Investment evaluation with respect to commercial uncertainty

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Summary

N.V. Nederlandse Gasunie is responsible for the trading and transport of all natural gas that is produced in the Netherlands. For the planning of investments in transportation and production means, the uncertainty of future supply and demand is a serious problem. In this thesis, new tools are developed for analysing to what extent any investment plan contributes to robustness against commercial uncertainty. The thesis is an elaboration of some ideas that came up during the research project Plato-OOG, a cooperation of Gasunie and the University of Groningen.

The production of natural gas

Investment planning is modelled as a two-stage decision problem: the investment decisions are meant to give enough production capacity, such that the future production planning can meet the market requirements. In Chapter 2 a part of the annual production planning of Gasunie is modelled through a number of linear restrictions on the production decisions. In every quarter of the year, the production of different gas types should meet:

1. the energy demand of different demanders,
2. the contractual quality requirements on the gas delivered,
3. the capacity restrictions and
4. some gas flow balances

To guarantee the sufficiency of production capacity also on a cold day, the model is extended with restrictions 1 to 4 now including parameter values that represent an extremely cold day. The extended model is denoted as matchplus.

The restrictions on the production decisions in matchplus depend both on uncertain commercial variables and on production capacities, which are influenced by investment decisions. The following uncertain commercial variables are distinguished:

\[ DH = \text{annual demand for gas with high calorific value (H-gas)}, \]
\[ DL = \text{annual demand for gas with low calorific value (L-gas)}, \]
\[ ACQ = \text{annual quantity of supply that has to be processed according to contract} \]

A realization of all three variables together is called a commercial scenario. We distinguish production capacity for Slochteren gas, non-Slochteren gas (both
H-gas and L-gas) and nitrogen, and if necessary in- and outflow capacity of an eventual underground storage is added.

Robust investments and commercial scope

Using the MATCHPLUS model, in Chapter 3 some aspects of investment planning are worked out theoretically. With respect to commercial uncertainty, a company will strive for a certain level of robustness. In Section 3.2, the concept of commercial robustness is defined and contrasted with the related concepts of flexibility and risk.

In Section 3.3, the central notion of this thesis, the commercial scope, is defined to be the set of all future commercial scenarios that can be dealt with by the production planning, given the technical capabilities of the company. For a robustness analysis it would be very useful to have a description of this set in terms of the investment decisions, without interference from the production decisions. It turns out that the production variables can be eliminated from the production planning restrictions. The result is a number of so-called induced constraints on the commercial variables and the investment decisions, which together give the required explicit representation of the commercial scope.

The commercial scope is influenced by investments in production capacity. It is a crucial attribute of any investment proposal. Based on the commercial scope, in Sections 3.4 to 3.6 simple robustness and risk measures are given, which together with the traditional financial criteria can be used to evaluate investment decisions. Some of them are well-known, like the shortages and surpluses under a given scenario, the probability of a feasible realization (more often known as customer reliability or expected service level) and the risk of infeasibility (known for instance as the risk of stock-outs). Other measures are new, like the directional scopes under a given scenario and the expected directional scope. The directional scope for a certain direction gives the distance of a certain scenario to the boundary of the commercial scope in that direction. In the context of Gasunie, these instruments can answer questions like: 'As seen from the base scenario, how much additional non-Slochteren supply can be absorbed under investment plan \( x \)?'. As a by-product of the calculation of the robustness and risk measures it is not only easy to construct boundary points for the commercial scope, but also corresponding induced constraints that construct a part of the scope boundary. In this indirect way it is possible to get an adequate explicit representation of the commercial scope.

Experiments using the MATCHPLUS model

The commercial scope, investment criteria and induced constraints are applied in some experiments based on the MATCHPLUS model. The data used are realistic but fictitious, so that the results of the experiments do not refer to any real world planning problem.
In Chapter 4 treats the situation without investments (alternative $x^0$). As investment alternatives, in Chapter 5 we consider the introduction of underground storage capacity (alternative $x^1$), the extension of nitrogen production capacity (alternative $x^2$) and the combination of both (alternative $x^3$). All four alternatives are analysed by means of both a small number of scenarios and a probability distribution on the commercial scenario. For the scenario analysis, one central scenario $s^0$ and eight extreme scenarios are used. For all alternatives, from $x^0$, the directional scopes are computed in the coordinate directions (which comes down to ceteris paribus variation of the different commercial variables) and in the directions of the extreme scenarios. For the extreme scenarios that are infeasible under one of the alternatives, the surpluses and corresponding penalty costs are computed. For the stochastic analyses the commercial vector is assumed to follow a multivariate normal distribution, with the central scenario $s^0$ as its expected value. Here the reliability and expected penalty costs are calculated.

For the evaluation of the commercial scope of $x^0$, the directional scopes diverge remarkably in the different directions. There are dangerous directions, where the directional scope is almost zero, and less dangerous directions, where the directional scope is large or even infinitely large. The central scenario $s^0$ lies close to the boundary of the scope. In the stochastic analysis it appeared that without investments the probability of a feasible commercial scenario is indeed very low: about 50%. Obviously, investments are necessary. Compared to the zero-investment alternative $x^0$, alternative $x^1$ gave a significant improvement of almost all robustness measures considered. Alternative $x^2$ in turn scores better than $x^1$. And, of course, the combination of both, alternative $x^3$, gives the best results. Doubtless labouring the obvious we remark that, since the data used are fictitious, these results do not have any implication as to the actual situation of Gasunie.

The commercial scope under $x^0$ appears to be sufficiently described by only three induced constraints, which all have a nice interpretation. Two of them give upper bounds on the annual amount of H-gas that can be processed by the L-gas system. These constraints, incidentally the two that most restrict the scope, are loosened by the investment alternatives considered. The third induced constraint does not depend on investments. In the end, only five induced constraints suffice to describe the commercial scope of all four investment alternatives considered, which is a very small number.

**Generalizations of the model**

In Chapter 6 the underlying MATCHPLUS model, which describes the production planning, is modified in different ways. In this way it is possible to study to what extent the usefulness of the instruments depends on the specific properties of the example considered.
The extension of the matchplus model with an additional restriction on the methane content of the L-gas delivered introduces some new induced constraints. In a numerical example, the commercial scope is only influenced if the methane content restriction holds for almost all L-gas demand. If the number of uncertain variables is extended by dropping the fixed demand profiles, the resulting model is still linear. In our example, the number of relevant induced constraints increases, but less than expected and they are still easily interpreted. If matchplus is disaggregated into subperiods of one month length, the structure of the model is completely preserved. Different fixed monthly demand profiles are taken such that they correspond to the previously used quarterly profile. It appears that the results are very sensitive to the demand profiles used. If investment planning is considered as a problem with different decision stages over the years, the commercial scope is no longer well defined. Yet the so-called carry forward decision, putting production obligations forward to an earlier year, is easily incorporated in the matchplus one-year model. Indeed, it turns out to be an effective instrument for improving commercial robustness.

In this thesis, we constantly worked with given investment alternatives. However, the robustness and risk measures developed can be used in models of stochastic programming, to generate sound investment alternatives based on a balancing of cost, risk and robustness. In such models, the induced constraints can be usefully applied.

Incorporation into a planning procedure

In Chapter 7, some ideas are given as to how and under which conditions the scope and its derived criteria can be usefully incorporated into a planning procedure. In the final report of the Plato-OOG project, it is recommended to distinguish between kernel scenarios, for which one should be prepared at all costs, and other scenarios which are eventually covered on the basis of a balance between robustness and investment cost. Furthermore, it is recommended to feed information on the commercial robustness back to the commercial departments that came up with the forecasts. Chapter 7 concludes with the description of a planning procedure incorporating both recommendations, which is based on the commercial scope and its related instruments.