Schmidt, Reinhart

Coordination of bank branches under uncertainty

Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 99

Provided in Cooperation with:
Christian-Albrechts-University of Kiel, Institute of Business Administration

Nr. 99

Coordination of Bank Branches under Uncertainty

Reinhart Schmidt*

* Prof. Dr. R. Schmidt
Institut für Betriebswirtschaftslehre
der Christian-Albrechts-Universität Kiel
Lehrstuhl für Finanzwirtschaft
Olshausenstraße 40-60

D-2300 Kiel 1

Paper presented at the Eighth Annual Meeting of the European Finance Association on September, 10-12, 1981, in Scheveningen.

1. Introduction

Bank planning models should at least meet two requirements. Firstly, the multiperiod character of most banking activities should be considered. Secondly, one should allow for the uncertainty of future events. Lots of models have been constructed fulfilling these requirements. But only in a few models the problem of the underlying organizational structure of the bank has been incorporated. This must be criticized because the success of model implementation depends upon how the formal planning model is embedded in the organization.

Within a hierarchical organization the problem of decentralized decisions arises together with the problem of coordinating the decision units. Existing theoretical modeling approaches for banking assume that all decision variables are determined by one decision unit, i.e. the top management or the central office. This assumption is also made in the case of branches[1] or subsidiaries[2] where more or less decentralization of decisions is typical in reality. In these cases the constructors of such centralized planning models suppose that all relevant information is transmitted to the central unit. Independent of the fact that such a communication causes immense costs or is technically impossible, it ignores the role of motivation within organizations. Thus, there is a need for theoretical models which take into account the decentralization of decisions and their coordination.

It is the aim of this paper to develop a model of multiperiod bank planning under uncertainty in the case of decentralized decision units, especially bank branches.

In the literature only parts of our problem have been treated. The first step in the development of bank planning models was the formal representation of institutional constraints arising in a multiperiod banking world. It can be stated that this step has been terminated successfully.[3]

---

1) See Sunderland (1974).
2) See Cohen and Lam (1979).
3) See Meyer zu Selhausen (1977) as an example.

The inclusion of uncertainty has been discussed with respect to methodological aspects[4], rarely having led to applicable problem formulations[5]. The coordination problem has been handled by several authors without having arrived at a formal decision model for the coordination of bank branches. But in the literature on capital budgeting of decentralized organizations there have been presented different approaches[6] which could be applied to the banking firm. In this context, the problem of coordination under uncertainty has been handled by Obel and Vander Weide[7] recently; these authors formulate a one-period decomposition model together with the possibility of multiple objectives within the organization.

In the following we apply the capital budgeting approaches for decentralized organizations by Maier and Vander Weide[8] and by Obel and Vander Weide[7] to the coordination of bank branches under uncertainty. Our model goes beyond their models in the consideration of uncertainty by the two-stage programming approach. The model also allows for a connection between payment variables and balance sheet variables, thus ending with planned financial statements of the whole bank and its branches. The explanation of the model will be followed by a discussion of application problems. Finally, we present some numerical results as an example.

---

4) See Charnes and Thore (1966), Thore (1968), Bradley and Crane (1975), and Booth and Dash (1979).
5) See the application by Bradley and Crane (1975).
6) E.g. Carleton, Kendall, and Tandon (1974), Morris (1975), Maier and Vander Weide (1976), and Rosenberg (1979).
7) Obel and Vander Weide (1979).
8) Maier and Vander Weide (1976).

2. The Model

2.1. Problem Structure

The main subject of bank planning is the construction of future balance sheets, because in banking the activities are closely related to the balance sheet. But planning bank balance sheets does not imply that service activities are excluded. These activities rather enter the profit and loss statements, and thus the balance sheets. For the sake of simplicity let us assume that the bank balance sheet contains the following positions.

BALANCE SHEET

ASSETS	LIABILITIES
CASH	DEPOSITS
SECURITIES	BONDS
LOANS	EQUITY
	DECLARED DIVIDENDS

In branch banks there is a division of decisions so that some activities are planned by the central office only, especially the amounts of cash and securities and the bond issues. This is also true for decisions concerning equity and dividends. On the other side, loans and deposits can be planned by the branches and the central office. Without loss of generality we assume that decisions concerning the latter items are made by the branches only. Activities which are not directly related to the balance sheet are excluded for the moment, that means these activities are taken as exogenous variables. These activities could be converted to decision variables easily, but this conversion would not change the model structure.

The multiperiod planning problem is characterized by T periods of equal or unequal length, whereby we assume equal length without loss of generality. It is further supposed that the decisions are made at the beginning of each planning period implying corresponding payments at the beginning and possibly at the end of each period ($t=1,2,\ldots,T$). Financial consequences of a decision can

go beyond T up to H (t=T+1,...,H), the payments after T are discounted to T.

Uncertainty is taken into account by a tree structure of states of the nature, i.e. sequences of scenarios which may occur with known probabilities.[9] Figure 1 shows an example of such a tree of states. We assume that the consequences of a decision are independent of all other decisions. Dropping this assumption would result in a portfolio-type problem which in turn would require the application of another method.

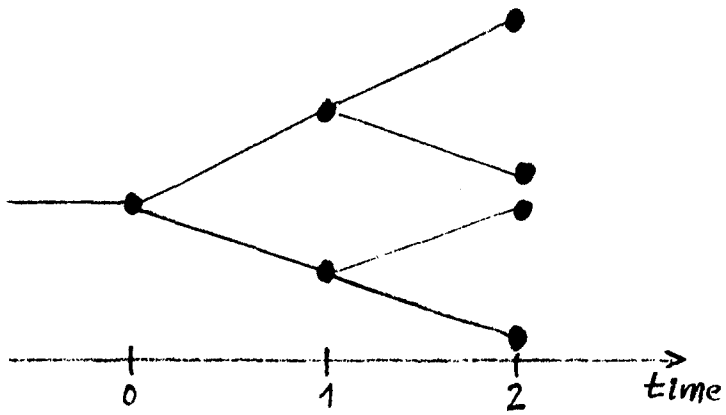

Figure 1: Tree of states of the nature

The firm is exposed to a lot of constraints some of them being established by the legal authorities, especially constraints with respect to reserves and capital adequacy. To maintain liquidity the bank sets up a payment constraint for each planning period and some further constraints which should indicate liquidity from the bank's point of view. The latter constraints may be legal constraints, too. We assume that the bank requires a certain relationship between securities and cash as a proxy for liquidity. Thus, liquidity is a problem of the central office.

The objective of the bank is the maximization of the bank's net worth at the end of period T. This corresponds with the maximization of the so called terminal value. Because there are several states of the nature it is assumed that the bank wants to maximize the expected terminal value at the end of period T. Under this objective, risk aversion can be taken into account by setting up constraints for the values of some risky decision variables.

9) See Laux (1971) for this approach.

2.2. The Mathematical Model

Following the coordination approach by Maier and Vander Weide we have different types of equations which can be classified and labelled:

- equations of the optimization problems being solved by the central office (C)
- equations of computations which are carried out after an optimization by the central office and which lead to budgets (B) and prices for the resources (P)
- equations of the optimization problems being solved by the divisions, i.e. the branches (D)
- equations of computations which are carried out after an optimization by a division and which lead to coefficients for the objective function of the central office (E).

All variables, coefficients, and constants are presented together with the corresponding abbreviation in Appendix I. Though the planning process starts with divisional optimizations we at first discuss the optimization model of the central office because this model shows the overall structure of the problem.

The objective function contains the maximization of the expected terminal value at the end of period T. It contains the expected values of terminal wealth resulting from the branches and the central office.

$$(C1)\quad \sum_{k=1}^{K} \sum_{q \in Z_k} E[DCF_{kqT}]\,\lambda_{kq} + \sum_{S=1}^{S_T} p_S \cdot [SEC_{TS} - BONDS_{TS} + CASH_{TS}] = max!$$

The K branches have reported a set of proposals to the central office, whereby $E[DCF_{kqT}]$ is the expected value of discounted cash-flows (discounted to T) reported as proposal q by branch k. These proposals originate from all previous optimizations of the branches within the given decision problem. The number of proposals must not be equal for all branches. λ_{kq} is the unknown weight for proposal q which belongs to branch k. As (C2) shows, the weights must sum to one for each branch.

The second term in (C1) contains investment in securities and cash at point T and bond issues at the same point of time. These decision variables show an index s for the state of the nature at T. The values of the decision variables are weighted with the probabilities p_s, where p_s is the unconditional probability that state s will occur. S_T is the number of nodes of the state tree in T (see Figure 1). In contrary to normal capital budgeting models,[10] the objective function allows for investment in securities and cash though the return on cash is zero. This variation comes from the necessity of holding reserves.

$$(C2) \qquad \sum_{k \in Z_k} \lambda_{kq} = 1 \qquad (k = 1, \ldots, K)$$

(C3.1) and (C3.2) represent the payment restrictions for the beginning of all new activities in t=0 and all the following points of time up to T. The number of restrictions depends mainly upon the number of states of the nature S_t which will occur at point t. Thus, each state of the nature requires a special restriction.[11] Because it is assumed that all consequences at point t=0 are known with certainty, (C3.1) consists of only one restriction.

$$(C3.1) \qquad \sum_{k=1}^{K} \sum_{q \in Z_k} PAY_{kq01}\, \lambda_{kq} + SEC_{01} - BONDS_{01} + CASH_{01} \leq \overline{PAYEX}_{01}$$

$$(C3.2) \qquad \sum_{k=1}^{K} \sum_{q \in Z_k} PAY_{kqts}\, \lambda_{kq} + SEC_{ts} - BONDS_{ts} + CASH_{ts} + TAX_{ts} + DIV_{t-1,s-} + (1+b_{ts})\, BONDS_{t-1,s-} - CASH_{t-1,s-} - (1+l_{ts})\, SEC_{t-1,s-} \leq \overline{PAYEX}_{ts} \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

Furthermore PAY_{kqts} is the amount of money that is demanded by branch k's proposal q for period t if state s will occur.

10) See e.g. Weingartner (1963) and Hax(1964).
11) See Laux (1971).

We assume - like other authors on capital budgeting problems - that some investments and credits mature after one period, in our case the securities and bonds of the state s^- at point t, where s^- represents the state of the nature in period t-1 which is situated just before state s of period t. The lending and borrowing rates therefore depend upon the state of the nature, too(l_{ts} and b_{ts}).

$\overline{PAYEX}_{ts}$ stands for exogenous payments which result from former business activities of the bank or which are related to preplanned future actions, e.g. issuing equity at point t if state s will occur.

Taxes (TAX) and dividends (DIV) are decision variables which will be defined in equations later.

(C4) is a set of constraints concerning cash reserves. RES_{kqts} is the amount of reserves in period t and state s if proposal q of branch k is admitted. $\overline{RESEX}_{ts}$ represents exogenous reserve requirements.

$$(C4) \quad \sum_{k=1}^{K} \sum_{q \in Z_k} RES_{kqts} \, \lambda_{kq} - CASH_{ts} \leq \overline{RESEX}_{ts} \qquad (t = 0,1,\ldots,T;\ s = 1,\ldots,S'_t)$$

(C5.1) and (C5.2) consider capital adequacy by a relationship between the equity at the beginning of the period ($EQUITY_{t-1,s^-}$), equity demands by the branches ($EQUI_{kqts}$), and exogenous equity demands of former operations or of preplanned loans ($\overline{EQUIEX}_{ts}$). m is a factor which is numerically specified by the supervising authority.[12)]

$$(C5.1) \quad \sum_{k=1}^{K} \sum_{q \in Z_k} EQUI_{kq01} \, \lambda_{kq} \leq \overline{EQUIEX}_{01}$$

$$(C5.2) \quad \sum_{k=1}^{K} \sum_{q \in Z_k} EQUI_{kqts} \, \lambda_{kq} - m \, EQUITY_{t-1,s^-} \leq \overline{EQUIEX}_{ts} \qquad (t = 1,\ldots,T;\ s = 1,\ldots,S'_t)$$

12) In Germany the value of this factor is 18.

(C6) contains a strategic coefficient z which is specified by the bank in order to maintain liquidity.

$$(C6) \qquad SEC_{ts} - z \cdot CASH_{ts} \geq 0 \qquad (t=0,1,\ldots,T;\ s=1,\ldots,S_t)$$

(C7.1) and (C7.2) are equations defining the equity which can be changed by exogenous issues of new equity ($\overline{NEWEQ}_{ts}$) and by the part $\tilde{r}$ of earnings after taxes (EAT_{ts}) which is retained by the bank.

$$(C7.1) \qquad EQUITY_{ts} - EQUITY_{t-1,s^-} - \tilde{r} \cdot EAT_{ts} = \overline{NEWEQ}_{ts} \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

$$(C7.2) \qquad EQUITY_0 = \overline{EQUITY}_0$$

(C8.1) and (C8.2) represent equations defining the dividends.

$$(C8.1) \qquad DIV_{ts} - (1-\tilde{r})\ EAT_{ts} = 0 \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

$$(C8.2) \qquad DIV_{01} = \overline{DIV}_0$$

(C9) is a set of definitions for the taxes, τ^* being explained in Appendix II.

$$(C9) \qquad TAX_{ts} - \tau^* \cdot EAT_{ts} = 0 \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

Finally, there is a set of definition equations for the earnings after taxes. These equations include profit contributions from the branches ($PROF_{kqts}$), from the decision variables of the central office, and from exogenous profit sources.

$$(C10)\quad \sum_{k=1}^{K} \sum_{q \in Z_k} PROF_{kqts}\, \lambda_{kq} + \ell_{t,s}\, SEC_{t-1,s-} - b_{t,s}\, BONDS_{t-1,s-} - \gamma^{**}\, EAT_{ts} = \overline{PROFEX_{ts}} \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

Besides equations (C1) up to (C10) there are the usual nonnegativity constraints for all decision variables.

The approach by Maier and Vander Weide is a mixed decomposition approach because the central office sends down budgets (B) and shadow prices (P) to the branches. Each time the central planning problem (C) has been solved, the central office computes the following budget restrictions for branch k in state s of period t, thereby using the optimal values λ^*_{kq} as weights.
For all k=1,...,K, t=0,1,...,T, and s=1,...,S_t:

$$(B1)\quad PAYLIM_{kts} = \sum_{q \in Z_k} PAY_{kqts}\, \lambda^*_{kq}$$

$$(B2)\quad RESLIM_{kts} = \sum_{q \in Z_k} RES_{kqts}\, \lambda^*_{kq}$$

$$(B3)\quad EQUILIM_{kts} = \sum_{q \in Z_k} EQUI_{kqts}\, \lambda^*_{kq}$$

The central office also determines the shadow prices for the possibly scarce "resources" in state s of period t. The prices concerning (C3), (C5), and (C6) are

$$(P1)\quad \alpha_{ts},\ \beta_{ts},\ \text{and}\ \gamma_{ts} \qquad (t=0,1,\ldots,T;\ s=1,\ldots,S_t)$$

The prices concerning (C10) are

$$(P2)\quad \delta_{ts} \qquad (t=1,\ldots,T;\ s=1,\ldots,S_t)$$

Finally, the best proposal, transmitted so far to the central office by branch k, contributes to the value of the objective function of the central office:[13)]

13) See Maier and Vander Weide (1976).

(P3) $\sigma_k \qquad (k = 1, \ldots, K)$

As we shall see, the values from (B) and (P) will be used when the branches solve their special optimization problems. For all k=1,...,K and for a given iteration (q) within the communication between the central office and branch k, the following problem must be solved.

$$(D1) \quad \sum_{s=1}^{S_T} p_s \cdot \left\{ \sum_{i \in Z_k} (-d_{iTs}) \cdot X_i \right\}$$

$$- \sum_{t=0}^{T} \sum_{s=1}^{S_t} \alpha_{ts} \, PAY_{kqts} - \sum_{t=0}^{T} \sum_{s=1}^{S_t} \beta_{ts} \, RES_{kqts}$$

$$- \sum_{t=0}^{T} \sum_{s=1}^{S_t} \gamma_{ts} \, EQU_{kqts} + \sum_{t=1}^{T} \sum_{s=1}^{S_t} \delta_{ts} \, PROF_{kqts}$$

$$- \sigma_k = max!$$

(D1) represents the objective function of branch k which maximizes the expected value of the terminal value caused by this branch. The objective function contains three parts. Firstly, some of the decision variables belong to branch k, X_i representing the number of project units which shall be executed by this branch. The outlays which are connected with the realization of one monetary unit of X_i are a_{its} for state s in period t. If a_{its} represents a receipt the value of a_{its} will be negative. A loan thus has a positive value of a_{its} at the beginning and negative values in the following periods, for deposits vice versa. The discounted cash-flow of all payments after T, being discounted to T, is $-d_{its}$. The first part of the objective function therefore consists of the present value at T of all payments after T.

Secondly, a branch is charged for the use of central resources by the prices transmitted from the central office. For instance, $\beta_{ts} \cdot RES_{kqts}$ is the amount of opportunity costs which are caused by the reserve requirements.

Thirdly, σ_k - which is independent of the division's decisions at this moment - is a constant which equals the so far best value of a proposal made by this divisions in earlier iterations. σ_k therefore acts as a treshold for new proposals that should be transmitted to the central office.

(D2), (D3), (D4), and (D5) are sets of definitions for the aggregated variables PAY_{kqts}, RES_{kqts}, $EQUI_{kqts}$, and $PROF_{kqts}$, respectively. These equations in the best way explain the underlying concept of decentralized decisions. While the branches may have a lot of decision alternatives X_i, they only report the aggregated values of their planned decisions to the central office. This procedure creates some autonomy for each branch, especially if one remembers the actual changes when decisions are executed.

$$\left.\begin{aligned}
&(D2) \quad \sum_{i \in Z_k} a_{its} X_i - PAY_{kqts} = 0 \\
&(D3) \quad \sum_{i \in Z_k} r_{its} X_i - RES_{kqts} = 0 \\
&(D4) \quad \sum_{i \in Z_k} e_{its} X_i - EQUI_{kqts} = 0
\end{aligned}\right\} \quad (t = 0, 1, \ldots, T;\ s = 1, \ldots, S_t')$$

$$(D5) \quad \sum_{i \in Z_k} c_{its} X_i - PROF_{kqts} = 0 \quad (t = 1, \ldots, T;\ s = 1, \ldots, S_t')$$

(D6), (D7), (D8), and (D9) represent constraints caused by the market or by risk considerations [see (D6)] and constraints set up by the central office in the previous iteration of its optimization problem. Thus, "budget" restrictions exist for deposits - which require reserves - and for loans - which require adequate equity - beside the usual budgets found in the literature on capital budgeting.

$$(D6) \qquad X_i \leq \overline{X}_i \qquad \forall\, i \in Z_k$$

$$\left.\begin{array}{ll} (D7) & PAY_{kqts} \leq \overline{PAYLIM}_{kts} \\ (D8) & RES_{kqts} \leq \overline{RESLIM}_{kts} \\ (D9) & EQUI_{kqts} \leq \overline{EQUILIM}_{kts} \end{array}\right\} (t = 0, 1, \ldots, T;\ s = 1, \ldots, S_t)$$

While we demand for nonnegativity of the most decision variables:

$$X_i,\ RES_{kqts},\ EQUI_{kqts} \geq 0\ ,$$

some decision variables - i.e. PAY_{kqts} and $PROF_{kqts}$ - are unrestricted in sign.

After having solved the problem (D), a branch computes the expected value of the discounted cash-flows after T, thereby the optimal decision variables X_i^* from (D) are used:

$$(E1) \qquad E[DCF_{kqT}] = \sum_{s=1}^{S_T} \sum_{i \in Z_k} p_s \cdot (-d_{iTs}) \cdot X_i^*$$

2.3. The Decomposition Algorithm

The decomposition algorithm by Maier and Vander Weide[14] has been implemented on a PDP 10 at the computing center of the University of Kiel[15]. The file organization was constructed under the requirement that information storage, communications and computations should be analogous to reality. That means there are some informations at the central office, some other informations at the branches. The messages from the branches to the central offices and vice versa are documented. Thus, one can easily follow the decomposition algorithm by looking at the inputs and outputs of a numerical example which is presented in Appendix III.

At the beginning each branch solves the problems (D1) to (D6) and (D1) to (D9), the latter problem being only solved if the first problem leads to a positive value of the objective function. The aggregated values of the decision variables in (D2) to (D5) are reported to the central office together with the value from (E1). The central office then solves its problem (C) and computes limits for the budgets (B). These limits are sent to the branches together with the opportunity costs (P). These messages are used by the branches which try to find a better solution for (D) under the budgets and opportunity costs received. The algorithm terminates when no division is able to transmit a new proposal.[16] Experiments show that the algorithm converges quickly. Nevertheless it can be useful to terminate the algorithm after having compared the value of the objective function with an upper bound.[17]

Postoptimal analyses can show the depedencies of the opportuniy costs on parameter changes. This is of special importance if one should try to apply the model in a real situation.

---

14) Maier and Vander Weide (1976).
15) Thanks are due to G. Dählmann for programming.
16) Maier and Vander Weide (1976).
17) See ibid.

2.4. Organization of the Planning Process

Concerning the organization of the planning process, two problems arise. A first question touches the role of the branches within the decision processes, a second problem is the forming of the multiperiod planning process under uncertainty.

Though the branches do not report their detailed programs to the central office, their autonomy concerning decisions is limited. They should realize their proposals according to the optimal fractions, computed by the central office. In practice, some more autonomy can be attained by the fact that the decisions are made during the whole period, not only at one point of the time. Because it is not useful or generally impossible to run a decomposition algorithm every day, the solutions of a certain coordination run must be valid through the first period. In this case the "budgets" and opportunity costs are the guidelines for the daily decisions of the branches.[18] Thus, in reality the autonomy of the branches is greater than the model implies.

Taking into account the uncertainty by the two-stage programming approach seems to be adequate if the violation of constraints must be considered explicitly.[19] This argument holds for banks, especially. But it is another question whether the conditional plans - resulting from the optimal solution - will be realized. In reality, only the decisions for point t=0 will be executed. At the end of the first period a new multiperiod problem under uncertainty will be solved, thus leading to possibly new decisions for t=1. Though it seems that one could forgo the uncertainty approach, the proposed method has the advantage that decisions of today are based upon the different scarcities in different possible states of the nature: The opportunity costs of a constraint may be unequal for the states of the same period.

---

18) See the opportunity costs approach by Slevogt (1972).
19) See the discussion by Hogan, Morris, and Thompson (1981).

2.5. Variations and Extensions of the Model

A simplified version of the model is reached if the assumption of uncertainty is dropped. Such a model under certainty drasticly reduces the sizes of the optimization problems for the central office and for the branches as well. This means that one can have more branches or periods.

Furthermore the model does not consider loss situations of the whole bank - while inequalities between the branches[20] may exist. It has been handled elsewhere how loss situations can be portrayed.[21]

Extensions of the model may be necessary with respect to large-scale credits. Such decision alternatives may cause decisions by the central office, especially if there exist special constraints for such loans. In this case loans can be decision alternatives of the master program or of a fictitious division as well.

Finally it sould be pointed out that the model is able to assist the planning of branches, their locations and their putting together.

3. Conclusion

Most of the bank planning models assume centralized decisions. This assumption ignores the costs of communication and the importance of motivation. Therefore a model was developed which incorporates some autonomy of bank branches. It has been demonstrated that such a model can consider necessary institutional conditions of banking and that the used algorithm can be implemented successfully. The results of such a model give hints for the branches how they should act in order to achieve the overall objectives of the bank.

---

20) See Merl (1973) for different possibilities.
21) See Schmidt (1976).

References

Booth, G.G. and G.H. Dash, Jr., 1979, Alternate Programming Structures for Bank Portfolios, Journal of Banking and Finance, 67-82.

Bradley, S.P. and D.B. Crane, 1975, Management of Bank Portfolios (Wiley, New York).

Carleton, W.T., G. Kendall and S. Tandon, 1974, Application of the Decomposition Principle to the Capital Budgeting Problem in a decentralized Firm, Journal of Finance, 815-827.

Charnes, A. and S. Thore, 1966, Planning for Liquidity in Financial Institutions: The Chance-Constrained Method, Journal of Finance, 649-674.

Cohen, K.J. and C.H. Lam, 1979, A Linear Programming Model for Bank Holding Companies, Journal of Bank Research, 152-164.

Hax, H., 1964, Investitions- und Finanzplanung mit Hilfe der linearen Programmierung, Zeitschrift für betriebswirtschaftliche Forschung, 430-446.

Hogan, A.J., J.G. Morris and H.E. Thompson, 1981, Decision Problems under Risk and Chance Constrained Programming: Dilemmas in the Transition, Management Science, 698-716.

Laux, H., 1971, Flexible Investitionsplanung (Westdeutscher Verlag, Opladen).

Maier, S.F. and J.H. Vander Weide, 1976, Capital Budgeting in the Decentralized Firm, Management Science, 433-443.

Merl, G., 1973, Zweigstellenplanung: Die Möglichkeiten eines internen Zinsausgleichs im Geschäftsstellensystem, Österreichisches Bank-Archiv, 249-263.

Meyer zu Selhausen, H., 1977, Commercial Bank Balance Sheet Optimization - A Decision Model, Journal of Banking and Finance, 119-142.

Morris, J.R., 1975, Application of the Decomposition Model to Financial Decision Models, Journal of Financial and Quantitative Analysis, 37-65.

Obel, B. and J. Vander Weide, 1979, On the Decentralized Capital Budgeting Problem under Uncertainty, Management Science, 873-883.

Rosenberg, O., 1979, Koordination von Investition und Finanzierung bei dezentraler Planung, Proceedings in Operations Research 8 (Physica, Würzburg and Wien), 478-486.

Schmidt, R., 1976, Zur Planungsflexibilität bei der Planung von Bankbilanzen, Proceedings in Operations Research 6 (Physica, Würzburg and Wien), 484-495.

Slevogt, H., 1972, Lenkpreisrechnung als Bankkalkulation für Planung und Marketing, Österreichisches Bank-Archiv, 84-106.

Sunderland, N.V., 1974, Bank Planning Models (Haupt, Bern).

Thore, S., 1968, Programming Bank Reserves under Uncertainty, Swedish Journal of Economics, 123-137.

Weingartner, M.H., 1963, Mathematical Programming and Analysis of Capital Budgeting Problems (Prentice Hall, Englewood Cliffs).

APPENDIX 1: List of Symbols

BONDS	bond issue by the central office
CASH	cash investments by the central office
$\overline{\text{CON}}$	exogenous contributions to profit
DCF	present value - discounted to point T - of all decision alternatives transmitted by a branch, the present value containing only payments after T
DIV	dividends
$\overline{\text{DIV}}$	exogenous dividends
E	expected value operator
EAT	earnings after taxes from the decision variables
EBT	earnings before taxes from the decision variables
EQUI	use of the equity constraint by a branch
$\overline{\text{EQUIEX}}$	exogenous use of the equity constraint (neg. value)
EQUILIM	upper limit for the use of the equity constraint by a branch
EQUITY	book value of equity
$\overline{\text{EQUITY}}$	equity at the beginning
H	planning horizon
K	number of branches
$\overline{\text{NEWEQ}}$	exogenous equity changes
PAY	net payments which are caused by a proposal of a branch
$\overline{\text{PAYEX}}$	exogenous liquidity sources
PAYLIM	upper limit for the use of the payment constraint by a branch
PROF	net profit contribution of a branch, containing only profits which are dependent on the decisions of the branch
$\overline{\text{PROFEX}}$	negative value of exogenous profit sources
RES	reserve requirements with respect to the transmitted proposal of a branch
$\overline{\text{RESEX}}$	negative value of exogeous reserve requirements
RESLIM	upper limit for the use of the reserve constraint by a branch
S	number of states of the nature
SEC	investment in securities by the central office
T	number of planning periods
TAX	taxes
Z	set of alternatives or proposals

a	outlay of a decision alternative of a branch (receipts are taken negative)
b	interest to be paid on bonds
c	profit contribution of a decision alternative of a branch
d	negative present value of a decision alternative of a branch, after the planning period T and discounted to point T
e	use of the equity constraint by a decision alternative of a branch
i	index for decision alternatives of the branches
k	index for the branches
l	interest earned on securities
m	maximum value for the required relationship between loans and equity
p	unconditional probability that a state of the nature will occur
q	index for iterations of the decomposition algorithm
r	use of the reserve requirement constraint by a decision alternative of a branch
$\tilde{r}$	retained earnings as a part of earnings after taxes
s	index for the states of the nature
s^-	the state of the nature just before a certain state of the nature
t	index for the time periods
z	strategic coefficient for liquidity
α	shadow price concerning the payment constraint
β	shadow price concerning the reserve constraint
γ	shadow price concerning the equity constraint
δ	value of the dual variable for the profit restriction
λ	decision variable for the fraction of acceptance which is assigned to a proposal by the central office
σ	value of the best proposal transmitted so far to the central office
τ^*	taxes as a part of earnings after taxes
τ^{**}	earnings before taxes divided by earnings after taxes

APPENDIX II: Relationships between Taxes, Dividends, and Earnings

$$(A1) \quad EBT + \overline{CON} = EAT + TAX$$

$$(A2) \quad DIV = (1 - \tilde{\tau}) \cdot EAT$$

$$(A3) \quad TAX = \tau_1 \cdot (EAT - DIV) + \tau_2 \cdot DIV$$

$$(A4) \quad TAX = \left[\tau_1 \cdot \tilde{\tau} + \tau_2 (1 - \tilde{\tau})\right] \cdot EAT = \tau^* \cdot EAT$$

$$(A5) \quad EBT = \left[1 + \tau_1 \cdot \tilde{\tau} + \tau_2 (1 - \tilde{\tau})\right] \cdot EAT - \overline{CON}$$

$$= \tau^{**} \cdot EAT - \overline{CON}$$

APPENDIX III: Numerical Example

This appendix will be presented at the meeting separately.