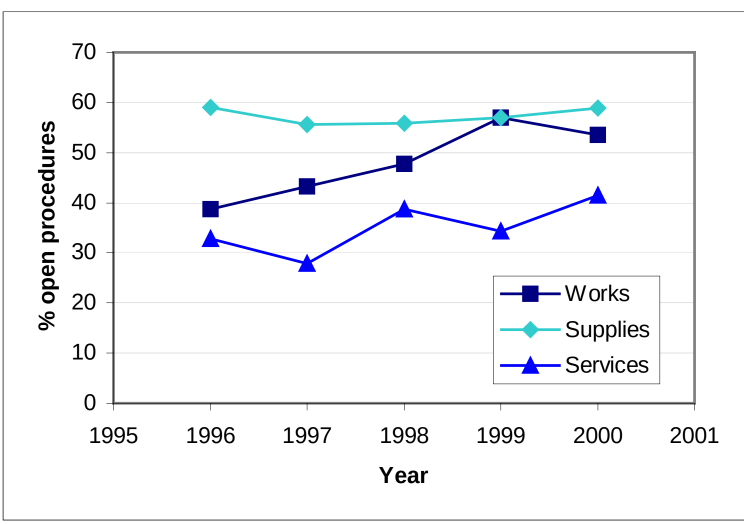


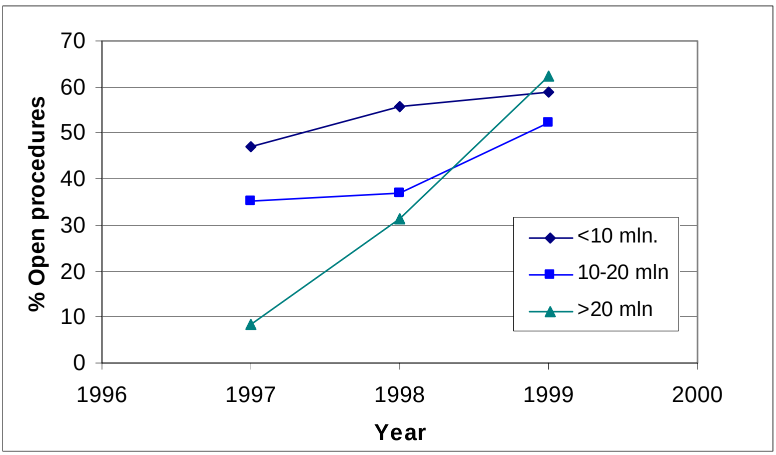
Figure 5.11: *Development in the preference for open procedures in the Netherlands.*



services is slightly declining, for public works and supplies it certainly is not. The Netherlands has on average not a clear preference for one of the procedures and maybe that is why it has been one of the countries with the greatest changes in preference in the last few years as can be seen in Figure 5.11. It shows that also here there is a trend toward open procedures, although for services the percentage of open procedures is still well below 50%, meaning that the restricted procedure is still preferred there (as the percentage of other procedures is small).

Fourthly, we studied the relation between the use of procedures and the contract price. This was done for all public works contract awards in the Netherlands from 1997 until 1999. Figure 5.12 shows the results. The relation between the use of procedures and the contract price is remarkable. As shown in Figure 5.11 for public works in the Netherlands, the open procedure has been used more often in the last few years. However, at first, it was hardly used for valuable contracts (less than 10% in 1997). Apparently in most cases the policy was to use the restricted procedure for contracts above a certain threshold price. However this changed dramatically in two years, as in 1999 the percentage of open procedures hardly differs for the different price categories.

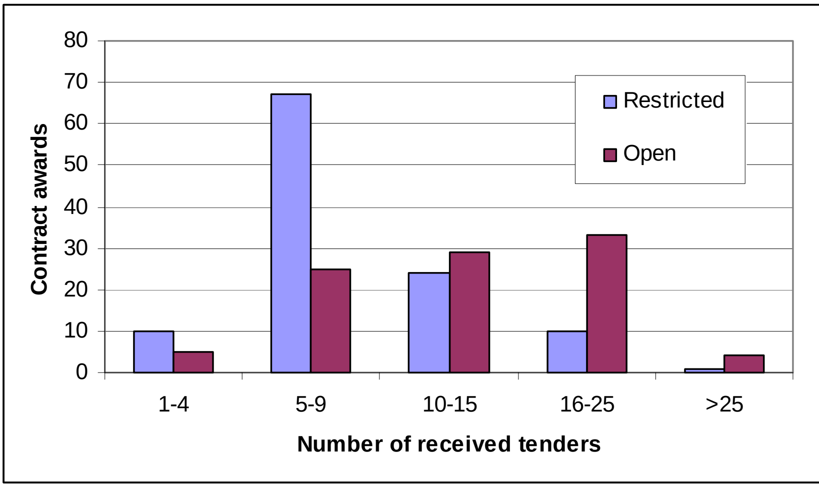
Figure 5.12: *Percent Use of Open Procedures over Time by Contract Price for Works in the Netherlands* (in Dutch guilders; 1 Dutch guilder = 0.45 Euro).*



*Percentages are based on the award notifications published in a particular year in which the contract price was mentioned (93% of all contract award notifications).

Finally, we investigated the relation between the award procedure used and the number of received tenders. Again, this was done for all public works contract awards in the Netherlands from 1997 until 1999. Figure 5.13 shows the results. To make it more clear, for the restricted procedure the numbers shown in Figure 5.13 are the number of tenders received after the invitation, not the number of interested suppliers before pre-selection. Although the latter would also be interesting, unfortunately this data is not available in the TED database.

Figure 5.13: *Submitted tenders for works in the Netherlands in 1997-1999.*



From the practical evidence shown in this subsection it can be concluded that no uniform policy exists for choosing the open or the restricted procedure. The open procedure is used most and the percentage of open procedures is still increasing in the EU (67% open procedures in 2000 compared to 61% in 1996).

5.4.3 Criteria for choosing between the open and restricted procedure

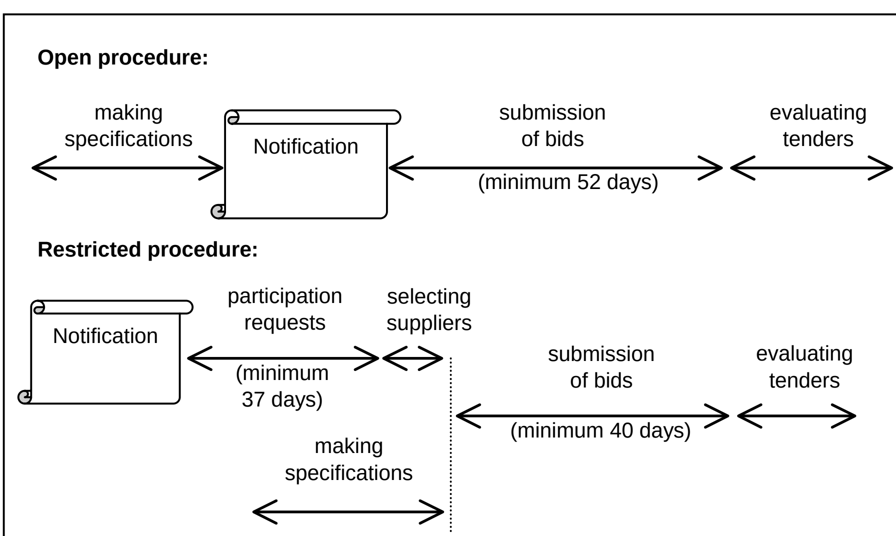
The open and restricted award procedures are two specific cases of tender procedures. Now the question arises whether the open or the restricted procedure should be chosen for a specific case.

Clearly the open procedure allows free entry of bidders, whereas the restricted procedure uses invited bidding. Hence the same advantages and disadvantages of the two different ways of bidding apply to the two different award procedures. With this background knowledge about tender procedures in general, criteria can be defined for choosing between the open and the restricted procedure:

- *Expected level of competition.* The level of competition in the market is indicated by two variables: the expected spread in the bids received and the expected number of tenders for the open procedure / participation requests for the restricted procedure to be received. The higher the level of competition is, the higher the savings can be by maintaining a high level of competition using the open procedure or the restricted procedure with a large number of selected suppliers. Obviously, if the spread in the bids is high, receiving more tenders will be more useful than when the spread is low (having all suppliers quoting more or less the same price).

- *Expected tendering costs.* These costs (mainly consisting of time spent by employees) can be split up into two parts: fixed and variable costs. Fixed costs include the costs of setting up the award procedure. These costs could be different for both procedures, but in practice they are similar as the same documents need to be made (specifications, invitation to tender, supporting documents). Variable costs include the costs related to each tender and in case of the restricted procedure also the costs related to each request for participation. The variable costs could be considerably less for the restricted procedure compared to the open procedure as the number of tenders is limited and known.
- *Available time.* The open procedure seems more favorable from a time perspective as the minimum time involved is 52 days. The restricted procedure is 77 days (37 days for the first stage and 40 days for the second stage). However the exact specifications have to be ready at the start of the open procedure, but for the restricted procedure they only have to be finished after the selection of suppliers (first stage). Thus selecting suppliers and making the specifications at the same time may save the extra time. Furthermore, after the last deadline the round up of the restricted procedure may go faster than the open procedure because usually fewer tenders have to be evaluated. The time involved for each procedure is illustrated in Figure 5.14.
- *National legislation and cultural differences.* As stated previously national legislation could prohibit the use of one of the procedures. Moreover, policies within the public agencies could exist that state how the procurement process should be executed (using one of the award procedures), reflecting the culture of the agency.

Figure 5.14: *Timeline for the open and restricted procedure.*



5.4.4 Quantitative analysis of the decision between the open and the restricted procedure

The first two criteria at the end of the previous section (the expected level of competition and the expected tendering costs) have been combined in a quantitative model (extending the ETQ-model) to find how the costs of the best offered bid and the tendering costs are reflected in the choice between the open and the restricted procedure. To be clear about the decision problem, a public agency has the following choices for purchases that have to comply with the EU Directives before starting the award procedure: (a) choose either the open or the restricted procedure and (b) choose the number of candidates to be selected in case of the restricted procedure.

The assumptions used for the ETQ model also apply to this extended model. In addition we assume that the suppliers not only submit a bid as described for the ETQ model (section 5.2), but also that the bid distribution used by the suppliers is independent of the award procedure chosen by the public agency.

To extend the ETQ-model for the decision between the open and the restricted procedure, the different tendering costs for both procedures have to be modeled. First the fixed tendering costs have to be taken into account. For the decision only the difference between the fixed costs for both procedures is relevant.

For the variable costs we start by defining the (proportional) costs per tender for the open procedure as K. In the restricted procedure there are two evaluation/selection processes: selecting the candidates in the first stage and evaluating the tenders in the second stage. For the first stage these costs per participation request are defined as $\alpha \cdot K$. Here α will typically be near 0, something like 0.1, because evaluating a supplier based on a few criteria in the first stage is much less work than evaluating the whole tender. For the second stage the evaluation costs per tender is defined as $\beta \cdot K$. Here β will be typically near but lower than 1, because evaluating the tender after the first stage will still be almost as much work as that without the first stage as seen in the open procedure. Furthermore typically $\alpha + \beta$ will be somewhat larger than 1 as splitting up the evaluation for a tender in the restricted procedure will result in more work than doing it all at once, as is happening in the open procedure.

Another extension of the model is that the number of suppliers that will submit a tender has to be estimated. This number could depend on the procedure used. This can be caused by the fact that it is easier (cheaper) to submit a participation request than a complete tender. Also, suppliers might have different perceptions with respect to the chances of winning the contract depending on the procedure used. The expected number of tenders in the open procedure is defined as T_o and in the restricted procedure the expected number of participation requests as P_r. These expectations can be modeled by a probability distribution. In the restricted procedure the public agency can decide itself on how many suppliers to invite for submitting a tender. This number is defined as T_r. With the expected number of tenders the expected lowest bid can be calculated.

Choosing the open or the restricted procedure now boils down to calculating which procedure has the lowest total costs. The expected total costs *TC* are defined as the sum of the expected lowest bid (the actual contract price) and the expected total tendering costs. Given the input above the *TC* of the open procedure (TC_o) can be calculated, whereas for the restricted procedure these *TC* are still dependent on the choice of T_r (number of candidates). However, the optimal T_r (the ETQ for the restricted procedure or ETQ_r) can be determined by using the ETQ-model. Then TC_r are the total costs of the restricted procedure choosing the ETQ_r.

To illustrate how the model works an example is given below. Here it is assumed that all bids are a random pick from a uniform probability distribution between a minimum *a* and a maximum *b*. The difference between *a* and *b* (b-a) is defined as the bidspread. Given *n* tenders, for a uniform distribution the expected minimum bid E_{min} is (De Boer et al., 2000):

$$E_{\min} = a + \frac{bidspread}{n+1} \tag{5.4}$$

The fixed tendering costs are omitted as we assume they are the same for both procedures. For the open procedure expecting T_o tenders, the expected total costs in this case are:

$$TC_o = K \cdot T_o + a + \frac{bidspread}{T_o + 1} \tag{5.5}$$

For the restricted procedure with P_r participation requests and ETQ_r selected candidates the expected total costs are:

$$TC_r = \alpha \cdot K \cdot P_r + \beta \cdot K \cdot ETQ_r + a + \frac{bidspread}{ETQ_r + 1} \tag{5.6}$$

The ETQ_r can easily be determined by minimizing TC_r, taking first and second differences with respect to ETQ_r:

$$\frac{\partial TC_r}{\partial ETQ_r} = 0; \quad \frac{\partial^2 TC_r}{\partial ETQ_r{}^2} > 0 \tag{5.7}$$

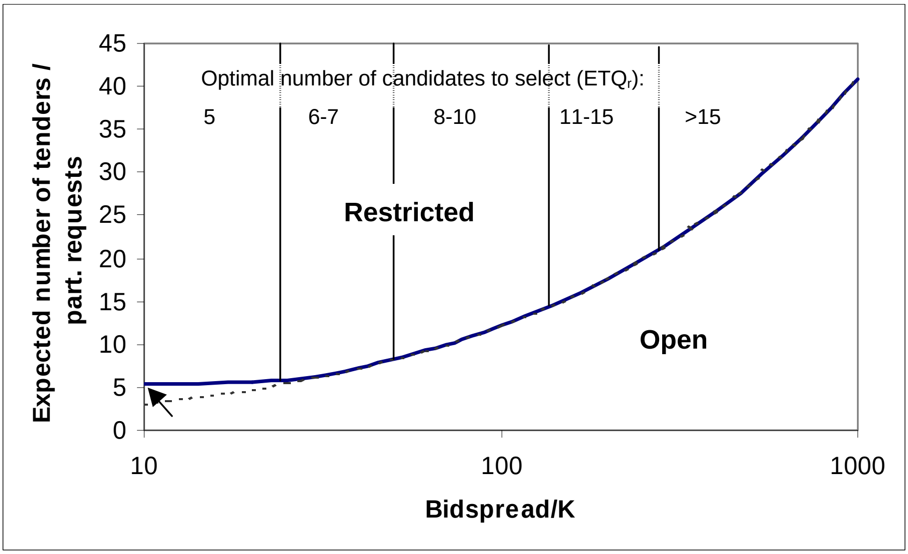
The result for the optimal number of candidates to select is:

$$ETQ_r = -1 + \sqrt{\frac{bidspread}{\beta \cdot K}} \qquad (5.8)$$

Here ETQ_r is taken as a continuous variable, to be more precise the actual ETQ_r is an integer, so either the integer value just above or below the value found with (5.8). And of course at least one tender is required, thus ETQ_r is at least 1. As a rough indicator consider the case where the bidspread is in the order of 10-100% of the contract price, while the costs per tender are in the order of 1% of the contract price (and β close to 1). ETQ_r will then range from 1 to 10.

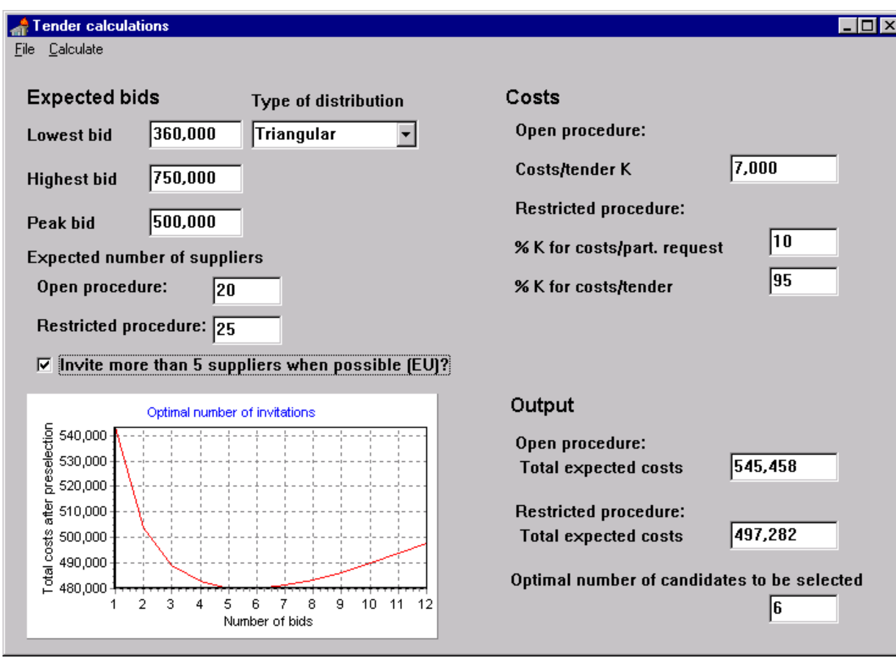
If the number of participation requests is below the value found in (5.8), then selecting ETQ_r candidates is not possible; only fewer can be invited. In that case, selecting as much as possible (as close to ETQ_r as possible), thus all P_r suppliers will give the minimum expected total costs for the restricted procedure. Furthermore if ETQ_r is below five, than it has to be taken as equal to five because of EU Directives (or equal to the number of participation requests if that is below five). In summary, preference for either the open or the restricted procedure will depend on the difference between (5.5) and (5.6), hence depending on: α, β, T_o, P_r and the ratio of the bidspread to K.

Figure 5.15: *Choosing between the open and restricted procedure for a uniform distribution (α = 0.1; β = 0.95; To=Pr).*



To give an idea of which procedure should be preferred, we take α and β fixed and we assume that the number of expected tenders in the open procedure is equal to the number of participation requests in the restricted procedure ($T_o=P_r$). This leaves only two dimensions and makes a graphical representation possible as can be seen in Figure 5.15. A borderline divides the plot area into two parts: the right lower part with the lowest expected *TC* for the open procedure and the left upper part for the restricted procedure, assuming that the optimal number of suppliers is selected (therefore subdividing the left upper part for different ETQ_r). What also can be seen in Figure 5.15 at the arrow is the effect of the EU legislation requiring the invitation of at least five candidates in the restricted procedure (the dotted line would apply when this rule did not exist). Logically as the number of candidates in the restricted procedure cannot be chosen optimally, the open procedure gains some territory.

Figure 5.16: *Screenshot of the DSS for choosing between the open and restricted procedure.*



To overcome the limitations of graphic representation and to facilitate practical use the model has been implemented into a DSS similar to the ETQ-DSS. A screenshot can be seen in Figure 5.16. Different scenarios (values of the input parameters) can be checked quickly and also other probability distributions for the bids (like the triangular one) can be chosen. Interesting to see is that with the numbers used in Figure 10 there is about a 10 % difference in the expected total costs for both procedures. This is a typical percentage that can be found giving an idea of the savings that can be achieved by making the most economic decision.

5.4.5 Discussion

The model presented in the previous section gives a good insight to the trade-off between costs and benefits for both award procedures. However the merit of actual outcome (the numerical values) depends on the quality of the estimation of the input parameters. The expertise of the (tactical) purchaser is needed for that (knowledge of the market, knowledge of his/her agency's own purchasing process). The research results from section 5.3 already indicated that estimating the distribution of the bids beforehand was difficult, whereas estimating the tendering costs (average number of working hours allocated to each tender) was easier.

Furthermore, as the model only presents expected total costs, the eventual realization might be different, as it is based on estimated parameters. Therefore the model must be seen as an indicator for which procedure to use. Again the expertise of the purchaser will be needed to see to what extent the model is applicable in a particular situation.

Clearly the model promotes using a differentiated policy, i.e., basing the actual decision on the characteristics of each case separately and not having a general rule of, for instance, always using the restricted procedure with a fixed number of candidates. Also preferring one procedure above a certain threshold value of the contract award does not make sense, as it is not a variable that influences the decision in this model. But the expected spread in the bids is. And the absolute value of the bid spread could be more for contracts with a higher value.

It is good to realize that only the contract price and the costs are included in the model. Other criteria, like the time involved and quality of the contracts are not taken into account. Considering these other factors may lead to a different decision. The same holds when the underlying assumptions of the model do not apply or only hold to a certain extent.

First, it is not clear yet whether it is reasonable to assume that each bid will be offered from the same probability distribution. The model could be extended to let each bidder choose from its own probability distribution, see section 5.5 on the ETS. Secondly, the assumption that all bids are independent is very important in this model, because it is the reason that the lowest expected bid will be lower for more suppliers. When there is a collusion of suppliers, the price mechanism is completely different. For instance the model shows that the EU rule of having to select at least five suppliers in the restricted procedure does not make sense, as it only increases the total expected costs. However it may be a necessary precaution to reduce the chance of the market mechanism being compromised. Thirdly, the tendering costs have been taken linear with the number of tenders, but in principle any cost function can be included just as easily.

We plan to test the practical use of the model (with the DSS) in the near future. It should aid the purchaser of a public agency in deciding between the open and the restricted procedure in such a way that it leads to a more efficient decision. Also it should facilitate communication of those decisions to others, because tools like this add to the objectivity of the decision by not having based every decision on the experience and knowledge of the purchaser alone.

Finally, although the model here specifically addresses the award procedures in the EU, it can be generalized to deciding between open and invited bidding, because the open and restricted award procedure are just an example of these two types of bidding. With this generalization the practical use of the model is not limited to the public sector only, as private companies are free to arrange the bidding procedure as they like.

5.4.6 Conclusion regarding EU award procedures

In the EU different ideas exist about which kind of award procedure to use for different situations. This is probably the reason why there is a free choice between two procedures and not just one procedure that has to be followed. Empirical evidence shows that preferences vary in different countries, for different contract types and are changing over time, the last few years more and more toward the open procedure.

According to the literature, the preference for either the open or restricted award procedure should be based on the following criteria: the expected level of market competition, expected tendering costs and time that will be involved. The values of the criteria are different for each specific case and it is therefore recommendable for a policy to be effective that these criteria and values are incorporated in it. And of course legislation and existing policies within public agencies have to be taken into account, but those can be changed (the latter one more easily than the first one, obviously). Especially as the preference nowadays is still closely tied to the specific country, it seems that cultural differences are more important than the other criteria mentioned above.

A quantitative approach to this decision problem has led to a model and a DSS calculation of the expected total costs of both procedures based on the level of competition and the tendering costs under certain conditions. The practical applicability still has to be proven, but this tool already gives a good indicator of the most efficient procedure in general. Extensions already indicated in the discussion and based on feedback from practice will increase applicability (like allowing for a certain level of collusion of suppliers, including more dimensions with regard to the contracts, i.e., not only price but also quality, service level, etc)

Concluding, to award contracts efficiently, it is necessary to vary the award procedure used. Thus observing this variance in preference in practice is a good sign. At this point we can only hope it is based on the correct analysis.

5.5 The economic tender set

An obvious extension of the ETQ model is to include individual behavior of suppliers. This has also been suggested by the practitioners we interviewed (section 5.3). Especially when a tender procedure involves a (modified) rebuy of a product or service, the purchaser probably has data available on previous purchases. Moreover, often a (short)list of suppliers is already available. Such known sets are quite common in practice and usually referred to as ‘approved vendors’ or ‘preferred suppliers’. If there is sufficient data, it could be possible to estimate the bid of each supplier separately rather than looking at the market as a whole.

The problem statement then changes to: how many and *which* of the suppliers should be invited to submit a tender in order to have minimal total costs? The set of invited suppliers that leads to the minimal total costs is defined as the Economic Tender Set (ETS). This preliminary discussion of this ETS extension can already be found in De Boer et al (2000).

In mathematical terms we assume that each supplier i submits a random bid from his own probability distribution $f_i(x)$, instead of having just one probability distribution $f(x)$. Compared to the section 5.2, calculating the expected minimum bid changes somewhat. We assume a set of in total N suppliers. The cumulative distribution of the minimum bid $F_{min,S}(x)$, when inviting a subset S out of the N suppliers is:

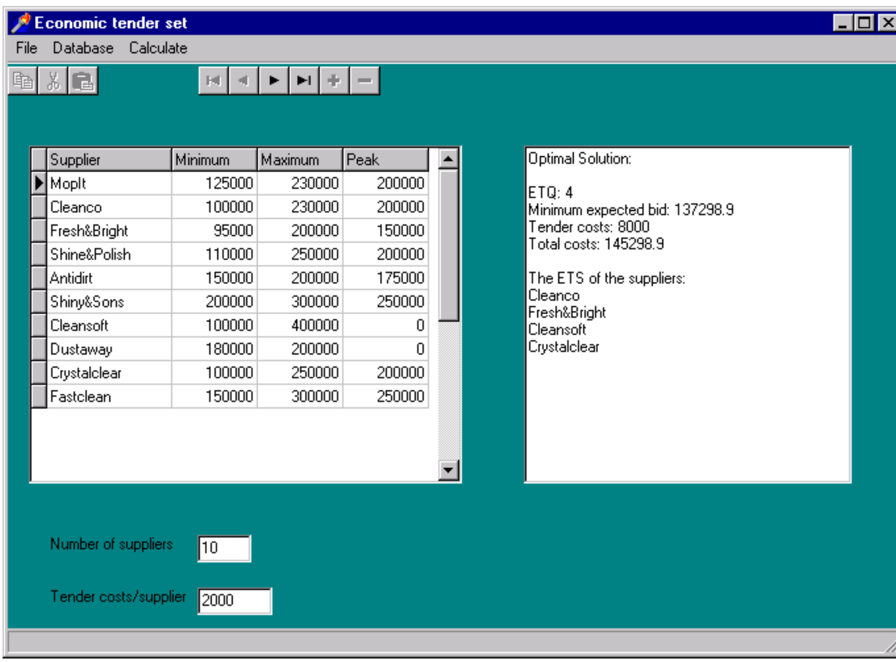
$$F_{\min,S}(x) = 1 - \prod_{i \in S} \left(1 - F_i(x)\right) \tag{5.9}$$

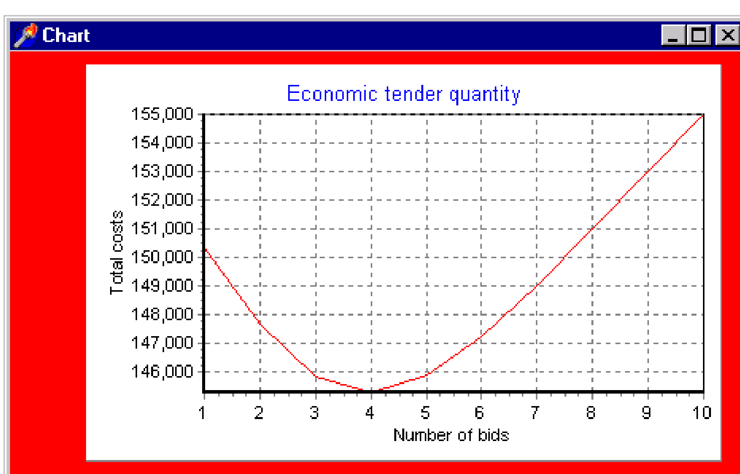
The expected value of the lowest bid $E[X_{min,S}]$ for the same set is given by:

$$E\left[X_{\min,S}\right] = \int_0^\infty \prod_{i \in S} \left(1 - F_i(x)\right) dx \tag{5.10}$$

We assume no changes to the original ETQ model in the tendering costs. Hence, they are still proportional to the number of suppliers in set S, which is invited to bid. Calculating the ETS is a combinatorial optimization problem. Actually, determining from all subsets of a certain cardinality the subset which minimizes the expected value of the lowest bid is NP-hard (Eppstein and Lueker, 2001). However, for up to about 20 suppliers the number of possible combinations is small enough to do a full enumeration.

Figure 5.17: *DSS for calculating the ETS. A supplier database for cleaning services is shown. The graph shows the expected costs as a function of the number of suppliers invited.*





Looking at (5.10) the problem the (numerical) calculation of the integral can be simplified. Let us for simplicity assume that each bid distribution has a minimum value below which and a maximum value above which the probability is zero. As (5.10) involves the product of distributions, it is easy to see a supplier whose minimum value is larger than the smallest maximum value of any other supplier will not help to reduce the expected minimum value. Therefore, this supplier can be excluded from the problem. This also holds for the tails of all bid distribution extending above this smallest maximum value. Hence, for calculating the integral this smallest maximum value can be used as the upper bound.

In general (5.10) shows that it will be worthwhile to invite more suppliers when the overlap in the bid distributions is higher. Intuitively this is also clear. When the overlap is small, it means one or a few suppliers will always submit a lower price than the others. Hence, competition is limited and the expected minimum value will only depend on that one (or few) supplier(s).

Similar to the ETQ-DSS we developed a prototype DSS for the ETS problem. As input a supplier database is needed which an expected bid distribution for each supplier. In addition the tendering costs have to be estimated. The DSS then presents the optimal solution along with a graph showing the total expected costs as a function of the number of suppliers. A screenshot can be seen in Figure 5.17. Note that we still assume the same tender costs per supplier. If different tender costs for individual suppliers are expected, then this could easily be included.

5.6 Multicriteria ETQ

As already has been pointed out earlier, it would be useful to include multiple criteria in the ETQ model. Below we present an idea to achieve this. First we describe it shortly and after that we illustrate it by means of an example.

5.6.1 How to add multiple criteria

We compare different criteria by using the simple method of attributing scores and weights to them (De Boer, 1998). We assume indistinguishable suppliers. In addition, we assume each of them submits a random bid on each criterion. Thus, there is a bid distribution for each criterion. The bid a supplier picks on one criterion is assumed to be independent of the bid he picks on another criterion. As a next step correlation between criteria could be included, because for instance independence between price and quality is not likely to hold in practice. However, here we restrict ourselves to independent criteria.

The problem then remains how to relate the evaluation costs to the scores on the criteria. We do this by using the price criterion. Using its weight price and therefore costs are translated into the overall score. Hence the overall score will be lowered somewhat for each extra bid that has to be evaluated. Instead of minimizing the total costs the goal now becomes to maximize the overall score.

5.6.2 An illustration

We give an example to illustrate this idea. We consider two criteria price and reliability. The bid distribution of each criterion is uniform. Table 5.6 shows the parameters of each criterion. Scores attributed proportionally to the value of the criterion. For price it means 60,000 Euro gives score 10, 100,000 Euro gives score 6 and all values in between are scaled proportionally. Hence, 90,000 Euro would give score 9.

Table 5.6: *Parameters of price (in Euro) and reliability (percentage of delivered products of sufficient quality level) criterion.*

Criterion	Expected minimum	Expected maximum	Score of minimum	Score of maximum	Weight of criterion
Price	60,000	100,000	10	6	40%
Reliability	95%	97%	7	8	60%

Figure 5.18 shows the price and reliability bid distribution. It also shows the overall distribution obtained by adding up the price and reliability distribution. It boils down to the following distribution function *f(x)*:

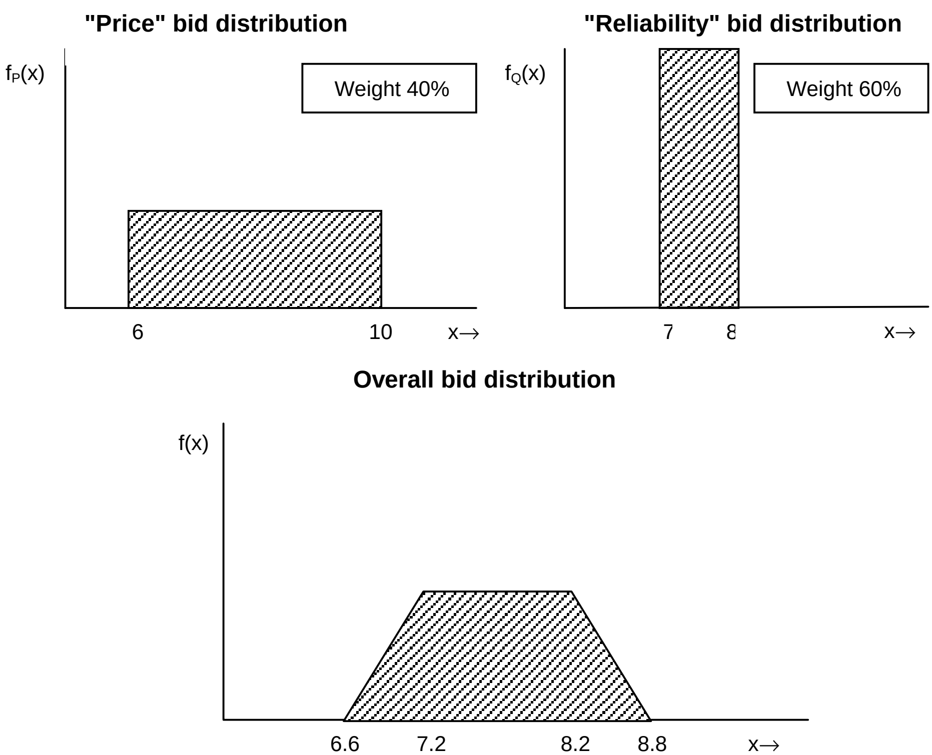
$$f(x) = \begin{cases} 0 & x \le 6.6 \\ 1.0417 \cdot (x - 6.6) & 6.6 < x \le 7.2 \\ 0.625 & 7.2 < x \le 8.2 \\ 0.625 - 1.0417 \cdot (x - 8.2) & 8.2 < x \le 8.8 \\ 0 & x > 8.8 \end{cases} \tag{5.11}$$

Evaluation costs are assumed to be 2,000 Euro per bid. As we can see in Table 5.6, a price difference of 40,000 Euro gives a score difference of 4. Hence, each bid that has to be evaluated relates to a negative score of 0.2 and with a weight of 40% it becomes 0.08.

As mentioned above the ETQ is now the number of bids which maximizes the overall score. Analogous to (5.3) the following equation for ETQ can be derived:

$$ETQ = \arg\max_{n>0}\left\{-K\cdot n + \int_0^\infty \left(1-\left(F(x)\right)^n\right)dx\right\} \tag{5.12}$$

Figure 5.18: *Adding the price and reliability bid distribution into the overall distribution.*

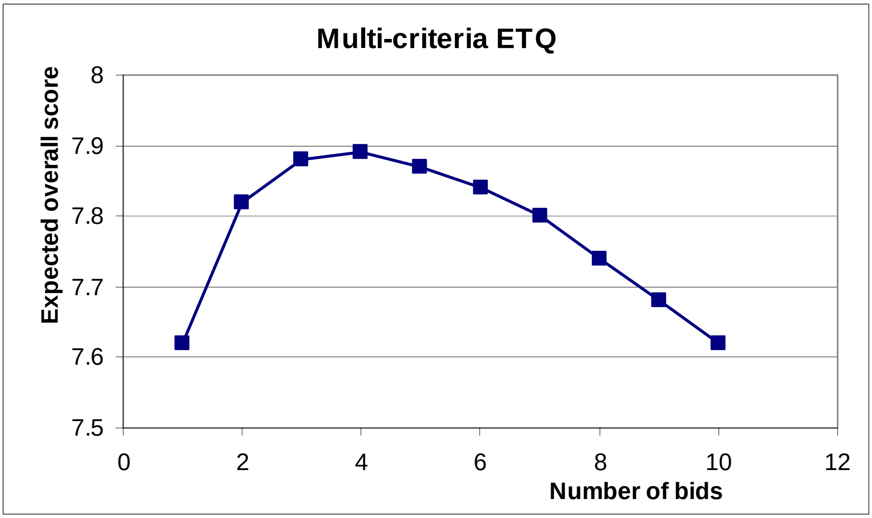


In our example K = 0.08 and $f(x)$ has been defined in (5.11). The result of the calculations for our example above are presented in Figure 5.19. We see the expected overall score is maximized when inviting four suppliers to tender.

5.6.3 Conclusion

The example shows that it is possible to add other criteria when slightly modifying the ETQ model. Again it would also be possible to include individual behavior of supplier by extending the ETS model in the same way.

Figure 5.19: *Graphical illustration of the example showing an ETQ of four.*



Furthermore, we should realize that simply using scores and weights for the comparison of criteria has its disadvantages (De Boer, 1998). In this situation a very low score on one criterion could be compensated by a very high score on another criterion, giving an overall satisfactory score. However, such a situation is not always desirable as a very low score below a certain value could give serious drawbacks for production for instance. Similarly, very high scores above a certain level do not give many extra advantages.

Finally, we have to realize that using scores and weight is an easy method widely used in practice (De Boer, 1998). Therefore, linking the ETQ-model to this method increases practical applicability.

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Chapter 6

Purchasing raw materials

fixed-price contracts versus the volatile spot market

For many companies raw materials form a major cost component. Raw materials (or primary commodities) can be metals, oil or agricultural products. What nearly all raw material markets have in common is a large number of buyers and most of the time also a large number of suppliers. These raw materials can be purchased on spot markets that bring suppliers and purchasers together in one marketplace. Examples are the London Metal Exchange, the Chicago Mercantile Exchange and New York Mercantile Exchange. Furthermore, the main characteristic of the primary commodity markets is that prices fluctuate heavily over time (Kingsman, 1985).

When a major part of the total purchase spend consists of buying raw materials, it is evident that savings in these purchases have a major impact on ROI (see chapter 3). Furthermore, the volatile market prices allow for the possibility of achieving these savings. This is why in a lot of companies buying raw material is seen as a strategic task, which should only be performed by a highly specialized and experienced purchaser, who makes use of sophisticated forecasting techniques.

We argue that the contrary may be true. The aim of this chapter is to show that using basic principles in purchasing, simple decision making tools and strategies can be very effective when applied to buying raw materials. To do this we choose the following setup. In the next section, we discuss what alternatives are available to secure the supply of raw material. In section 6.2 we present an overview of existing literature related to raw material purchasing. We illustrate the use of basic purchasing principles in section 6.3 by discussing a company's purchasing policy for raw material of which a fixed quantity is required periodically. In particular we consider the situation in which there are two options: (a) to buy this quantity at the spot market or (b) to engage in a fixed-price contract for a number of periods. We model this decision mathematically. In section 6.4 optimal policies are derived. In addition, we discuss the extension to contracts of different length in section 6.5. Conclusions are drawn in the last section together with suggestions for further research.

6.1 Purchasing alternatives for raw materials

Companies have several possibilities to assure the supply of raw materials. Sykuta (1996) distinguishes five alternatives:

- buying at the spot market
- forward contracts
- long-term contracts
- futures
- vertical integration

We briefly discuss the characteristics of each alternative including advantages and disadvantages for a company.

To start with the last alternative, vertical integration is clearly different from the first four. Instead of buying raw material, a company decides to start controlling it, usually by acquiring a raw material supplier. This involves a make-or-buy decision in which the costs of contracting are compared to the costs of controlling the resource. Naturally, a company should take this into consideration, but within the scope of this chapter we assume the decision is to buy. This leaves a trade-off between different contract forms (the other four alternatives).

Buying raw material at the spot market is the easiest way in terms of effort for a purchaser. A transaction on the spot market calls for immediate exchange of goods and payment. However, actual delivery takes time and of course on delivery storage capacity has to be sufficient. Hence, spot market transactions do require some coordination efforts to assure supply.

Forward contracts and long-term contracts give more assurance on future deliveries, but they do not have the flexibility of buying at the spot market. The difference between forward and long-term contracts lies in the contract terms (Sykuta, 1996): "Forward contracts may or may not be repeated or call for multiple deliveries at different points in time. A forward contract is transaction specific. A long-term contract, on the other hand, implies on-going repeated exchange. Whereas a forward contract covers the terms of a transaction, a long-term contract covers the terms of a series of repeated transactions."

The price of the raw material is fixed in the contract. Hence, there is no price risk. This is advantageous when future prices on the spot market increase, but it can just as well be the opposite when future prices drop. The contract terms are legally binding, which can be costly when fewer raw materials are needed. Raw material that is not required has to be paid or at least a certain amount will have to be paid even when the company manages to cancel the delivery through negotiations.

Using futures combines the flexibility of the spot market with the assurance of forward and long-term contracts. Futures are very important financial instruments nowadays. Therefore, we discuss them in detail. A futures contract is a standardized forward contract, an agreement between a buyer and seller to buy/sell a standardized quantity of a certain (standardized) raw material at a particular price at a fixed future point in time. This raw material is called the underlying physical product. Due to this standardization futures can very easily be used for trading, which has resulted in futures markets with high liquidity. Nowadays, futures markets exist in every major financial center in the world and futures are more heavily traded than the goods they represent. The value of futures contracts is calculated continuously, i.e. if the spot-market price of the underlying physical product increases, the value of the contract increases for the buyer and decreases for the seller. In the future markets most parties are not interested in actually buying the underlying product, but they are simply speculating on price fluctuations (a good overview of the dynamics in futures markets is provided by Hull, 2002). Therefore, most of the time futures transactions are only settled by paying the cash difference between agreed-upon price, not exchanging the physical products. Settlement by delivery of the physical product to the buyer happens very rarely.

If the aim of the buyer of the futures contract is to actually purchase the physical product, then what happens normally is the futures contract is settled with cash and at the same time the physical product is purchased at the spot market. This means that effectively the price of the physical product paid by the purchaser is the agreed-upon price of the futures contract. Hence, the futures contract reduces price risk similar to forward and long-term contracts. Table 6.1 illustrates this with an example of a purchaser, who wants to make sure the price for copper he wants to buy in April equals the current (January) price. Using futures to reduce price risk is known as hedging.

Table 6.1: *The price of Copper is $ 1.700 per ton in January and a purchaser buys a copper futures contract for April with this copper price (ignoring transaction fees); three scenarios*

	Scenario 1	Scenario 2	Scenario 3
New price in April	1.700	1.800	1.500
Value futures contract	0	100	-200
Effective copper price	1.700	1.700	1.700

Furthermore, the high liquidity of futures markets allows the purchaser to immediately buy and/or sell contracts when company requirements are changing, similar to the spot market. However, selling these contracts could result in a loss, when prices of the raw material have dropped in the meantime. The standardization is good for trading, but it can be a disadvantage as well. The standard quantity and quality may not necessarily be the most suitable for the company specific situation. Finally, futures are not available for all raw materials. But for hedging purposes futures of related raw materials can be used, because generally price fluctuations of these materials are highly correlated to each other.

For the four purchasing alternatives mentioned above we implicitly assumed that the raw material is purchased based on the requirements for a certain period. Not all raw materials are used at once, therefore it is important to consider inventory policies. Of course the well-known economic order quantity plays a role, because keeping inventory is costly. However, due to the price fluctuations inventory can also be used strategically. Stocking up extra raw material when prices are low, can reduce the average spend. Again, this is a means of reducing price risk, but losses may occur when prices drop and inventory has to be sold because of lower production.

Which purchasing alternative(s) a company should choose depends on the company's overall objectives, especially its attitude towards risk. The risk directly associated with purchasing the raw material is its total spend (hence its effect on ROI) and the volatility in the prices. In addition, important factors to consider are the policies of competitors and how easy price fluctuations in the raw materials can be transferred into the prices of the final products (Baker, 1995). The last factor shows that it can be riskier to have a long-term contract than buying at the spot market. If price changes can quickly be transferred into the product prices, there is little risk in buying at the spot market, whereas having a fixed long-term price is much riskier.

Furthermore, instead of choosing just one alternative that fits with the company's strategy a company can consider using multiple alternatives together. We focus on the possibility of combining long-term (or forward / futures) contracts and buying at the spot market.

6.2 Literature review: little research on purchasing policies for raw materials

When exploring existing literature related to purchasing raw material one can not escape from the vast body of knowledge that exists on futures markets. Entire journals are devoted to research on futures, in particular the Journal of Futures Markets, but also financial journals such as the Journal of Banking & Finance, the Journal of Empirical Finance, the Journal of Financial markets regularly pay attention to this subject. Because futures markets are directly related to the underlying commodity market, articles on futures implicitly or sometimes explicitly discuss the underlying commodity market as well. Major topics include (with a few recent publications):

- Hedging. Many publications focus on hedging strategies for traders, but some publications mentioned here focus on the use of hedging for producers of raw materials (e.g. Veld-Merkoulova and De Roon, 2003; Lien and Schaffer, 2002; Tomek and Peterson, 2001; Giacotto et al, 2001).
- Trading. This includes investigation of trading strategies and behavior of traders (e.g. Wang, 2003; Frechette and Weaver, 2001).
- Futures/commodity market behavior. Many publications exist on this topic focusing on modeling past and forecasting future behavior (e.g. Szakmary et al, 2003; Wang et al, 2003; Sørensen, 2002; Adrangi et al, 2001; Voituriez, 2001; Schwarz and Smith, 2000; Agnon et al, 1999; Garcia et al, 1997; Winters and Sapsford, 1990).

Despite of the major attention to future and commodity markets, little research has been done in this area that takes the viewpoint of a company merely using these markets to purchase raw materials for its own consumption. Sykuta (1996) comes to the same conclusion, namely that the unit of analysis is still the futures contract itself, independent of any other contracting activity. Some recent practitioner oriented papers have outlined the possibilities of using futures markets when purchasing raw materials (Flynn and Hite, 2001; Leak, 2001; Shuldiner and Norkus, 1996; Baker 1995).

An equally vast body of knowledge exists on inventory management. The field focuses mainly on finding optimal inventory policies under conditions such as: (a) uncertain demand, (b) uncertain production capacity, (c) multi-echelon systems, (d) uncertain arrival time and (e) backorders. In addition, some research addresses market price fluctuations, such as research by Golabi (1985), Tersine and Gengler (1982), Kalymon (1971) and Fabian et al (1959). In their research optimal inventory policies are derived that consist of critical price levels (thresholds) below which a certain amount satisfying the demand of X future periods should be purchased. However they consider only spot market buying, no other (long-term) contract alternatives.

Morris (1959) is one of the first to consider a purchasing strategy not based on inventory but solely based on market price fluctuations. He derives optimal price thresholds depending on the time left until a certain deadline in which a fixed quantity has to be purchased. Models similar to Morris (1959) and Golabi (1985) have also been studied by Kingsman (1985; 1969; Guimaraes and Kingsman, 1990). Kingman's book (1985) is an extensive study of the raw material purchasing problem that includes commodity price movements, forecasting techniques, measuring purchasing performance and practical buying situations.

However, Kingsman and others in the field of inventory management do not consider the trade-off between different contract forms (long-term vs. spot market). Basically, price changes are met by inventory changes, but in practice this may pose problems with respect to storage capacity. It is also worthwhile to consider a more constant periodical supply of raw material and dealing with price changes by means of diversification in contract forms.

Bonser and Wu (2001) form an exception, as they do address the trade-off between spot market buying and a long-term contract. They discuss a model that allows for purchasing variable quantities within a long-term contract with a minimum quantity. They optimize the allocation of quantities purchased either through the long-term contract or directly on the spot market. This somewhat flexible long-term contract exists for the procurement of fuel in the US utilities industry, the sector that Bonser and Wu (2001) consider, but this is not the case in the other markets.

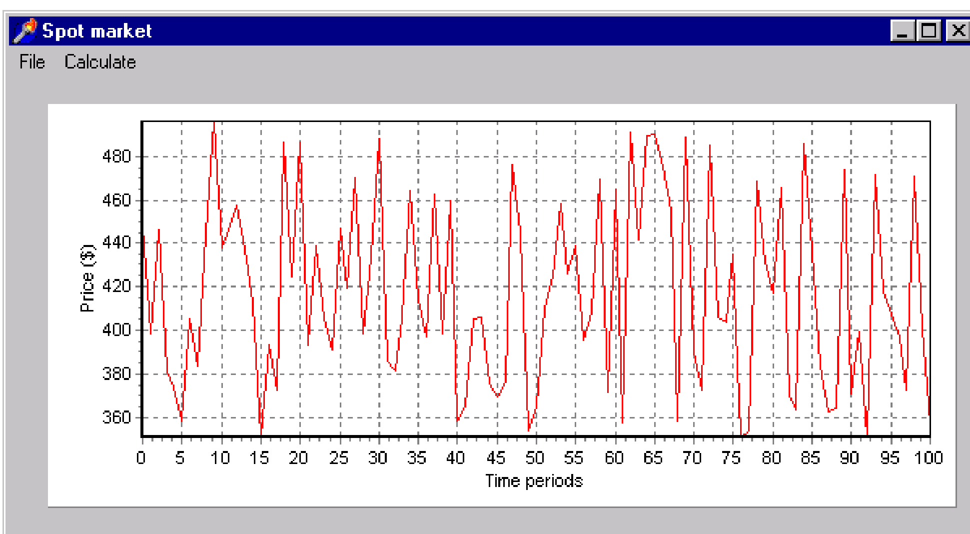
Summarizing, existing literature covers many aspects of primary commodity and futures markets as well as issues related to inventory management. However, the trade-off between contract forms when purchasing these primary commodities is not one of them. Thus, we aim to fill the gap in the next section.

6.3 Modeling the decision between fixed-price contracts and spot market purchases

We present a stylized decision model for choosing between spot market buying and a fixed-price contract for a longer period. We assume a constant demand for certain raw materials in a company. Moreover, the company's policy is to purchase a fixed quantity for every period, for instance an EOQ. Inventory is not used strategically, i.e. no extra quantities are purchased when prices are low. Hence, the fluctuation in inventory is limited.

Furthermore, regarding the spot market we assume that for each period t there is a market price p_t at which this fixed quantity can be purchased. This price p_t is assumed to be a random pick from a stationary probability distribution function $f(x)$ for positive x. Stationary implies the average value of the distribution (as well as the other characteristics) does not change with time, hence the long-term price trend is nearly horizontal (exactly horizontal on a infinite horizon). Figure 6.1 shows an example of prices generated from a uniform distribution with a minimum price of \$350 and a maximum price of \$500.

Figure 6.1: *An example of spot market prices generated from a stationary uniform distribution.*



Apart from simply purchasing at the spot market, we assume one other alternative. This alternative is to fix the current spot market price in a contract for a fixed number of periods L (or equivalently to buy the amount required for L periods at once, but with periodical delivery). So we only allow one contract length. Later we will also discuss the possibility of contracts of different length. For the company it boils down to the following for each period. If there is still a valid contract from a previous period, then the company has to comply. The price is fixed; no action has to be taken. If there is no contract then the company has two options:

- to purchase the quantity needed at the spot market paying price p_t and wait for the next period
- to fix the current price p_t in a contract that assures supply for L periods.

Clearly, fixing the price in a contract should be considered when prices are low. But having this contract one looses the opportunity of having an even cheaper contract when prices drop further. However, waiting too long for a very low price has the disadvantage that too often the company ends up simply paying the spot market price.

The company's goal is to minimize the spend for this raw material. Assuming an infinite horizon this goal is equal to minimizing the average price paid A, in mathematical terms:

$$\min\ A = \lim_{n\to\infty} \frac{1}{n} \sum_{t=0}^{n} p_t^* \tag{6.1}$$

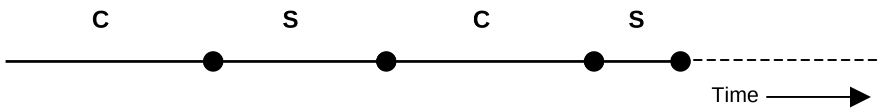
Here p_t^* is the price that company actually pays in that period: the spot market price or fixed contract price.

6.4 Optimal purchasing policies: threshold prices

For a spot market with a stationary price distribution an optimal purchasing policy of course does not depend on time as well, only on price. Note that we assume an infinite horizon, for a finite horizon the number of periods left until this horizon is reached is also a parameter to consider. For low prices a contract is the best decision, whereas for higher prices it is better to buy for one period at the spot market and hope prices will drop in the next period. Hence, the optimal policy is to take a contract only when the price falls below a certain threshold value b. Logically, this threshold value is lower than the average spot market price. Otherwise, taking a contract would never be advantageous, as it would only increase the average price a company pays.

The threshold policy results in the following cycle. First, the spot market price is paid for a number of periods (which could be zero). Second, in a certain period the company decides to take a contract (for L periods). When the contract ends, the spot market price is paid again for a number of periods until a new contract is decided upon. Figure 6.2 illustrates this.

Figure 6.2: *Oscillation between contracts and spot market purchases.*



In any period there is a probability q that the market price falls below the threshold price b:

$$q = \int_0^b f(x)dx \tag{6.2}$$

As a consequence a contract is decided upon. The average value a_c of this contract is:

$$a_C = \frac{1}{q}\int_0^b xf(x)dx \tag{6.3}$$

In addition, probability 1-q exists that only the quantity needed is purchased at the spot market for that period. The average market price a_s paid in this case is:

$$a_S = \frac{1}{1-q}\int_b^\infty xf(x)dx \tag{6.4}$$

The contract period is fixed namely L. The number of periods L_s in which market prices are paid until the next contract varies (L_S = 0,1,2,….). The average length of L_S depends on the threshold value b and therefore on q. There is a probability q that $L_S = 0$, a probability $q(1-q)$ that $L_S = 1$, a probability $q(1-q)^2$ that $L_S = 2$, etc. Hence:

$$P[L_S = k] = q(1-q)^k \tag{6.5}$$

This is a geometrical distribution with an average length of L_S equaling:

$$E[L_s] = \frac{1}{q} - 1 \tag{6.6}$$

The overall average price A can be calculated by looking at the average cycle. This cycle has on average length $L + E[L_S]$. The average contract and spot market price are also known, hence

$$A = \frac{L \cdot a_C + \left(\frac{1}{q} - 1\right) \cdot a_S}{L + \left(\frac{1}{q} - 1\right)} \tag{6.7}$$

Note that q, a_C and a_S all depend on b. Hence, the threshold price b that minimizes this expression is optimal. Using (6.3) and (6.4) expression (6.7) can be rewritten into:

$$A = \frac{(L-1)\int_0^b xf(x)dx + E[f(x)]}{(L-1)\int_0^b f(x)dx + 1} \tag{6.8}$$

Minimizing A by taking the first derivative gives:

$$\frac{\partial A}{\partial b} = 0 \Leftrightarrow b + (L-1)\left(b\int_0^b f(x)dx - \int_0^b xf(x)dx\right) - E[f(x)] = 0 \tag{6.9}$$

Solving this expression for b gives the optimal threshold value b^* that is only dependent on the contract length L and the characteristics of the distribution. We know b^* is always smaller than the average market price $E[f(\mathrm{x})]$, hence the (L-1)-term in (6.9) is positive. Hence, when the contract length L is larger the optimal threshold will be lower. So assuming a stationary distribution it is optimal to use the threshold b^*. Although exact calculations are not always possible, numerical calculation by means of a computer is easy.

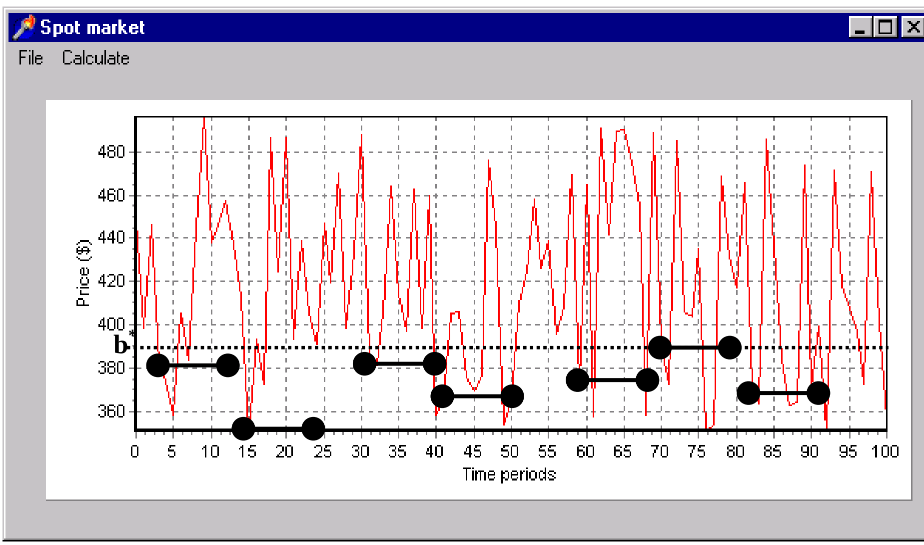
As an example for calculating an optimal threshold we consider a market price with a uniform distribution between p_{min} and p_{max}. Then (6.9) boils down to:

$$b + \frac{1}{2}(L-1)\frac{b^2 - p_{\min}^2}{p_{\max} - p_{\min}} - \frac{1}{2}(p_{\max} + p_{\min}) = 0 \Leftrightarrow$$

$$b = p_{\min} + \frac{p_{\max} + p_{\min}}{1 + \sqrt{L}} \tag{6.10}$$

Again, the larger the contract length, the lower the optimal threshold. Logically, the optimal threshold will always be higher than p_{min}. For the example presented in Figure 6.1, the optimal policy results in a threshold value of \$387.50 using (6.10) and assuming a contract length of 9 periods. Figure 6.3 shows the result of using this threshold policy.

Figure 6.3: *Applying the optimal threshold policy to the example of Figure 6.1 (the bold lines indicating the contracts).*



The average price paid is minimal when using the optimal threshold value. Moreover, it can be shown that this minimal average price paid A_{min} equals this threshold value b^* substituting (6.9) into (6.7):

$$A_{\min} = \frac{(L-1)\int_0^{b^*} xf(x)dx + E[f(x)]}{(L-1)\int_0^{b^*} f(x)dx + 1} \overset{(6.9)}{=}$$

$$\frac{b^* + b^* \cdot (L-1)\int_0^{b^*} f(x)dx}{(L-1)\int_0^{b_*} f(x)dx + 1} = b^* \tag{6.11}$$

Therefore, the average discount that is realized by using the optimal threshold policy equals the average market price minus the optimal threshold ($E[f(x)]-b^*$).

A final remark is that the same model can be applied when additional fixed costs have to be paid when taking a contract. These additional costs simply cause an increase in the optimal threshold. Of course when these costs reach a level at which the average price paid is higher than the average market, it is no longer profitable to take fixed-price contracts.

6.5 Including the possibility of an additional long-term contract of different length

A logical extension of the previous model is to include a contract of different length. Let us assume there are two contract possibilities C_1 and C_2, one of length L_1 and one of length L_2 with $L_2 < L_1$.

The optimal policy would now be to have two thresholds: taking the longer contract C_1 when the price falls below threshold b_1 and the shorter contract C_2 when the price is below threshold b_2 and above b_1 ($b_1 \leq b_2$).

Similar to the previous example probabilities q_1 and q_2 exist that there is a contract of length L_1 or L_2:

$$q_1 = \int_0^{b_1} f(x)dx \qquad q_2 = \int_{b_1}^{b_2} f(x)dx \tag{6.12}$$

In addition, the average prices a_{C1}, a_{C2}, and a_S of having either one of the contracts or buying at the spot market are:

$$a_{C_1} = \frac{\int_0^{b_1} xf(x)dx}{q_1} \qquad a_{C_2} = \frac{\int_{b_1}^{b_2} xf(x)dx}{q_2} \qquad a_S = \frac{\int_{b_2}^{\infty} xf(x)dx}{1-q_2-q_1} \tag{6.13}$$

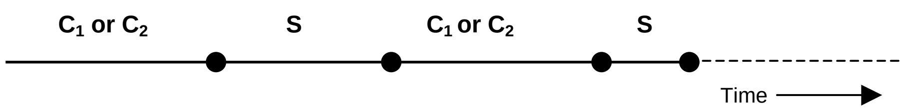
The same cycle still applies: having either contract C_1 or C_2, paying the spot market price for a number of periods and after that have either one of the contracts again (see Figure 6.4).

The calculation of the average length L_S of buying at the spot market before taking a contract again is also similar in the case of two contracts. There is a probability q_1+q_2 that $L_S=0$, a probability $(q_1+ q_2)(1-q_1-q_2)$ that $L_S=1$, a probability (q_1+q_2)

$(1-q_1-q_2)^2$ that $L_S=2$ etc. Hence:

$$P(L_S = k) = (q_1 + q_2)(1 - q_1 - q_2)^k \tag{6.14}$$

Figure 6.4: *The cycle for two contracting possibilities.*



This is a geometrical distribution with:

$$E[L_S] = \frac{1}{q_1 + q_2} - 1 \tag{6.15}$$

We can also calculate the average length of a contract L_{av}:

$$L_{av} = \frac{q_1 \cdot L_1 + q_2 \cdot L_2}{q_1 + q_2} \tag{6.16}$$

In addition, the time average of contract price a_C is:

$$a_C = \frac{q_1 \cdot L_1 \cdot a_{C_1} + q_2 \cdot L_2 \cdot a_{C_2}}{(q_1 + q_2) \cdot L_{av}} \tag{6.17}$$

Using the equations above, the overall average price paid A becomes (similar to (6.7)):

$$A = \frac{L_{av} \cdot a_C + \left(\frac{1}{q_1 + q_2} - 1\right) \cdot a_S}{L_{av} + \left(\frac{1}{q_1 + q_2} - 1\right)} \tag{6.18}$$

Expressing q_1, q_2, a_C and a_S in terms of b_1 and b_2 leads to:

$$A = \frac{(L_1-1)\int_0^{b_1} xf(x)dx + (L_2-1)\int_{b_1}^{b_2} xf(x)dx + E[f(x)]}{(L_1-1)\int_0^{b_1} f(x)dx + (L_2-1)\int_{b_1}^{b_2} f(x)dx + 1} =$$

$$\frac{(L_1-L_2)\int_0^{b_1} xf(x)dx + (L_2-1)\int_0^{b_2} xf(x)dx + E[f(x)]}{(L_1-L_2)\int_0^{b_1} f(x)dx + (L_2-1)\int_0^{b_2} f(x)dx + 1} \tag{6.19}$$

Now we want to find the thresholds b_1 and b_2 that minimize (6.19), which means finding the zero value of the first derivatives. For the existence of a global minimum it should hold that:

$$\frac{\partial A}{\partial b_1} = 0 \wedge \frac{\partial A}{\partial b_2} = 0 \tag{6.20}$$

Solving (6.20) reveals that a global minimum implies:

$$b_1 = b_2 \tag{6.21}$$

This result implies that in the optimal policy the shorter contract C_2 should never be chosen. Hence, introducing the possibility of a shorter contract does not gain any extra savings. When there are more contract options, it suffices to take only the longest contract into account.

The drawback of having only the alternative of a very long contract lies in the convergence of the average price towards its minimum value (the threshold price). For a long contract the threshold price will be very low, and the probability that the market price falls below this threshold is very low. If this probability is for instance 1%, it may take many periods before a contract is taken and until this happens the market price is being paid. Hence, for this first number of periods the average price paid equals the average market price. As market conditions are changing in time, in practice a company will have a limited horizon. Thus this poses some limits to the contract lengths that should be considered. With a limited time frame it is not only a question of the minimizing expected average price paid, but also a question of the probability that certain savings will be realized within this time frame.

6.6 Conclusion

Purchasing raw materials is of strategic importance to a company, when these materials form a large cost component. However, this does not necessarily mean that the task of purchasing these raw materials is complicated. Worldwide commodity markets allow for instantaneous purchases. Eliminating or limiting price fluctuations is easy to achieve by means of hedging (using futures).

Also, our stylized decision model shows that combining different purchasing alternatives can be beneficial. In particular, we have shown that in a spot market with a horizontal long-term trend a company can easily achieve a price paid which is lower than the average market price. Only the implementation of a simple threshold policy is required: when the market price drop below the threshold the company engages in a fixed-price contract for a number of periods; otherwise it keeps paying the spot market price. Hence, this does not require a highly specialized purchaser. A specialized, experienced purchaser can be an advantage, if he / she is able to predict to a certain extent future prices or trends based on news events or market price history. But with respect to predictability commodity markets seem to have a lot in common with the stock market; it is virtually impossible. Market price forecasting is highly overrated, as the German physicist Heisenberg already said in 1925: "Uncertainty is the only certainty in life."

When focusing on savings on the raw material spend, we should not loose sight of the other important aspects: on-time delivery, storage, changing requirements in production both in raw material quality and in quantity or the possibility of using substitute materials. Managing all these aspects simultaneously may require an experienced purchaser after all.

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Chapter 7

Supplier switching strategy for single sourcing

the supplier's introduction of new products;

when to introduce a new supplier?

7.1 Introduction

Routine or non-critical purchases are items which have little impact on a company's profit (low value) and have little supply risk (Kraljic, 1983). Typically these are MRO (Maintenance, Repair and Operations) items such as office supplies. Increasing purchasing efficiency by means of supply base reduction is the key objective for the procurement of routine items nowadays (Kolchin and Trent, 1999). Hence, a single sourcing strategy is often adopted having just one supplier for a range of related products (a commodity group).

Apart from the reduced bureaucracy as compared to dealing with many suppliers another advantage of having just one supplier for a commodity group is that larger discounts can be achieved through economies of scale. However, this advantage may gradually turn into a disadvantage due to the dynamic nature of a commodity group.

At the beginning the arrangement with just one supplier seems optimal from an efficiency and cost point of view, but this will not last indefinitely. Over time new products are introduced by the supplier to replace the older ones. This gives the supplier the opportunity to increase its profit margin, hence reducing the discount the buyer gets on the market price. However, even when a buyer notices this opportunistic supplier behavior, it can be troublesome to interfere immediately. Negotiations with the current supplier can be time consuming and therefore costly. Searching and switching to a new supplier can be even costlier considering the selection process, negotiations and extra handling (or setup) costs of introducing a new supplier in the company. In spite of these costs at some point renegotiation or switching suppliers will be an effort worthwhile.

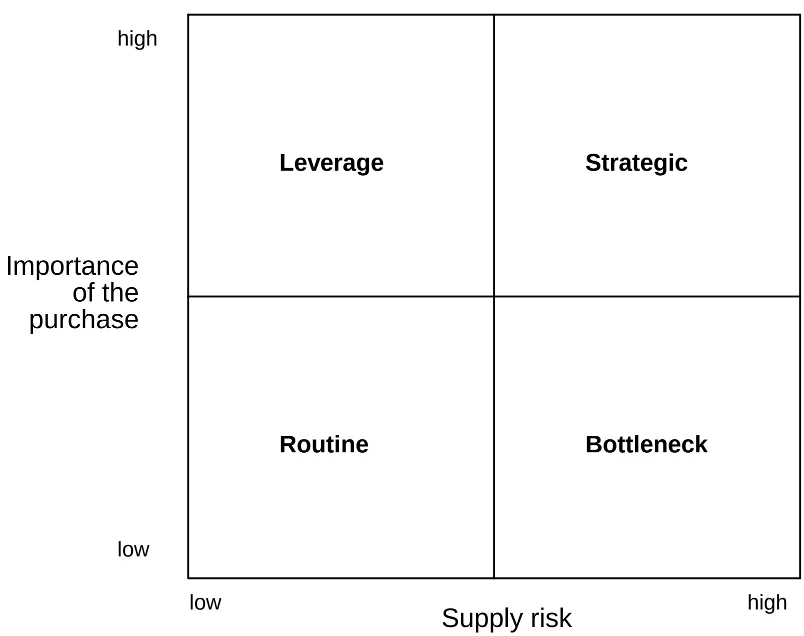
The objective of this chapter is to give an answer to the question when it is worthwhile to change suppliers for a certain product group, the assortment of which is gradually being renewed with lower discounts for the new products. In this chapter we present a mathematical model to calculate the switching (or renegotiation) time based on parameters such as the spend and the replacement rate of products in a commodity group.

The setup of this chapter is as follows. In the next section we present a literature review combining results from literature on procurement of routine products and single sourcing literature. Section 7.3 presents the mathematical model which we use to derive the optimal switching time. Section 7.4 discusses the practical applicability of the model. After that the limitations are discussed in section 7.5 followed by conclusions in the last section.

7.2 Synthesis between literature on purchasing routine items and single sourcing literature

For the management of buyer-supplier relationships the portfolio approach is a popular tool (Kraljic, 1983; Olsen and Ellram, 1997; Bensaou, 1999; Gelderman and Van Weele, 2002). In this approach commodities are classified into clusters based on two or more criteria. Two important criteria used first by Kraljic (1983) and later by Ellram and Olsen (1997) are (a) the supply risk / how easy it is to manage the supply and (b) the strategic importance of the purchase / the impact of the purchase on ROI. This leads to a categorization into four segments, one of them being the segment of non-critical or routine purchases. These purchases have little supply risk and are of little strategic importance (Figure 7.1).

Figure 7.1: *Purchasing portfolio (adapted from Kraljic, 1983; Olsen and Ellram, 1997).*



The recommended strategy for routine items does not differ much between researchers and can be summarized by the words of Olsen and Ellram (1997, p.105): "The keywords when managing these purchases are standardization and consolidation. The company should reduce the number of suppliers and the number of duplicate products/services. The supplier relationship should be managed by establishing a relationship that basically manages itself."

A single sourcing strategy seems to be the answer to purchase routine items most effectively. A single supplier for a range of routine products reduces the amount of paperwork drastically and discounts can be obtained by this bundling of purchase volume (Zeng, 2000). Bechtel and Patterson (1997) argue that for this reason a company should aim for a partnership with a MRO supplier. However, they do not acknowledge the drawbacks of such an arrangement on the long term. Cousins (1999) finds that this supply base rationalization often boils down to delegating the control of a number of suppliers to a first-tier supplier. Moreover, Cousins (1999) finds that the results are only satisfactory on a short-term basis, not on a long-term basis. Purchasers do not have the knowledge to manage the new relationship with the single supplier, on which they become highly dependent.

Trust and power are important ingredients in buyer-supplier relationships (Parker and Hartley, 1997). Single sourcing gives the selected supplier more power. It induces a lack of competition which gives an incentive for bad supplier performance (Richardson and Roumasset, 1995). Limited trust between buyer and supplier increases this effect. Because of this extra power a supplier may be able to increase prices without being challenged. Higher switching costs to another supplier for the buyer triggers such a complementary product pricing strategy, i.e. selling accessories and related products at a higher premium than the core group of products (Noble and Gruca, 1999). In a commodity group, new products are being introduced over time, replacing older obsolete products. Such a replacement provides an excellent opportunity for the supplier to lower the discount, because it is difficult to immediately establish an accurate market price for a new product.

Forker and Stennack (2000) found this behavior in an electronics firm that reduced its supply base too much. The recent development of electronic catalog systems increases these switching costs even more (see chapter 8). Newman (1989) already warned for this source dependency together with the possible lack of innovation by the supplier that this dependency might cause. This lack of innovation and opportunistic pricing behavior by suppliers was also found by Banerjee and Lin (2003).

Limiting this opportunistic pricing behavior seems necessary, but as it turns out dealing with this behavior does not always have a high priority for buyers. According to Swift (1995) purchasers accustomed to single sourcing tend to focus more on total life costs of products, technical support and availability rather than on the initial price. Therefore, buyers often see supplier certification as a logical step before granting a supplier single source status (Larson and Kulchitsky, 1998).

To limit the opportunistic behavior of a supplier a purchaser can include some form of competition. Price information from another supplier can serve as a monitor for the prices of the single source (Demski et al, 1987). Sticking to the single sourcing strategy, i.e. not allowing multiple suppliers for a commodity group, the only two options a purchaser has is to renegotiate the contract with the current supplier from time to time or to switch to a new supplier. According to Mudambi and McDowell Mudambi (1995) in general the decision to switch suppliers depends on:

- the transaction specific assets of the relationship. This is the proportion of the amount spent on relational investments that is specific to this relationship.
- the quality of buyer-supplier communication. Bad communication may lead to different expectations of the relationship's benefits leading to a loss of trust.
- the decision time horizon that buyers and suppliers have. If either of them have a short-term view they value the benefits which are gained in the future less. This may lead to more opportunistic (short-term) behavior by the buyer and an earlier supplier switch by the buyer.

Although these criteria point out qualitatively when switching suppliers or renegotiation should be considered, they have not been translated into a more normative model until now. For bilateral contracts in general Andersen and Christensen (2002) consider the mechanisms that play a role in contract renewal by means of a game theoretical model. They find that the costs of contract renewal prevent frequent renewals and that the incentive for contract renewal is driven by changes in outside opportunities. We aim to address the specific setting of having a single supplier for a commodity group from the perspective of the purchaser.

For this setting the decision problem we want to solve is to determine the optimal switching (or renegotiation) time. For this purpose we develop a quantitative model in the next section.

7.3 Modeling cost dynamics of purchasing a commodity group at one supplier

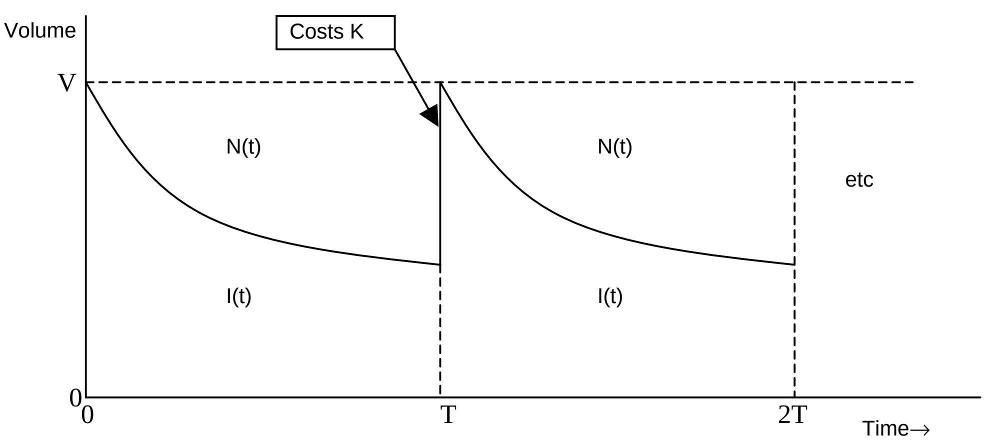
The model considers one commodity group for which a company has a single sourcing strategy. Moreover, we assume the company need for the products in this commodity group does not change in time, i.e. the same number of products is required for each period. We also assume a constant (average) market price and we denote V as the spend volume when buying all products at this market price.

Furthermore, the company is assumed to have negotiated a contract with a supplier in which a discount is obtained compared to the average market price. Initially, the average discount for the products (at the moment of establishing the contract) is d_I (in percentages). Because of (technological) developments new products slowly replace the initial products in the commodity group. Let us assume that in each period a fixed percentage of the products β is replaced. For these new products the supplier can manage not to give such a high discount as for the initial products. The average discount for the new products is d_N (in percentages). So d_N is lower than d_I.

At a certain moment a purchaser may want to renegotiate the contract or perhaps switch to another supplier. We consider both options to be equal in terms of effort and result. Actually, when a request for quotations is sent out to various suppliers including the current one, the value of the quotations will lead either to the former or to the latter option. Hence, we assume an effort is made to change the current undesired situation back into the initial situation. This effort requires fixed costs K. These costs mainly involve the amount of working hours the purchasers (and other employees) spend on this effort. In addition, after establishing the new contract we assume all products have the initial discount d_I again.

We assume the purchaser of this commodity group wants to maximize his average savings per period S, i.e. the savings he obtains compared to the average market price for the products. The savings consist of all discounts minus the negotiation costs on an infinite horizon. Clearly, it is optimal to either (a) never negotiate the contract again, because it is too expensive or (b) renegotiate the contract / switch supplier periodically after a fixed number of periods. Let us assume a switching (or renegotiation) time of T periods. Furthermore, $I(t)$ and $N(t)$ are respectively the percentage of initial products and new products at a certain moment in time. Figure 7.2 shows the behavior of the commodity group's content in time.

Figure 7.2: *Percentage of initial products and new products in a commodity group in time.*



We ignore the fact that the number of products is always an integer. For mathematical convenience we use the parameter α instead of β with:

$$\alpha = -\ln(1-\beta) \tag{7.1}$$

As β has values between 0 and 1, α will always be positive.

Between two consecutive switches the amount of initial products $I(t)$ decreases in time:

$$I(t) = (1-\beta)^t = e^{-\alpha t} \tag{7.2}$$

Similarly, between two consecutive switches the amount of new products $N(t)$ increases in time:

$$N(t) = 1-(1-\beta)^t = 1-e^{-\alpha t} \tag{7.3}$$

With (7.2) and (7.3) we can now calculate the savings per period S consisting of the average discounts per period minus the effort costs K:

$$S = \frac{1}{T}\left(-K + V\int_0^T \left(d_I \cdot I(t) + d_N \cdot N(t)\right)dt\right) \tag{7.4}$$

Solving the integral leads to the following expression:

$$S = \frac{V}{\alpha T}\left(-\frac{\alpha K}{V} + d_I\left(1-e^{-\alpha T}\right) + d_N\left(\alpha T - 1 + e^{-\alpha T}\right)\right) \tag{7.5}$$

To find the switching time T^* that maximizes the savings first requires finding the zero value(s) of the first derivative:

$$\frac{\partial S}{\partial T} = 0 \Leftrightarrow$$

$$\frac{V}{\alpha T^2}\left(T \cdot \left(d_I \alpha e^{-\alpha T} + d_N \alpha\left(1-e^{-\alpha T}\right)\right) - \left(-\frac{\alpha K}{V} + d_I\left(1-e^{-\alpha T}\right) + d_N\left(\alpha T - 1 + e^{-\alpha T}\right)\right)\right) = 0 \Leftrightarrow$$

$$\frac{V}{\alpha T^2}\left(e^{-\alpha T} \cdot \left(d_I \alpha T - d_N \alpha T + d_I - d_N\right) - d_I + d_N + \frac{\alpha K}{V}\right) = 0 \tag{7.6}$$

In (7.6) we see the optimal switching time T^* only depends on the difference between the initial discount and the new discount. Hence, for notational convenience we introduce the discount difference parameter d:

$$d = d_I - d_N \tag{7.7}$$

This simplifies (7.6) to:

$$\frac{V}{\alpha T^{*2}}\left(e^{-\alpha T^*}\cdot\left(d\alpha T^*+d\right)-d+\frac{\alpha K}{V}\right)=0\Leftrightarrow$$

$$e^{-\alpha T^*}\cdot\left(\alpha T^*+1\right)-1+\frac{\alpha K}{dV}=0 \qquad T^*\neq 0 \tag{7.8}$$

It is easy to see that the lhs is strictly positive for any positive switching time if:

$$-1+\frac{\alpha K}{dV}>0\Leftrightarrow K>\frac{dV}{\alpha} \tag{7.9}$$

In this case no optimal switching time exists, because relatively too much effort is needed to change the situation. The switching costs are too high compared to the savings that are generated from it. We now define K_{max} being the maximum value that these switching costs can have in such a way that an optimal switching time T^* exists:

$$K_{\max}=\frac{dV}{\alpha}=\frac{\left(d_I-d_N\right)\cdot V}{-\ln\left(1-\beta\right)} \tag{7.10}$$

To show that there is a unique optimal positive switching time T^* (when $K < K_{max}$) we rewrite (7.6) to:

$$\left(\alpha T^*+1\right)=\left(1-\frac{\alpha K}{dV}\right)e^{\alpha T^*} \tag{7.11}$$

Figure 7.3: *Finding the optimal switching time at the intersection.*

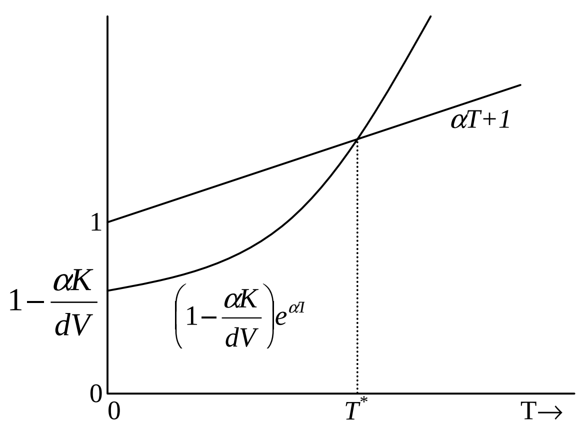


Figure 7.3 shows that the functions always intersect at only one point (T*>0). In addition, it can easily be verified that this switching time gives indeed maximum savings, i.e. the second derivative of (7.5) at T* is negative.

Although exact calculation of T^* is not possible, an accurate approximation of T^* can easily be calculated found by applying numerical methods to (7.11) such as bisection. The value of the maximum savings can be calculated by substituting (7.8) into (7.5):

$$S_{\max} = V\left(\left(d_I - d_N\right)e^{-\alpha T} + d_N \alpha T\right) \tag{7.12}$$

7.4 Application

For practical application of our model we have constructed two graphic representations of the optimal switching time and its dependence on the other parameters. Figure 7.4 presents the relative costs as a function of the replacement rate for a constant optimal switching time, whereas Figure 7.5 presents the optimal switching time as a function of the replacement rate for constant relative costs.

To illustrate the practical use we discuss an example. We consider a commodity group with a spend volume V of one million Euro per year. We assume the supplier gives an initial discount of 15%. For the new products that are being introduced the supplier reduces the discount to only 5%. Furthermore, each year about 30% of the products in the commodity group are renewed. Using (7.10) we can now calculate the maximum costs K_{max} for which it is still profitable to consider switching suppliers after some time:

$$K_{\max} = \frac{\left(0.15 - 0.05\right)\cdot 10^6}{-\ln\left(1 - 0.3\right)} \approx 280{,}000 \tag{7.13}$$

Otherwise it is optimal never to consider this effort. This value can also be obtained from Figure 7.4. For 30% of new products in a period the maximum relative costs of the effort for switching to be profitable should not exceed the value at which the bold dotted line crosses the bold line. This is at relative costs of about 2.8 resulting in the K_{max} as given in (7.13). Suppose the effort of setting up a tender procedure to switch suppliers will cost about 125,000 Euro. In Figure 7.4 this means the relative costs on the vertical axis would be 1.25. Together with the replacement rate of 30% we see in Figure 7.4 the optimal switching time is about four years. Thus, for this commodity group given the single sourcing strategy and the parameters above it is optimal to start a tender procedure once every four years.

Figure 7.4: *Relative costs as a function of optimal switching time and the replacement rate.*

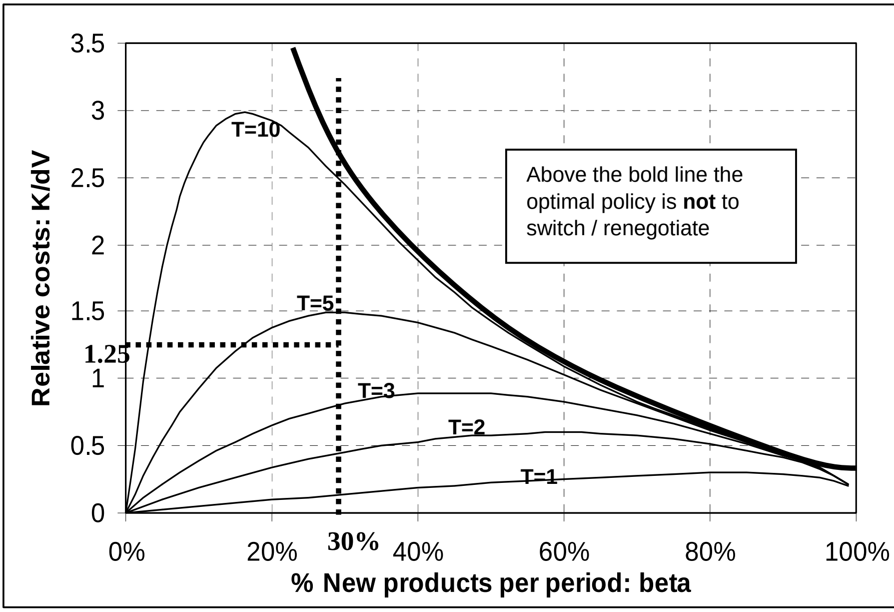
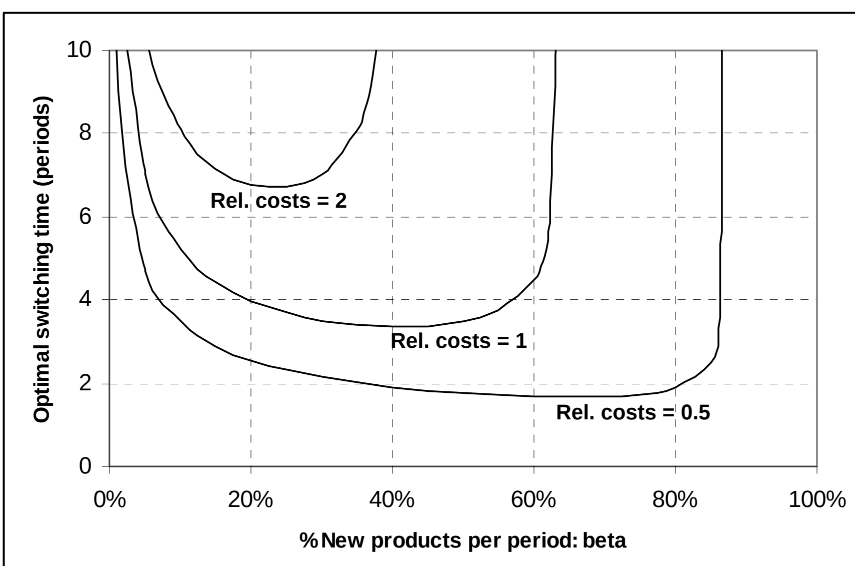


Figure 7.5: *Optimal switching time as a function of the relative costs and the replacement rate.*



Furthermore, Figure 7.5 gives an important insight when considering constant relative costs. When the replacement rate increases from zero, it is necessary to renegotiate/switch more often; the switching time decreases. However, when the replacement rate becomes too high the switching time increases again. Items are replaced so often that the effort of renegotiation becomes almost pointless, because the high discount only lasts shortly for most products. This continues up to a point when even considering making this effort becomes too costly. Looking at Figure 7.5 we can see it happens for relative costs of 2, when the replacement rate gets close to 0.4. When the relative costs are lower, we see this point occurs at a higher replacement rate. At this point perhaps the whole idea to use a single source in the first place should be reconsidered.

Also, Figure 7.5 shows that for given relative costs a minimum switching time exits. For instance, when the relative costs are 1, the optimal switching time never drops below 3.3 periods for any replacement rate. Hence, no matter what the replacement is, to consider switching supplier more often than once every 3.3 periods is never optimal.

7.5 Discussion

Although the example above shows how to apply this model in practice the model has some limitations. First of all, estimation of the model parameters can prove to be troublesome in practical situations. The model requires the availability of the replacement rate as well as the market prices of the products involved. In addition, calculating the costs of the effort to set up a tender procedure is not straightforward as it is based on working hours needed which have to be estimated beforehand (see also Chapter 5).

Another limitation is the fixed spend volume V that we assumed. However, the model can be extended rather straightforward manner to include linear trends in this spend over time. Such trends would result in the switching time also changing in time. Also, as such a trend would probably be known only up to a certain point in time, a limited time horizon could also be considered.

Discussing possible model extensions brings us to the empirical verification. Especially the replacement of older products by new ones and the price changes that are related to that are interesting. We assume gradual replacement, which seems realistic. However, no empirical research is available to support such an assumption.

Moreover, in practice other aspects may be involved in the decision process of switching suppliers, which have not been included in the model. Starting a tender procedure for a commodity group may be postponed because of other purchasing activities having higher priorities, or it can start earlier because a purchaser has time to spare. Still in both cases, given a list of commodity groups with a single supplier, the model can be used to provide priorities, i.e. the order in which commodity groups should be dealt with.

Finally, the model does not make a decision between which kind of action should be taken: renegotiation with the current supplier, negotiation with another supplier or starting a tender procedure. In addition, the supplier may supply more than just this one commodity group, which can complicate matters.

7.6 Conclusions

As many studies indicate, single sourcing is a good strategy for reducing administrative purchasing cost as well as for creating economies of scale by bundling more volume at a single supplier. It is especially suited for routine items. However, the main disadvantage is the fact that the power balance changes in favor of the supplier.

Some studies indicate that more power can give rise to opportunistic pricing behavior by the supplier. The replacement of older obsolete items by new ones is a mechanism a supplier can use to increase its profit margin, because it gives an opportunity to lower the discount on these new products. For a purchaser it is therefore necessary to renegotiate the contract after some time or to switch suppliers.

The model we presented is a first attempt to estimate the optimal renegotiation time mathematically rather than just having a global idea of factors that would be of influence. For practical application the next step is to empirically verify the assumptions we made. Given that, Figure 7.4 can already act as an important guideline for purchasers to decide when it is time for certain commodity groups with a single supplier to be investigated.

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Chapter 8

Electronic purchasing

determining the optimal rollout strategy

This chapter is partly based on:

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Electronic purchasing (EP), also known as electronic ordering through catalogs is the most established form of e-procurement nowadays, yet it is still in its infancy. Theoretically, changing from the "traditional" way of purchasing to EP can lead to huge cost savings. However, the implementation (rollout) of EP including many commodity groups and many departments (divisions) is a large and costly task. In addition, not much experience on good rollout strategies is available yet. This chapter contributes to the analysis of this problem by presenting two mathematical models. The first somewhat simplified model quantifies costs and benefits to provide insights in financial aspects of the rollout such as ROI, payback time and cash flow. The second model includes different characteristics of commodity groups and departments. It determines the optimal order of commodity groups and departments for which EP is implemented based on maximization of the cost savings. Results from the second model suggest the order of implementation is an important factor in the rollout process, because it can contribute considerably to the savings that can be realized. In addition, the second model shows it may be optimal *not* to implement EP for certain commodity groups or departments.

8.1 Introduction

Since the 80s automation has found its way into the purchasing process. Traditionally, the operational purchasing process involves a lot of administrative repetitive tasks that add little value: processing purchase requisitions, purchase orders, invoices and all sorts of reports. In the purchasing process computers were first mainly used for data storage and simple spread sheet analyses. Later, Electronic Data Interchange (EDI) emerged, automating the interchange of business transactions between buyers and suppliers and thereby reducing the transaction costs per purchase considerably. Although a lot has been written about the advantages of EDI, EDI adaptation has been limited until now, mainly because of the considerable implementation costs of these dedicated (and therefore not so flexible) networks (see e.g. Bergeron and Raymond, 1997; Segev et al, 1997; Kaefer and Bendoly, 2000; Angeles, 2000).

With the Internet and Internet related technology it has become possible to communicate electronic data between and within companies based on global standard protocols. This has opened up a wide range of opportunities for business in general, e-commerce, and for purchasing in particular, e-procurement (early indications by Telgen, 1997; also see e.g. Min and Galle, 1999; McIvor et al, 2000; Long, 2001). With this background the definition of e-procurement (or electronic procurement) by Harink (1999) is appropriate: "using Internet technology in the purchasing process."

There are many forms of e-procurement (De Boer et al, 2001 and 2002). In this chapter we focus on the most established form of e-procurement nowadays: electronic purchasing (EP). We define EP as: the process of creating purchase requisitions by an internal customer by means of an electronic catalog and using a software system based on Internet technology for (a part of) the information flow and verifications in the operational purchasing process (adapted from De Boer et al, 2001 and 2002). Other common terms for EP with similar definitions are e-catalogs (Padmanabhan, 2001), electronic catalog systems (Harink, 1999), Internet-EDI (Angeles, 2000) and web-based procurement (Croom, 2000).

EP offers an opportunity to streamline administrative routines in operational purchasing both for product related (direct) purchases and for non-product related (NPR) purchases (Croom, 2000). Currently many EP systems are available on the market. Major vendors are Ariba, Baan, CommerceOne, PeopleSoft and SAP. Despite success stories like IBM (IBM, 2000) and Global Pharmaceutical (Croom and Giannakis, 2002) companies still hesitate. In 2001 many companies were planning to start a project in the near future, but only a few were actually implementing it (80-90% versus 8% of the 5000 largest US companies according to Aberdeen Group, 2001). Both Arbin (2002) and Davila et al (2003) conclude that the implementation of EP is still in its infancy. Davila et al (2003) find that only a quarter of respondents (US companies) on their survey purchased EP software. In addition, this software is mainly used for indirect purchases such as office supplies, computers and MRO items, only making up for 2% of total spend on average.

A reason for this hesitation to adopt EP may be that selecting and implementing a new IT system such as EP for an entire organization requires an enormous effort. Also, the costs in relation to the expected cost savings, i.e. figures such as ROI and the payback time are not always clear. This is because EP has a company-wide impact: on its structure, on its processes and on the compatibility with its existing IT systems (De Boer et al, 2002).

Furthermore, the (amount of) success depends on the way this implementation project is organized (Aberdeen Group, 2001; Sherrill et al, 2001). Implementation takes considerable time. Bad performance in an early stage of the project may cause a premature ending. Hence, the order in which certain commodity groups and departments (or divisions) are taken into consideration for adding them to an EP system may influence the final result.

This chapter aims at contributing to the decision making process when rolling out an EP system into an organization. We focus on the financial aspects, i.e. we try to translate the implementation and impact of EP into costs and cost savings. *The main research question is to determine the optimal rollout strategy based on maximization of the cost savings*. Considering the diversity in commodity groups that a company is purchasing and considering the different departments concerned, an optimal implementation strategy should involve setting priorities on commodity groups and departments, i.e. determining the optimal order in which they are added to the EP system.

To be able to answer our main research question, first a number of other questions need to be answered. The setup of this chapter is such that each of the following sections deals with one of them. First, we investigate in the next section what the impact is of using EP on ordering procedures. We do a literature review and we make a comparison with the traditional ordering process. Second, the question arises how this impact can be translated into cost savings. This is discussed in section 8.3. In section 8.4 we turn to the EP rollout (implementation) process itself. We want to know in which setting the EP rollout takes place, i.e. how the process looks like and which costs are incurred.

We then ask ourselves in section 8.5 how to calculate key financial performance indicators based on the costs, cost savings and characteristics of the rollout process. These key financial performance indicators are ROI, payback time and cash flow per period. Whereas section 8.2, 8.3 and 8.4 are of a more qualitative nature, in section 8.5 we transform the information of these sections into a quantitative model. We describe the input data needed and we describe the implementation process in a formal way. This model does not take into account detailed characteristics, which enables us to quickly calculate these financial indicators.

In section 8.6 we generalize the model of section 8.5, taking into account different characteristics for the commodity groups and departments of an organization. While in section 8.5 the implementation order is unimportant, in this generalized model it is this implementation order, which determines the (financial) performance of the rollout strategy. Section 8.7 deals with issues regarding solving the model, i.e. the actual calculation of the optimal implementation order. Also the model is illustrated with a numerical example in this section. Finally, conclusions are drawn in the last section together with suggestions for further research.

8.2 The impact of EP on ordering procedures

The procedure of ordering items is one of the basic procedures in purchasing and it is the heart of the operational purchasing process. Therefore the ordering procedure always received a lot of attention: every general textbook on purchasing describes a way in which this procedure should be arranged and this description does not differ a lot between them. Adapted from several textbooks (Leenders and Fearon, 1993; Dobler and Burt, 1996; Lysons, 1996) below the necessary steps for the ordering procedure are given:

1. purchase requisition from internal customer: this could be an actual request from a person within the company, but also it could be an automated request from an ERP system.
2. authorization of purchase: checking with company regulation and / or obtaining the authorization from the appropriate person(s)
3. sending the purchase order to the supplier (and retaining a copy for administration)

supplier: delivery together with goods delivered notice

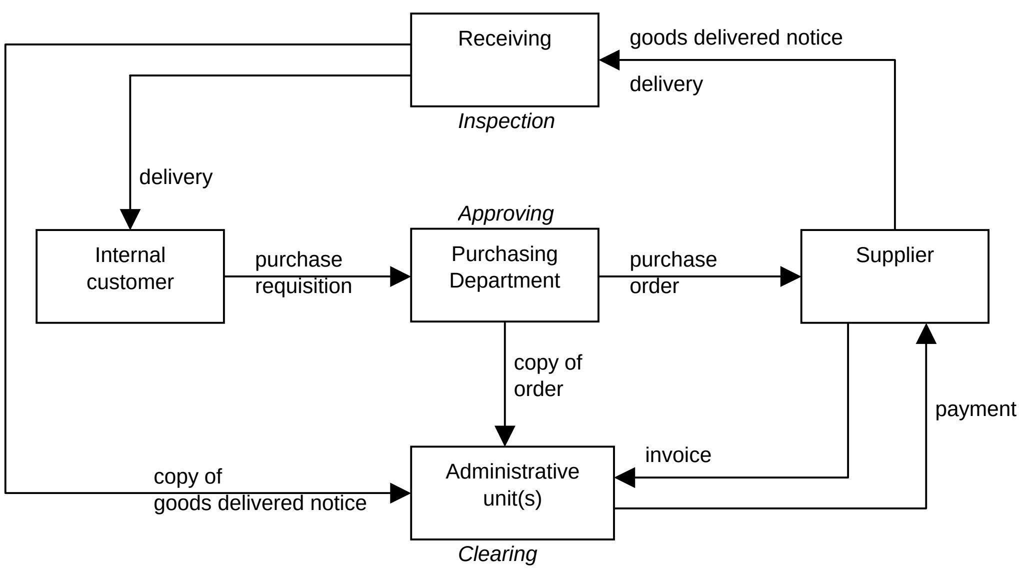
4. inspection of goods, checking it with the goods delivered notice (and sending a copy to administration)

supplier: sending invoice (could also arrive before the delivery)

5. clearing invoice: checking invoice with copies of the purchase order and goods delivered note, checking compliance with contract terms
6. payment to supplier

The description above only applies to repetitive purchases. It is assumed that the specifications are clear and that there is a contract with a supplier, so extra steps regarding those issues can be left out of the procedure. Figure 8.1 gives an illustration of the ordering procedure. In Figure 8.1 the purchasing department only takes care of the ordering; other administrative units take care of the registration of orders, delivery notices and invoices. In practice the administrative organization could have slightly different arrangements, for instance a separate unit for carrying out the actual payments.

Figure 8.1: *Schematic overview of the ordering procedure (adapted from Harink, 1999).*

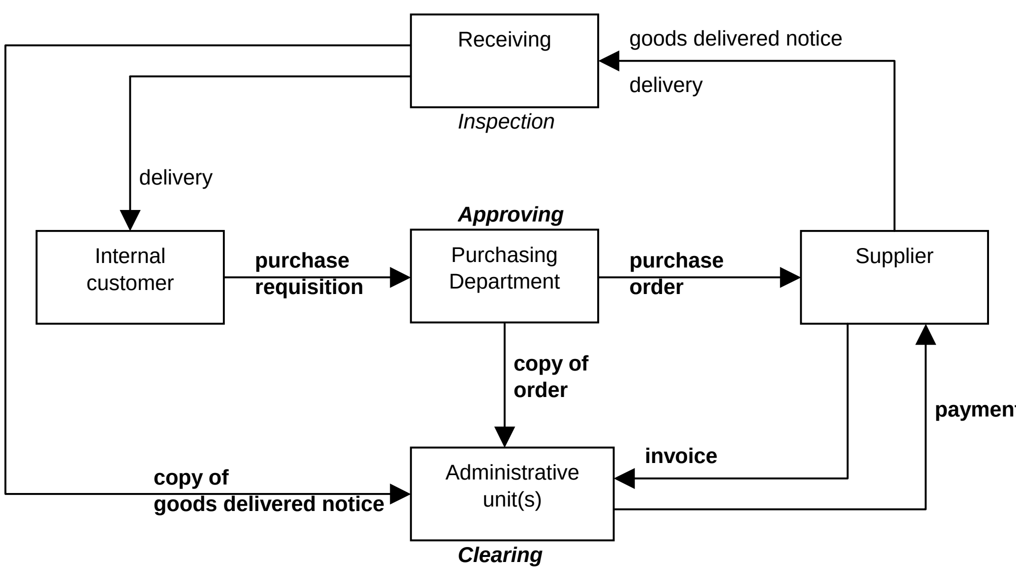


The majority of the repetitive purchases following this ordering procedure have little value. They are located in the routine and bottleneck quadrants of the Kraljic matrix (Kraljic, 1983). Reducing this administrative burden would free more time to be spent on value adding activities such as tactical and strategic purchasing especially related to the strategic and leverage quadrants.

Although the procedure above can be performed manually without any automation, the advantages of using computers and the automated flow of information are also indicated in the textbooks on purchasing mentioned earlier (Leenders and Fearon, 1993; Dobler and Burt, 1996; Lysons, 1996). These advantages can be summarized into two aspects: automation of data storage (maintaining records, standardized forms, etc) and automatic communication (EDI) with suppliers, automatic matching and other possible information flows within the organization. Both aspects help to reduce the administrative tasks, hence reducing labor costs and streamlining and speeding up the process.

With the definition of EP in the previous section the changes resulting from using EP on the ordering procedure above can be derived. In step 1 this means that the purchase requisition by the internal customer will be done by using an electronic catalog and the requisition will automatically be sent to the purchasing department.

Figure 8.2: *Processes in the ordering procedure that could be done electronically (in bold).*



Even having only this change in place, the organization can already be considered as having an EP system. In this case the incoming requisitions would be printed out by the purchasing department and the other steps of the ordering procedure would be performed in the traditional way. Extending the EP system then means that other steps are also handled electronically. Figure 8.2 illustrates the part of the ordering procedure that could be fully automated. One can speak of different functionality levels of an EP system. The system could include only step 1, or for instance step 1,2 and 3 or step 1,3 and 6. Note that when authorization and the purchase order are done automatically, basically the purchasing department is circumvented and is not involved in the order anymore. If all steps for which it is possible are fully automated, there is no human interference in the purchasing department and the administrative unit blocks of Figure 8.2. Human involvement will still be necessary though, not as administrator in the process, but as controller of the process: to handle exceptions and input data such as: content management, setting authorization levels and contract data.

8.3 Translating the impact of EP into potential cost savings

Using the description of the differences between the "traditional" ordering procedure and EP the advantages of EP with respect to the traditional ordering procedure in terms of cost savings can be explained. Two advantages are the most important: reducing transaction costs and reducing maverick buying.

The transaction costs of a purchase are the total internal costs to complete a purchase from requisition to payment. Reducing transaction costs is achieved by a reduction in the average time spent by (administrative) personnel on a transaction, reducing clerical errors and therefore also reducing the average lead-time. A survey by CAPS among 169 US organizations showed that for MRO purchases the costs for an average transaction is still more than US $75, which is more than the average MRO invoice (Kolchin and Trent, 1999). Quotes from Harink (1999) and the Aberdeen Group (2001) indicate that transaction costs with EP can typically be reduced from on average more than US $100 to about US $30 or less per purchase order. Clearly the reduction of the transaction costs will depend on the functionality level of the EP system: the more steps are done electronically, the more reduction there will be.

The second major advantage is the reduction of maverick buying (purchases neglecting the available company contracts). Research indicates that maverick buying could amount to more than 50% of spend for certain commodity groups resulting in an average higher price (typically 10-20%, Sherrill et al, 2001). IBM (2000) reported a reduction in the maverick buying from 45% on average to less than 1% from 1994 to 1999 using e-procurement. Implementing an electronic catalog system can only be done with a very limited number of suppliers per category (because of the costs), hence when an internal customer uses the electronic catalog maverick buying is prevented automatically. This advantage is already obtained with the basic functionality of the EP system: only the electronic catalog. A higher functionality level of the EP system basically will not affect maverick buying directly as this is not perceived by the internal customer. But it could have an indirect effect through e.g. reduced lead times (resulting from a higher functionality level of the EP system).

Besides the two main advantages mentioned above there are also other positive side effects. First, with an EP system information about the purchase volume, frequency, etc can be more easily extracted. Better information on the purchase volume per supplier gives the opportunity to negotiate better contracts. Also, reducing the maverick buying will increase the purchase volume per supplier, creating an even better opportunity (reductions of 5-20% in the spend through EP according to Sherrill et al, 2001). Secondly, as already mentioned, implementing an EP system is only done with a limited number of suppliers, because of the implementation costs. Thus introducing EP will automatically reduce the number of suppliers. For the same reason the number of products will also be reduced, as only the products of the suppliers connected to the EP system will be available. These products will still have to cover the functional needs of the internal customers as much as possible to prevent maverick buying. Finally, introducing an EP system (especially for several steps of the ordering procedure) means that there has to be a clear understanding of the tasks to be performed in that step in order to be able to automate it. For instance in the authorization step all authorization levels for a purchase for all personnel have to be defined. Being forced to think about the existing ordering process can lead to a reorganization of that process which could be more efficient even without using an EP system.

To summarize, a company considering implementing EP needs information on the following figures, i.e. the current figures and the expected figures after EP implementation:

- spend
- number of transactions
- average maverick buying percentages
- average higher price when maverick buying
- average transaction costs

These figures could be collected on company level, but for more insight it is required to collect (some of) these figures on department level for each commodity group. This is especially useful, when large differences between departments and/or commodity groups are expected.

8.4 EP rollout: the process and the costs

As implementing EP is a huge task and still relatively new, common practice is to start with a pilot, typically implementing EP for one commodity group (a few suppliers) only available for a small number of employees (for example one department). The reason for such a pilot is to become gradually familiar with the technology, to see if the promised benefits actually occur and to recognize possible pitfalls for successful implementation, without running too great a (financial) risk.

After successfully finishing the pilot the next step is a major one: rolling out the EP system into the entire organization. This rollout comprises three dimensions. The first two are that other commodity groups will have to be added as well as other departments. The third dimension is increasing the functionality level of the EP system, e.g. instead of only being able to search an online catalog also automate the ordering, authorization degree, interaction with financial systems at the supplier and the buyer's side, payment etc.

The implementation costs can be considerable. In their survey Davila et al (2003) found for companies using an EP system the average investment in this system was US $5.4 million. In general the implementation costs consist of three components. The first component is the fixed costs for buying and installing the system. The other two components are related to adding commodity groups and departments to the EP system. Adding a commodity groups boils down to adding supplier catalogs to the EP system. The implementation costs of adding a supplier catalog can differ a lot between suppliers depending on the experience with Internet technology of the supplier and the compatibility of its current IT systems to the EP system of the buyer. Furthermore, making catalogs means making clear specifications of each item in the catalog, which will create difficulties depending on the commodity group. Also, the number of suppliers required to cover all items in a commodity group differs. Costs related to adding departments (employees) to the EP system include determining business rules (authorization limits), training of employees and compatibility issues regarding IT systems which could differ between departments. Also, for all implementation costs apart from the one-time implementation costs update or maintenance costs can occur.

It is important to note that costs for adding commodity groups and departments are independent of each other, because these additions are done separately. The costs of adding one department are independent of the number of commodity groups that already have been added. The other way around, the costs of adding one commodity group are independent of the number of departments that already has been added.

Furthermore, selecting the proper EP system is not straightforward. The system has to be able to handle the company-specific information flows and the required dimensions of the system. Also, good compatibility with the existing IT systems of both the company and most of the suppliers is a definite advantage. Attaran (2001) recognizes a number of these pitfalls or attention areas to be addressed before the start of the implementation: the content management, the necessary expertise and the organizational change. The last two apply to implementing IT systems in general, content management is specific for EP: maintenance and updates of the electronic catalog (new items, obsolete item, new prices, etc). Padmanabhan (2001) defines three approaches to this issue: content management can be done by the buying organization, the suppliers or by a third party. The best solution will depend on the in-house expertise, the costs and expectation regarding control, response time and security, in case the second or third option are chosen.

How does the rollout process look like in general after the successful pilot project? As the rollout is a huge task, it is likely to take place gradually over time. Moreover, commodity groups and departments can be added independently to the system, which allows them to be added one (or a few) at the time. Table 8.1 shows a typical rollout assuming just one functionality level of the EP system. In total *N* commodity groups and *N* departments are added one by one alternately. In period 1 only the pilot versions works with commodity group C1 and department D1. In period 2 commodity group C2 is added and becomes available for department D1. In period 3 department D2 is added. Now this department D2 immediately has both commodity groups C1 and C2 available. This process continues until period 2*N*-1. Of course other rollout options are also available such as first adding for instance three departments and after that two commodity groups, etc. In addition, when different characteristics of commodity groups and departments are known, it makes sense to specify in which order the individual commodity groups and departments to add, for instance first C3, followed by D5 then D3, etc.

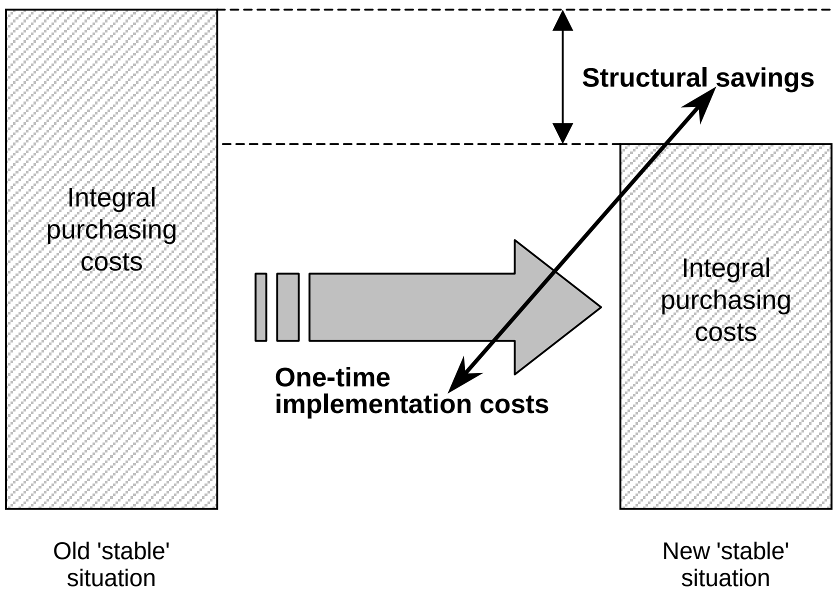
Table 8.1: *Adding commodity groups and department one by one to the EP system (number in the table denotes the order in which the cells become available for cost savings).*

Department → ↓Commodity	**D1**	**D2**	**D3**	**...**	**DN**
C1	1	3	5	...	2N-1
C2	2	3	5	...	2N-1
C3	4	4	5	...	2N-1
...	...	...	...	etc	2N-1
CN	2N-2	2N-2	2N-2	2N-2	2N-1

The rollout order also determines when cost savings start to occur. Cost savings on a commodity groups for transactions of a particular department will occur only if both this commodity group and this department have been added to the EP system (with a certain functionality level). Table 8.1 shows that D3 is added in period 5 and therefore only starting from that period cost savings will occur in connection with commodity groups C1, C2 and C3.

For most organizations it is possible to realize structural cost savings with an EP system based on the advantages in the previous section. However, these savings should outweigh the effort and costs of implementing an EP system. Figure 8.3 shows this trade-off. Deciding to go ahead with the implementation of an EP system will be based on the analysis of the ROI and often a comparison takes place between the different possible IT investments (Kim et al, 2000). Also, other financial performance indicators such as payback time and expected cash flow during the project may play a role.

Figure 8.3: *Structural savings through implementing EP (from De Boer et al, 2002).*



The financial performance indicators depend on the configuration an EP system will have and the rollout strategy. The configuration consists of the functionality level of the EP system and which commodity groups and departments will be added. Note that a company could decide *not* to add certain commodity groups or departments. The rollout strategy is the order in which commodity groups and departments are implemented. This order determines *when* certain costs and cost savings are incurred and therefore influence ROI as well.

Calculating financial performance indicators is not entirely straightforward because of the one-time and structural costs and costs savings, which occur or start to occur at different points in time. Therefore we first present a simplified model, which does not take into account the individual characteristics of commodity groups and departments. We do this to gain insight into the general characteristics of these financial indicators for an EP rollout.

8.5 Calculating ROI, payback time and first positive cash flow period: a simplified model

The simplified model we develop and use allows us to quickly estimate the main characteristics of the implementation process: ROI, the payback time and the first period with positive cash flow.

We assume *N* commodity groups and *N* departments (divisions, business units) as well. Also, in this first modeling attempt we assume there is only one level of functionality in the EP system. Furthermore, we assume the rollout process as shown in Table 8.1.

For the implementation costs (fixed costs and variable costs) we assume that they can be determined beforehand. The fixed costs *I* are the costs of the EP system itself without any customization. We assume all commodity groups and all departments are similar. Therefore, the variable costs *C* of adding one commodity group together with one department to the system are independent of the specific group or department. Both *I* and *C* are initial implementation costs; update costs are assumed zero for now.

Cost savings will only occur for a commodity group in a department if both the commodity group and the department have been added to the EP system. We denote with *R* the cost savings for one commodity group in one department for one period. Included in these cost savings are for instance savings through reduced maverick buying and through reduced transaction costs. Furthermore, these savings are structural. To be able to relate them to the implementation costs one has to take into account the savings for a number of years. We use a time horizon of *H* periods.

Clearly, with equal costs for each implementation and constant revenues, alternating between adding commodity groups and departments is the best way to rollout the EP system. Hence, we assume such a rollout. However, we define one period t as a period in which both a department and a commodity group are added to the EP system. This means *N* implementation periods are necessary and *H-N* periods are left in which no costs occur anymore, but cost savings are generated (assuming *H*>*N*). For the profit P_t generated in each period it boils down to the following:

$$P_t = \begin{cases} -C + R \cdot t^2 & t = 1..N \\ R \cdot N^2 & t = N+1..H \end{cases} \tag{8.1}$$

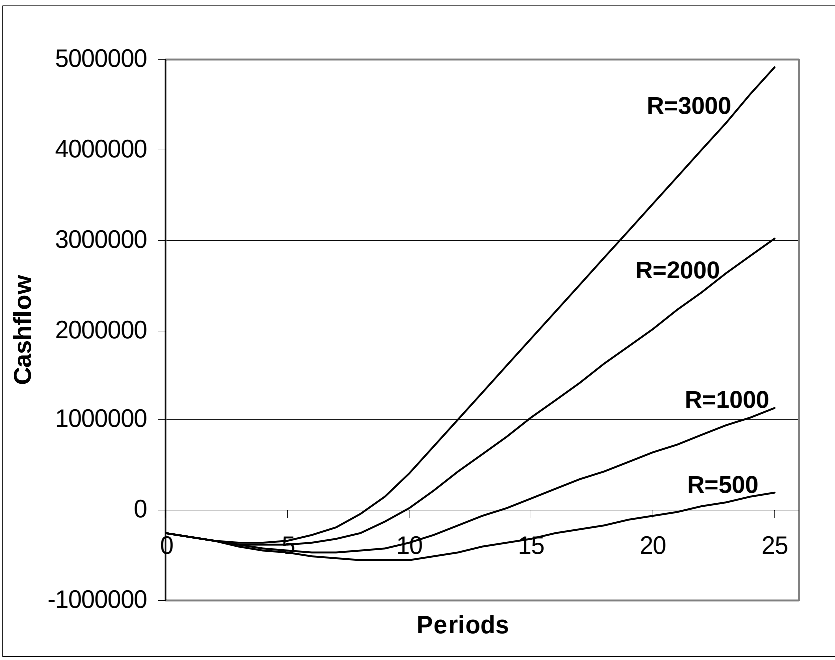
Of course, P_t can be negative. Including I the total profit *v* becomes:

$$v = -I + \sum_{t=1}^{N} \left(-C + R \cdot t^2\right) + \sum_{t=N+1}^{H} R \cdot N^2 =$$

$$-I - C \cdot N + \tfrac{1}{6} R \cdot N \cdot (N+1) \cdot (2N+1) + R \cdot N^2 \cdot (H - N - 1) \qquad (8.2)$$

ROI can now be calculated by dividing the total profit by the total investments (I + CN). Figure 8.4 shows an example of adding 10 departments and commodity groups to an EP system with I = 250,000, C = 50,000 and various values of R.

Figure 8.4: *Cash flow during the EP implementation with N = 10, I = 250,000 and C = 50,000.*



Apart from the total profit, it is also interesting to know when the cash flow turns positive and when the profit exceeds zero, i.e. the payback time of the total investment. If the cost savings are large enough the cash flow already turns positive during the implementation period ($t \leq N$). In Figure 8.4 this happens for R = 1,000, 2,000 and 3,000. Using (8.1) we see that the cash flow is positive for the first period (integer value) after t^* with:

$$t^* = \sqrt{\frac{C}{R}} \qquad (8.3)$$

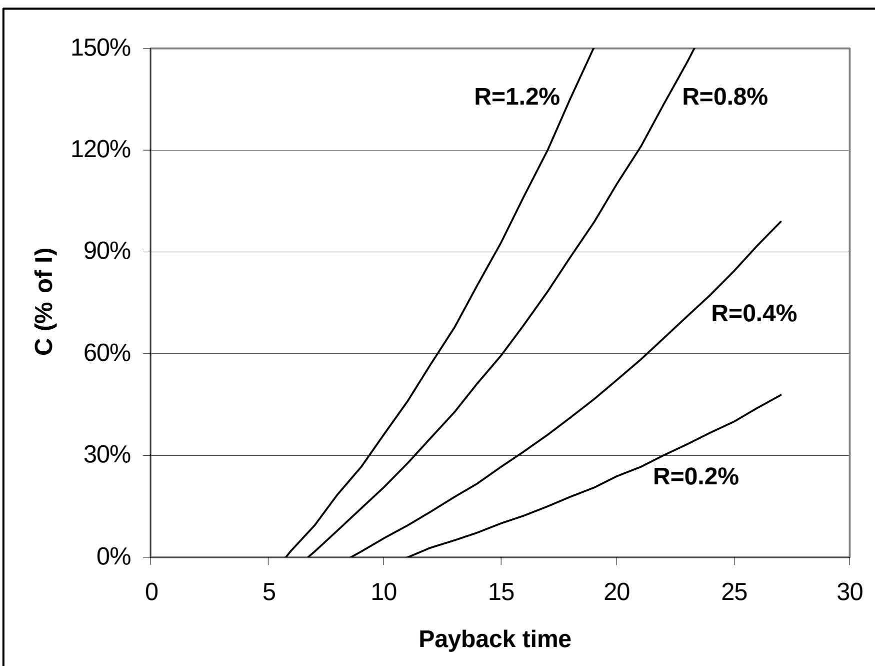
If the cash flow is not positive during the implementation period, it will always be positive afterwards, because no more costs occur from period N+1 onwards.

Similarly, the first period with positive total profit, the payback time of the investment, can be calculated. If the total profit after the implementation period (at $t = N$) is positive, then the payback time already occurs during the implementation period; it is the first period (integer value) after t^+ with

$$-I - C \cdot t^+ + \tfrac{1}{6} R \cdot t^+ \cdot \left(t^+ + 1\right) \cdot \left(2t^+ + 1\right) = 0 \tag{8.4}$$

Using (8.4) Figure 8.5 shows which values of C and R as a percentage of I make it possible to have a certain payback time.

Figure 8.5: *Determining C and R (both as % of I) for different demands of the payback time assuming it occurs before the end of the implementation period.*

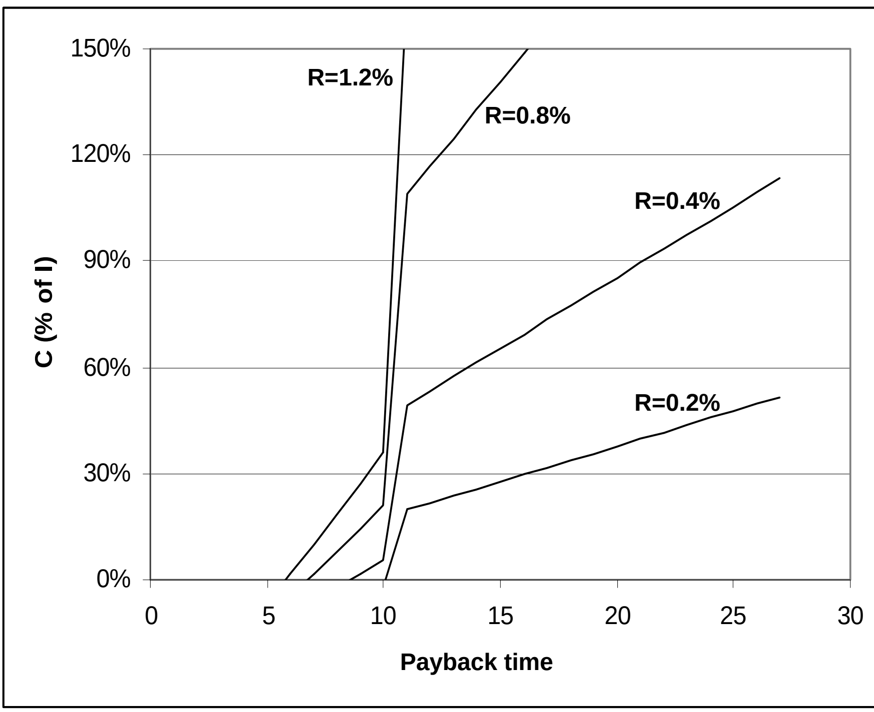


Otherwise, when the payback time only occurs after the implementation the t^+ is simply calculated by

$$t^{+} = \frac{I + C \cdot N - \frac{1}{6} R \cdot N \cdot (N+1) \cdot (2N+1)}{R \cdot N^{2}} \tag{8.5}$$

Figure 8.6 illustrates how a fixed implementation time of 10 periods affects the payback time. As the costs are zero beyond period 10, positive total profit will occur more quickly after that period.

Figure 8.6: *Same as Figure 8.5, but the payback time is not necessarily before the end of the implementation period, which is assumed to be 10 periods here.*



Although this simplified model allows for some interesting insights it does not take into account various aspects such as differentiation in costs and cost savings for the different commodity groups and departments and an unequal number of departments and commodity groups. To cope with this, we present a generalized model in the next section.

8.6 A generalized model for the EP rollout

To make a generalized mathematical model of the electronic purchasing rollout, more input data have to be defined together with a more general structure for the implementation process. An explanation of the mathematical model follows below. In Table 8.2 all notation used is listed for reference.

Table 8.2: *The notation used in the generalized model.*

Indices:	
j	commodity group (1...*jmax*)
k	department (1...*kmax*)
t	period (1...N)
N	number of implementation periods, equal to *jmax* + *kmax*
Input data:	
I	costs of the uncustomized EP system itself
CC_j	implementation costs of EP for commodity group j (≥ 0)
DC_k	implementation costs of EP for department / division k (≥ 0)
R_{jk}	aggregated costs savings (revenues) obtained when commodity group j and department k have been added to the EP system (≥ 0)
β	discount / depreciation factor ($0<\beta<1$)
Variables:	
c_j	value 1 or 0 if commodity group j respectively has or has not been added to the EP system
d_k	value 1 or 0 if department / division k respectively has or has not been added to the EP system
i_t	state of the EP-system at the end of period t, consisting of the values of c_j and d_k at the end of period t
z_t	decision what to add to the EP-system in period t (turning one c_j or d_k from 0 to 1)
P_t	direct profit in period t
$v_t(i_t)$	maximum profit in period t for state i_t

Input data

We assume that there are *jmax* commodity groups *j* and that there are *kmax* departments (divisions, business units) *k* for which EP has to be implemented. Again, we restrict ourselves to only one level of functionality in the EP system.

Just like in the previous section we assume fixed costs and variable costs that can be determined beforehand. Again, the fixed costs *I* are the costs of the EP system itself without any customization. Now we distinguish two types of variable costs: CC_j are the implementation costs for adding commodity group j to the EP system and similarly DC_k are the implementation costs for department k. We use one fixed amount for the implementation costs. For calculating this amount one could include several components: the initial implementation costs and update costs lasting for (and perhaps discounted over) several years. We assume that these components are not dependent on anything else except for the specific implementation; by implementing a commodity group or departments these update costs become inevitable. Hence they can be aggregated into one amount. As indicated in section 8.4 adding a commodity group to the system means the items of that group are available for all departments that already have been added. Also, adding a department means that all commodity groups that already have been added become available to that department.

Other input data needed are the costs savings or revenues of the implementation. We denote with R_{jk} the cost savings per commodity group j per department k. For the cost savings we take one fixed amount using the same reasoning as for the implementation costs. This amount is an aggregation of "all" future cost savings, which may include savings through reduced maverick buying and through reduced transaction costs. Calculating these future cost savings can be done in several ways like: multiplying the cost savings of one year by a fixed number of years, or discounting the savings over time with or without a time horizon. Note that R_{jk} here is an aggregated amount, whereas R in the previous section is only the cost savings of one period.

Modeling the rollout

At the start of the implementation project we assume for simplicity but without loss of generality that nothing has been implemented yet. We could also have started with an EP system where already some commodity groups and / or departments have already been added. The implementation process is then modeled as follows:

- The process consists of N periods. The commodity groups and departments are added to the EP system one by one. Thus, in each period t ($1...N$) EP is implemented for one commodity group or department, hence $N = jmax + kmax$.
- In period t the implementation costs being either CC_j or DC_k have to be paid. The fixed costs I are paid at the start of the implementation.
- The revenues (cost savings) in period t are the new revenues generated by the commodity or department added in period t. Hence these revenues are dependent on what already has been connected to the EP-system.
- Costs and revenues are discounted (depreciated) with factor β ($0<\beta<1$) between each period. By giving costs and revenues that occur earlier in time a higher value, priorities can be determined in the order of implementation. Also β is assumed constant for now, by which we implicitly assume that the implementation period is the same for all commodity groups and departments.

For notation purposes we introduce the variables c_j and d_k with values either 1 or 0, indicating whether commodity group j and department k respectively has or has not been added to the EP system. So all c_j and d_k are 0 at the start of the implementation and 1 at the end.

Now the best EP rollout strategy can be reformulated as the strategy (the order of implementation) for implementing all commodity groups and departments that maximizes the total profit (the total revenues minus the total costs) given the depreciation of the revenues and costs in time. Defining de total profit as v the objective can be formulated as:

$$\max \quad v = -I + \sum_{t=1}^{N} \beta^{t-1} \cdot P_t\left(i_{t-1}, z_t\right) \tag{8.6}$$

The variables are defined as follows:

- i_t is the state of the EP system at the end of period t. This state consists of the values of c_j and d_k in period t and it depends on the state at the end of the previous period i_{t-1} and decision made in period t. Furthermore, i_0 is the initial state (all c_j and d_k are 0).
- z_t is the decision what to add to the EP system in period t. Of course only commodities or departments for which c_j or d_k are still 0 in state i_{t-1} can be added. Thus the decision z_t is to turn one of those from 0 to 1, hence changing the state. Note that at time $t = 0$ there are still $jmax + kmax$ decision options, whereas for $t = N\text{-}1$ only one option is left.
- $P_t(i_{t-1},z_t)$ is the direct profit that is generated in period t. Like i_t it depends on i_{t-1} and the decision in period t. Note that the profit can be negative. The direct profit is calculated in the following way depending on whether a commodity or a department is added to the EP system:

$$P_t\left(i_{t-1}, z_t\right) = \begin{cases} \sum_{k=1}^{k\max} \left(d_k\left(i_{t-1}\right) \cdot R_{j^*k}\right) - CC_{j^*} & z_t : c_{j^*} := 1 \\ \sum_{j=1}^{j\max} \left(c_j\left(i_{t-1}\right) \cdot R_{jk^*}\right) - DC_{k^*} & z_t : d_{k^*} := 1 \end{cases} \tag{8.7}$$

Note that the fixed costs I is just a constant subtracted from the profit and therefore I has no influence on the optimal rollout strategy.

Using dynamic programming

The number of possible implementation sequences is $N!$, making the calculation of all values of v nearly impossible task already for small values of N. However, the problem (8.6) can be rewritten into a finite deterministic dynamic programming (DP) problem with backwards recursion. We define $v_t(i_t)$ as the maximum total revenues that can be obtained in state i_t at the end of period t. $v_t(i_t)$ can be calculated recursively:

$$v_t(i_t) = \max_{z_{t+1}}\left(P_{t+1}(i_t, z_{t+1}) + \beta \cdot v_{t+1}(i_{t+1})\right) \tag{8.8}$$

At the end of period N there is only one possible state (all c_j and d_k equal to 1) and no decision options are left, hence:

$$v_N = 0 \tag{8.9}$$

There is also only one initial state i_0 and with the recursive relation above $v_0(i_0)-I$ will be the maximum total profit and the decisions z_t that give rise to this maximum value determine the optimal order of implementation.

The number of states at the end of period t is $\binom{N}{t}$ and there are $N - t$ decision options left. Thus for determining the maximum profit $\sum_{t=0}^{N}(N-t)\cdot\binom{N}{t}$ calculations have to be made, an expression that can be simplified:

$$\sum_{t=0}^{N}(N-t)\cdot\binom{N}{t} = \sum_{t=0}^{N} t \cdot \binom{N}{t} = \frac{1}{2}N \cdot 2^N$$

$$\text{(using } t \cdot \binom{N}{t} + (N-t)\cdot\binom{N}{N-t} = N \cdot \binom{N}{t} \text{ and } \sum_{t=0}^{N}\binom{N}{t} = 2^N\text{)} \tag{8.10}$$

Above the restriction is used that all commodities and departments have to be implemented. Implementing certain commodities and departments could be non-profitable though, hence excluding them would increase the overall profit. Obviously this would be the case, if the implementation costs for a commodity j^* or a department k^* are larger than the revenues gained by adding j^* or k^* to the EP system:

$$\sum_{k=1}^{k\max} R_{j^*k} < CC_{j^*} \text{ or } \sum_{j=1}^{j\max} R_{jk^*} < DC_{k^*} \tag{8.11}$$

All non-profitable implementations are found at the end of the optimal implementation order. Because of the discount factor losses are postponed. Hence, the profit is maximized when recursively all commodities and departments are excluded that are implemented from period t^* until N. This period t^* is determined by starting from $v_N(i_N)$ and going backwards in the optimal order until $v_{t^*}(i_{t^*})$ becomes negative. A negative $v_{t^*}(i_{t^*})$ implies that the total profit from this period t^* until the last period N is negative, hence omitting the implementation that would be conducted during these periods will increase the overall result. This leads to the optimal rollout strategy without the restriction that all commodities and departments have to be implemented.

8.7 Solving the generalized model: calculating the optimal rollout order

Using the DP formulation of the previous section optimal EP rollout strategies can only be calculated on a computer within reasonable time limits for values of *N* up to approximately 25. This means that for problems with larger *N*, heuristics are required to determine a good approximation of the optimal strategy.

Heuristics

As an approximation we defined a "greedy m-step" heuristic: looking *m* steps ahead. In this heuristic at the end of each period *t* the decision z_{t+1}^{*} will be taken that maximizes the profit w_t over *m* steps:

$$w_t = \max_{z_{t+1}} \left(P_{t+1}(i_t, z_{t+1}) + \beta \cdot \max_{z_{t+2}} \left(P_{t+2}(i_{t+1}, z_{t+2}) + \beta^2 \cdot \max_{z_{t+3}} \left(... + \beta^{m-1} \cdot \max_{z_{t+m}} P_{t+m}(i_{t+m-1}, z_{t+m}) \right) \right) \right) \tag{8.12}$$

The total profit *v* will be:

$$v = -I + \sum_{t=1}^{N} \beta^{t-1} \cdot P_t \left(i_{t-1}, z_t^{\ *} \right) \tag{8.13}$$

Note that for the greedy 1-step heuristic (8.12) and (8.13) can be taken together:

$$v = -I + \sum_{t=1}^{N} \beta^{t-1} \cdot \max_{z_t} P_t \left(i_{t-1}, z_t \right) \tag{8.14}$$

This greedy 1-step heuristic is simply taking the best available option at every step, without looking at its consequences for further steps.

Naturally, it should hold that $1 \le m \le N$. Although the heuristic is not optimal in general, below a certain threshold value β_T of the discount factor β the greedy m-step heuristic always provides the optimal solution. This is proven in the textbox on the next page. However, realistic values for β are higher than β_T in general.

The number of calculations needed for the heuristic in each period t is:

$$(N+1-t)(N-t)\cdots(N+2-t-m) = \prod_{i=0}^{m-1} (N+1-t-i) \tag{8.15}$$

Theorem

Below a certain threshold value β_T of the discount factor β the greedy m-step heuristic gives the optimal solution.

Proof

Suppose the greedy m-step heuristic does not give the optimal solution, then for at least one period t^* it holds that the optimal decision $z_{t+1,opt}$ gives a lower profit in the next m steps than the decision based on the heuristic $z_{t+1,gr}$:

$$\sum_{t=t^*}^{t^*+m-1} \beta^{t-t^*} \cdot P\left(i_t, z_{t+1,opt}\right) < \sum_{t=t^*}^{t^*+m-1} \beta^{t-t^*} \cdot P\left(i_t, z_{t+1,gr}\right)$$

Still the value of $v_t(i_t)$ is higher than when the greedy decision is chosen:

$$v_{t^*,opt}\left(i_{t^*}\right) > v_{t^*,gr}\left(i_{t^*}\right) \Leftrightarrow$$

$$\sum_{t=t^*}^{t^*+m-1} \beta^{t-t^*} \cdot P\left(i_t, z_{t+1,opt}\right) + \beta^m \cdot v_{t^*+m,opt}\left(i_{t^*+m}\right) > \sum_{t=t^*}^{t^*+m-1} \beta^{t-t^*} \cdot P\left(i_t, z_{t+1,gr}\right) + \beta^m \cdot v_{t^*+m,gr}\left(i_{t^*+m}\right) \Leftrightarrow$$

$$\frac{1}{\beta^{m-1}} \sum_{t=t^*}^{t^*+m-1} \beta^{t-t^*} \cdot \left(P\left(i_t, z_{t+1,gr}\right) - P\left(i_t, z_{t+1,opt}\right)\right) < \beta \cdot \left(v_{t^*+m,opt}\left(i_{t^*+m}\right) - v_{t^*+k,gr}\left(i_{t^*+m}\right)\right)$$

As β can be chosen arbitrarily close to 0, choosing β below a certain threshold value β_T will lead to a contradiction.

For the total number of calculations it has been proven in the textbox on the next page that:

$$\sum_{t=1}^{N} \prod_{i=0}^{m-1} \left(N + 1 - t - i\right) = \frac{1}{m+1} \prod_{i=0}^{m} \left(N + 1 - i\right) \tag{8.16}$$

For the 1-step heuristic this boils down to $\frac{1}{2} N \cdot \left(N+1\right)$ calculations and for the 2-step heuristic to $\frac{1}{3}\left(N-1\right) \cdot N \cdot \left(N+1\right)$ calculations. Note that for large m calculating the DP problem could be faster.

Theorem

For N = 1,2,3,... and m = 1, 2, ..., N it holds that

$$\sum_{t=1}^{N}\prod_{i=0}^{m-1}(N+1-t-i)=\frac{1}{m+1}\prod_{i=0}^{m}(N+1-i)$$

Proof

Rewriting the indices of the l.h.s. leads to:

$$\sum_{t=1}^{N}\prod_{i=0}^{m-1}(N+1-t-i)=\sum_{t=0}^{N-1}\prod_{i=0}^{m-1}(t+1-i)=\sum_{t=1}^{N}\prod_{i=0}^{m-1}(t-i)$$

Now we prove with induction that:

$$\sum_{t=1}^{N}\prod_{i=0}^{m-1}(t-i)=\frac{1}{m+1}\prod_{i=0}^{m}(N+1-i)$$

For N = 1 this equation holds as 1 = 1. Suppose this equation holds for N, then what remains to be shown is:

$$\sum_{t=1}^{N+1}\prod_{i=0}^{m-1}(t-i)=\frac{1}{m+1}\prod_{i=0}^{m}(N+2-i)$$

Starting with the l.h.s. we get:

$$\sum_{t=1}^{N+1}\prod_{i=0}^{m-1}(t-i)=\sum_{t=1}^{N}\prod_{i=0}^{m-1}(t-i)+\prod_{i=0}^{m-1}(N+1-i)=$$

$$\frac{1}{m+1}\prod_{i=0}^{m}(N+1-i)+\prod_{i=0}^{m-1}(N+1-i)=\left(\frac{N+1-m}{m+1}+1\right)\prod_{i=0}^{m-1}(N+1-i)=$$

$$\left(\frac{N+2}{m+1}\right)\prod_{i=1}^{m}(N+2-i)=\frac{1}{m+1}\prod_{i=0}^{m}(N+2-i)$$

The 1-step heuristic has an obvious flaw, as in the first period no cost savings will occur (only having either a department or a commodity connected to the EP system), hence the commodity or department with the lowest implementation costs would be chosen. Here a large improvement can be made by looking two steps ahead, as in the second period the first savings occur. Considering reasonable calculation time the 2-step heuristic can be used for N even larger than 100, making it applicable for most practical situations. If not all commodities and departments have to be implemented, the non-profitable parts can be removed at the end of the implementation order found by the heuristic (as described at the end of section 8.6), hence increasing the maximum profit.

A numerical example

To illustrate how the generalized model can be used for practical calculations a small-scale example is given below with seven commodity groups and six departments to be connected to the EP system. The data in the examples is based on realistic values. Fixed costs of US$ 0.6 Million are assumed. Furthermore, the costs per commodity group are assumed to be in the order of US$ 117,000 and the costs per department around US$ 44,000. These amounts include discounted maintenance costs for five years. The variable costs are shown in Table 8.3. For the six commodity groups we assume around 15,000 transactions per year and a spend of US$ 25 Million. Also, we assume around US$ 50 can be saved on average per transaction, which means around US$ 0.75 Million per year. With an average of 25% maverick buying that will decrease to 5% with the EP system and assuming 10% higher prices with maverick purchases, the savings per year are around US$ 0.5 Million. This leads to an estimate of US$ 6.25 Million in total cost savings and these savings have been divided over the savings per commodity group per department in Table 8.4. Finally, a discount factor per year of 0.8 was taken. Assuming projects of 3 months this leads to $\beta = 0.946$.

Table 8.3: *Implementation costs of the commodity groups and departments (in 1000 US dollars).*

Commodity (j)	CC_j	Department (k)	DC_k
C1	185	D1	25
C2	100	D2	95
C3	95	D3	20
C4	145	D4	36
C5	92	D5	12
C6	60	D6	77
C7	145		

Table 8.5 gives an overview of the revenues and costs. Not including the discount factor the time the rollout takes, the profit would be about US$ 4.6 Million. Table

8.6 shows the optimal rollout strategy. The actual profit of US $ 3.05 Million is considerably lower than in Table 8.5. This is because of the discount factor and also because on average revenues are incurred at a later point in time than the costs. However, because of the discount factor the total investment is also considerably lower.

The last two periods are put between brackets in Table 8.6, as they are non-profitable and therefore should be excluded from the implementation. ROI, the payback time and the period with the first positive cash flow can also be calculated similar to the simplified model. Note that Table 8.6 does not show the actual payback time as, the cost savings (and costs) have been aggregated into one amount, which is added to the profit at the time of implementation. But these savings actually occur in the periods afterwards.

Table 8.4: *Expected cost savings Rjk per commodity per department (in 1000 US dollars).*

Department (k)→ **↓Commodity (j)**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
C1	300	566	240	190	150	9
C2	200	180	235	130	190	6
C3	70	125	100	523	110	3
C4	250	365	325	122	140	5
C5	310	175	60	120	155	14
C6	115	40	32	70	365	8
C7	15	34	13	27	25	50

Table 8.5: *Expected profit based on aggregated figures not taking into account the discount factor and the rollout process (in 1000 US dollars).*

Revenues:		
Reduced transaction costs	(750 x 5 years)	3,750
Reduced maverick buying	(500 x 5 years)	2,500
Total revenues		6,250
Costs:		
Initial		600
Commodity groups	(117 x 7 groups)	819
Departments	(44 x 6 departments)	264
Total costs		1,683
Expected profit		**4,567**

Table 8.6: *Optimal rollout strategy together with the revenues associated with each implementation period (in 1000 US Dollars).*

Period	Optimal solution	Direct profit	Direct profit (discounted)	Cumulative profit
1	D2	-695	-695	-695
2	C1	381	360	-335
3	D1	275	246	-89
4	C4	470	398	309
5	D3	545	436	745
6	C2	515	390	1,135
7	D4	406	291	1,426
8	C3	723	490	1,916
9	D5	578	371	2,287
10	C5	728	442	2,729
11	C6	562	323	3,052
(12)	(C7)	(-31)	(-17)	(3,035)
(13)	(D6)	(18)	(9)	(3,044)

Table 8.7 gives a comparison of five rollout strategies regarding the profit, implementation order and the total implementation costs. They vary between the strategies as the costs are distributed differently over the total implementation period. For this example the maximum profit is 49% higher than the minimum profit. Furthermore, the greedy heuristics approximate the optimal solution quite well. One can see the value of looking two steps ahead instead of one by the profit difference between the 2-step and 1-step heuristics. The 3-step heuristic already provides the optimal solution for this small example.

Table 8.7: *Results regarding the expected profit (in 1000 US dollars) using various rollout strategies.*

Method	Profit	Total investment	Implementation order
Optimal	3,052	1,295	D2,C1,D1,C4,D3,C2,D4,C3,D5,C5,C6
Greedy 1-step	2,920	1,232	D5,C6,C2,D1,C5,D3,C4,D2,C1,D4,C3
Greedy 2-step	3,041	1,282	D4,C3,D2,C1,C4,D3,D1,C2,D5,C5,C6
Greedy 3-step	3,052	1,295	D2,C1,D1,C4,D3,C2,D4,C3,D5,C5,C6
Worst case	2,042	1,481	C1,C4,C7,C2,C3,C5,C6,D6,D3,D5,D4,D1,D2

8.8 Conclusions

The advantages of EP seem undisputed regarding costs savings and administrative process automation. As implementation costs are lowering, EP is expected to be widely adopted by companies. At the moment EP is still in its infancy though. Pilot projects are under way, but companies still hesitate with the full rollout of EP into their organization, because the technology is new and implementation and maintenance costs scare off.

The simplified EP rollout model is a useful tool to quickly estimate ROI, the payback time and the first positive cash flow period. The generalized rollout model is a framework for providing a good rollout strategy based on expected costs and cost savings. It determines the optimal order of implementation for commodity groups and departments, together with total cost savings and how these savings will occur over time. In addition, it also shows for which commodity groups and departments it is optimal *not* to add them to the EP system. For larger practical cases greedy heuristics can be used to calculate (near) optimal strategies. Using small scale examples with realistic values of the costs and cost savings the model shows that there can be a large difference in the total savings between the optimal rollout strategy and other (random) strategies. A good rollout strategy is therefore an important factor in the successful implementation of EP.

Although many aspects already have been incorporated in the model, it is possible to make some extensions. Different functionality levels of EP systems, different lengths of implementation periods can be incorporated easily. One could also think of learning curves for implementing EP systems. Stochasticity could also be included, as input values may not be easy to estimate in practice.

The applicability of the model with possible extensions still has to be verified with empirical evidence. For practical purposes it is good to emphasize that only financial aspects of EP implementations are optimized in the model. To implement EP successfully also other organizational factors may need to be considered. These factors could influence the preferred implementation sequence. However with the model at least the financial consequences of other rollout strategies can be calculated.

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Summary

Purchasing management is a relative new scientific research field. In chapter 1 we analyze the scientific status of purchasing management research. We do this mainly by looking for similarities in the development of other scientific fields, in particular related but mature management fields such as operations management and marketing. We distinguish four types of scientific research: (1) quantitative deductive, (2) qualitative deductive, (3) quantitative empirical, and (4) qualitative empirical. It appears the mature status of operations management and marketing is caused by the fact that all types of research are present in these fields. We conclude that purchasing management still does not have this mature status, because one of the four types of research, quantitative deductive research, is hardly present. Therefore, the attention in purchasing management should be focused more on quantitative deductive research to ensure that the field will develop into maturity in the near future.

Chapter 2 conveys the setup of the PhD research project. The goal of the project is to contribute to the further development of the purchasing management field by introducing the quantitative deductive approach for a selection of strategic and tactical purchasing decision problems. This boils down to developing models and applying mathematical techniques for these decision problems. We focus on strategic and tactical purchasing decisions, because the quantitative deductive approach has hardly been applied for these decisions. Also, the impact on the costs is higher than for operational purchasing decisions. Each of the following six chapters deals with one decision problem. We chose these particular problems by applying originality, practical relevance and manageability as additional criteria. For each decision problem the same research approach has been used: a literature study, developing a mathematical model, proving theorems from the model, developing a decision support system (DSS) and if possible empirical verification of the model.

In chapter 3 we investigate from a purchasing perspective on which drivers companies should focus for ROI improvement. We present a model of ROI as a function of several key figures, most of which can be found in a company's annual report. The model is an extension of the well-known Du Pont chart; it takes explicitly into account the direct and indirect purchase spend. We show in which case the direct and indirect purchase spend are the most important ROI improvement drivers. We introduce the ROI sector plot that shows which ROI improvement drivers are the most important in a certain sector depending on the characteristics of companies in that sector. We apply this plot on a number of Dutch sectors using data from the CBS (Central Statistics Office Netherlands). In addition, we develop a DSS that calculates which ROI improvement drivers are the most important for a company specific situation. In general it appears that for Dutch industry the direct purchase spend and for the Dutch services the productivity of

employees are the most important ROI improvement drivers. In more detail we show how the direct and indirect purchase spend are involved in different situations.

In chapter 4 we investigate the allocation of joint savings to the members of a purchasing consortium using game theory. We model the allocation of savings in a purchasing consortium as a cooperative game. With this model we analyze how approaches in practice fit with the game theoretical concepts. The other way around, we also analyze the implications of the game theoretical concepts for the specific situation of a purchasing consortium. Furthermore, we show how this model can be used to determine the optimal size of a purchasing consortium. It appears that common allocation approaches in practice can lead to instability and do not always take into account the difference in purchasing power of individual members. The model we developed helps to provide clarity. It reduces the fear of other members benefiting parasitically, which helps to build trust and commitment in a purchasing consortium.

Chapter 5 considers the economic way of tendering (competitive bidding). Purchasers have to decide on the number of suppliers that are invited to submit a bid. For this decision a mathematical model exists, the ETQ model, developed by De Boer et al (2000), with which the optimal number of tenders can be calculated (the ETQ, Economic Tender Quantity). In this chapter we examine the assumptions of the model and the practical relevance using cases and interviews. To do this we develop a DSS. It appears that the ETQ model follows the intuition of purchasers closely, but estimating the distribution of the supplier bids gives difficulties sometimes. Furthermore, the ETQ model is extended to make a decision between the open and restricted procedure within the EU Directives for public procurement. Until now this decision varies strongly and appears to be mainly country dependent. This variation is not bad, but it is not clear whether it occurs based on the right analysis. Also, we show how individual behavior of suppliers can be incorporated into the ETQ model and how the ETQ model can be extended when using multiple criteria for the supplier selection.

Chapter 6 considers purchasing (raw) materials on a volatile market. In particular, we investigate the trade-off between long-term contracts with a fixed price for these materials and purchasing them directly at the current market price. Although the prices of these materials can fluctuate heavily in time, we show that simple decision rules for these purchasing decisions can be very effective. Using a threshold strategy, i.e. a long-term contract when prices are below the threshold and purchasing at current market price otherwise, it is already relatively easy to realize savings compared to the average market price.

Chapter 7 deals with the problem when it is worthwhile to switch suppliers or renegotiate the contract for a product group for which a single sourcing strategy is used. Single sourcing gives the supplier the opportunity to gradually increase prices, especially when the assortment of the product group is gradually being renewed. We present a mathematical model to calculate the optimal switching (or renegotiation) time based on parameters such as the purchase spend, the replacement rate of the products and the switching (renegotiation) costs. It is shown that it is never worthwhile to switch before a certain minimum period which naturally depends on the switching costs, but it is independent of the replacement rate.

Chapter 8 is about rolling out electronic purchasing (ordering) into an organization. Theoretically, electronic purchasing can lead to huge savings, but the implementation is often a large and costly task. Also, not much experience with good rollout strategies exists yet. We contribute to the solution of this problem by presenting a mathematical model, which determines the rollout strategy that maximizes the total cost savings. In addition, we provide insights into the ROI, the payback time and the cash flow during the implementation. The model shows that a wrong rollout strategy can have very negative consequences for the overall cost savings. It also shows when it is optimal not to add certain product groups and departments to the electronic purchasing system.

Samenvatting (summary in Dutch)

Kwantitatieve analyse van strategische en tactische inkoopbeslissingen

Inkoopmanagement is een relatief nieuw wetenschappelijk vakgebied. In hoofdstuk 1 analyseren we de wetenschappelijke status van het onderzoek inzake inkoopmanagement. Daarvoor beschouwen we o.a. naar overeenkomsten met de ontwikkeling van andere wetenschappelijke vakgebieden en in het bijzonder gerelateerde, volwassen managementvakgebieden zoals operations management en marketing. We onderscheiden vier types wetenschappelijk onderzoek: (1) kwantitatief deductief, (2) kwalitatief deductief, (3) kwantitatief empirisch en (4) kwalitatief empirisch. Het blijkt dat operations management en marketing hun volwassen status danken aan het feit dat alle types onderzoek binnen die vakgebieden vertegenwoordigd zijn. We concluderen dat inkoopmanagement die volwassen status nog niet heeft, omdat van de vier types onderzoek met name kwantitatief deductief onderzoek nauwelijks aanwezig is. De aandacht binnen inkoopmanagement zou dan ook meer gericht moet worden op kwantitatief deductief onderzoek om ervoor te zorgen dat het vakgebied in de nabije toekomst zich verder ontwikkelt tot volwassenheid.

Hoofdstuk 2 geeft de opzet van het promotieonderzoek weer. Het doel van het onderzoek is om bij te dragen aan de verdere ontwikkeling van het vakgebied inkoopmanagement door de kwantitatief deductieve aanpak te introduceren voor een aantal strategische en tactische inkoopbeslissingen. Dit komt neer op het ontwikkelen van modellen en toepassen van bestaande wiskundige technieken voor deze beslissingen. We richten ons op strategische en tactische inkoopbeslissingen, omdat de kwantitatief deductieve aanpak met name hierop nog nauwelijks is toegepast. Ook is de impact op de kosten groter dan voor operationele inkoopproblemen. Elk van de volgende zes hoofdstukken behandelt één beslissingsprobleem. We zijn gekomen tot het uitwerken van juist deze problemen door originaliteit, praktische relevantie en hanteerbaarheid als extra criteria te gebruiken. Voor elk onderwerp is dezelfde onderzoeksaanpak gehanteerd: een literatuurstudie, het ontwikkelen van een wiskundig model, het afleiden van stellingen uit het model, het ontwikkelen van een DSS (decision support system) en zo mogelijk empirische verificatie van het model.

In hoofdstuk 3 onderzoeken we vanuit een inkoopperspectief waar bedrijven zich op moeten richten voor het verbeteren van hun ROI (return on investment). We presenteren een model van de ROI als functie van verscheidene kerngetallen die meestal in een jaarverslag gevonden kunnen worden. Het model is een uitbreiding op het bekende Du Pont schema, waarin expliciet rekening gehouden wordt met de directe en facilitaire inkoopvolumes. We laten zien wanneer directe en facilitaire inkoop de belangrijkste factoren vormen voor ROI verbetering en wanneer juist niet. We introduceren de ROI sectorgrafiek, die aangeeft wat de belangrijkste factoren voor ROI verbetering zijn in een bepaalde sector afhankelijk van de eigenschappen van bedrijven in die sector. Deze grafiek passen we toe op een aantal Nederlandse sectoren met behulp van data van het CBS. Ook hebben we een DSS ontwikkeld, dat de belangrijkste factoren voor ROI verbetering aangeeft voor elke bedrijfsspecifieke situatie. Globaal blijkt dat voor de Nederlandse industrie de directe inkoop en voor diensten de productiviteit van werknemers de belangrijkste factoren voor ROI verbetering zijn. In meer detail is aangegeven in welke situaties de beide inkoopvolumes daarbij aan de orde komen.

In hoofdstuk 4 onderzoeken we de verdeling van gezamenlijke besparingen in een inkoopconsortium over de deelnemers met behulp van speltheorie. We modelleren de toewijzing van besparingen in een inkoopconsortium als een coöperatief spel. Gebruik makend van dit model onderzoeken we hoe de praktijkaanpak van het verdeelprobleem strookt met speltheoretische concepten. Andersom onderzoeken we ook de implicaties van speltheoretische verdelingsmethodes voor het specifieke geval van een inkoopconsortium. Verder laten we zien hoe dit model gebruikt kan worden om de optimale grootte van een inkoopconsortium te bepalen. Het blijkt dat verdelingen die in de praktijk gebruikt worden kunnen leiden tot instabiliteit en niet altijd rekening houden met de inkoopmachtsverhouding van de deelnemers. Het ontwikkelde model helpt duidelijkheid te scheppen, zodat vrees van deelnemers dat andere leden parasiteren op hun inkoopvolume vermindert met als gevolg meer vertrouwen en toewijding binnen een consortium.

Hoofdstuk 5 gaat over de meest economische manier van het doen van aanbestedingen oftewel het aanvragen van offertes. Inkopers moeten een beslissing nemen over het aantal leveranciers dat gevraagd wordt een offerte in te dienen. Voor deze beslissing bestaat een wiskundig model, het ETQ-model, ontwikkeld door De Boer e.a. (2000) waarmee het optimale aantal offertes berekend kan worden (de ETQ, "Economic Tender Quantity"). In dit hoofdstuk onderzoeken we de aannames achter het model en de praktische relevantie met behulp van cases en interviews. Hiervoor is een DSS ontwikkeld. Het blijkt dat het ETQ-model goed aansluit bij de intuïtie van inkopers, maar dat het inschatten van de spreiding in de aanbiedingen van de leveranciers nog wel eens problemen oplevert. Verder is het ETQ-model uitgebreid voor het maken van een keuze tussen de openbare en niet openbare aanbestedingsprocedure binnen de EU aanbestedingsrichtlijnen. Tot op heden blijkt dat deze keuze erg varieert en vooral landafhankelijk is. Deze variatie is op zich goed, maar de vraag is of dat nu op grond van de juiste analyse gebeurt. Ook laten we zien hoe individueel gedrag van leveranciers aan het ETQ-model kan worden toegevoegd alsmede het toepassen van meerdere criteria in de leveranciersselectie.

Hoofdstuk 6 gaat over het inkopen van goederen (grondstoffen) op een beweeglijke markt. Specifiek onderzoeken we de afweging tussen het afsluiten van lange termijn contracten voor deze goederen tegen een vaste prijs en het rechtstreeks inkopen op de (volatiele) markt. Hoewel de prijzen van deze goederen sterk kunnen fluctueren in de tijd laten we zien dat eenvoudige beslissingsregels voor het inkopen ervan toch erg effectief kunnen zijn. Door gebruik te maken van een drempelwaarde-strategie, d.w.z. onder de drempelwaarde een langetermijncontract en erboven inkopen op de markt, kan eenvoudig een besparing ten opzichte van de gemiddelde marktprijs worden gerealiseerd.

Hoofdstuk 7 behandelt het probleem, op welk moment het zin heeft van leverancier te wisselen of het contract ter heronderhandelen voor een productgroep waarvoor een single sourcing strategie wordt gebruikt. Single sourcing geeft de leverancier de gelegenheid de prijzen geleidelijk te verhogen, zeker wanneer het assortiment van de productgroep langzamerhand wordt vernieuwd. We presenteren een wiskundig model voor het berekenen van de optimale wisseltijd gebaseerd op parameters zoals het inkoopvolume, de vernieuwingsgraad van het assortiment en de wisselkosten. Het blijkt dat het economisch gezien nooit zinvol is sneller te wisselen dan een bepaalde minimumperiode die onafhankelijk is van de vernieuwingsgraad, maar natuurlijk wel afhankelijk van de wisselkosten.

Hoofdstuk 8 gaat over het uitrollen van een elektronisch bestelsysteem in een organisatie. Theoretisch gezien kan een elektronisch bestelsysteem tot grote besparingen leiden, maar de implementatie is vaak een kostbare en langdurige aangelegenheid. Ook is er nog niet veel ervaring met goede uitrolstrategieën aanwezig. Wij dragen bij aan het oplossen van dit probleem door een wiskundig model te presenteren voor het bepalen van de uitrolstrategie die de totale kostenbesparingen maximaliseert. Ook wordt inzicht verschaft in de terug-verdientijd en de cash flow gedurende de implementatie. Het model laat zien dat een verkeerde uitrolstrategie zeer negatieve gevolgen kan hebben voor de uiteindelijke besparingen. Ook laat het zien wanneer het optimaal is om bepaalde productgroepen en afdelingen niet aan het elektronische bestelsysteem toe te voegen.

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Although this little section has been carefully hidden at the end of this thesis, it tends to be one of the parts, which is read the most. This does not make the task of writing it any easier, as I would not want to disappoint anyone.

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About the author

Govert Heijboer was born on May 9, 1975 in Zwolle, the Netherlands. In secondary school at the Christelijk Gymnasium in Leeuwarden he won the Dutch Chemistry Olympiad. He continued his education by studying Applied Physics at the University of Twente in Enschede. After a successful internship at CERN in Switzerland he did his graduation assignment at NIKHEF resulting in his Master's thesis "GRAIL, Using electrostatical excitations of vibrational modes in a solid as a calibration method". He graduated in 1998, after which he decided to focus on a different field. In 1999 he started as a PhD student in Purchasing Management at the Faculty of Technology and Management at the University of Twente under supervision of Professor Jan Telgen. His research project entitled "Mathematical and statistical analysis of initial purchasing decisions" resulted in this thesis and several (scientific) journal publications.