Reserve Requirements and Economic Stabilization

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Reserve Requirements and Economic Stabilization[1]

I. Introduction

In numerous journal articles[2] and official statements by central banks[3], the allocative advantages of minimum reserve requirements have been analyzed. A classification into the following four functions of minimum reserves has emerged in this literature as a rough consensus:

1. Reserve requirements can ensure that there is a certain structural demand for central bank reserves. In the case of an unstable or even vanishing demand for central bank money, the central bank can thus guarantee the existence and rough stability of this demand.

2. Unremunerated reserve requirements are also a sort of tax on the creation of deposit money by commercial banks. This tax may be efficient from the point of view of the theory of optimal taxation or it may be perceived as a 'fair' price for some central bank services for the private banking sector.

3. By raising the banks' costs of creating deposit money, unremunerated reserve requirements may stabilize the monetary sector of the economy and thereby reduce the impact of monetary shocks on real economic activity. The increase of the interest rate elasticity of the demand for money is often cited as the most important element of this stabilization effect.

4. A reserve requirement that has to be fulfilled only as an average within a certain reserve maintenance period enhances the flexibility of banks in their money management and contributes to the smoothing of short-term interest rates, as transitory liquidity shocks are mapped into interest rate variations in a cushioned way.

As often as these functions have been affirmed, they have also been questioned many times.[4] Especially private banks who are subject to reserve requirements and who have

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[2]For example Goodfriend and Hagraves [1983], Friedmann [1988], Repullo [1990], Stevens [1991], Weiner [1992], Feinman [1993], Bank of Japan [1995], Hardy [1996a].

[3]For example Deutsche Bundesbank [1995, 128].

[4]See for example Carstensen [1988], Stevens [1991], King [1994], Bundesverband Deutscher Banken [1996].

to compete with foreign banks that are not have criticized reserve requirements for a long time. For example, the *Bundesverband deutscher Banken* [1996, 20] concludes in a study on the desirable instruments of the European Central Bank that minimum reserve requirements are neither necessary for an efficient monetary policy nor for money market management and thus should not be used in stage three of the European Monetary Union.

The crucial question in the current debate on minimum reserve requirements is probably whether the functions 3 and 4 mentioned above are really relevant or not. Both pretend that (constant) minimum reserve requirements can contribute to economic stabilization. They can be analyzed to a large extent separately: function 3 is tied to the incompleteness of remuneration and the size of the reserve requirement. It is independent of any averaging provision. Function 4 is dependent on averaging yet independent of the remuneration of required reserves, and it is even independent of the size of the reserve requirement as the banks' capacity to build up temporary balances at their central bank accounts can be chosen regardless of the size of the reserve requirement.

In this paper, I have attempted to base my analysis as much as possible on an 'incomplete information' approach. Economic reality differs from textbook neoclassical models in so far as in the real world coordination problems resulting from incomplete information have far-reaching economic consequences. Money itself is an institution which would have no relevance in the neoclassical world of perfect information and zero transaction costs. It is added to the real economy as a veil, or in other words, there is a perfect dichotomy between the real and the monetary 'sector'. This implies that any true microfoundation of the theory of money (which may be classified into the theory of monetary order and the theory of monetary policy) must be founded on the economics of incomplete information (or on the economics of 'transaction costs').

Hayek [1945, 519] was the first author to stress the fundamental role played by incomplete information in the analysis of economic order:

> "What is the problem we try to solve when we try to construct a rational economic order?... The peculiar character of the problem of a rational economic order is determined precisely by the fact that knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess."

The monetary order of an economy is one aspect of its general organization. Thus, according to Hayek, a genuine analysis of the problem of designing a monetary order must, as already remarked, be founded on the analytics of incomplete information. This naturally includes the question of whether or not minimum reserve requirements are beneficial and whether or not an averaging option should be granted to banks concerning their reserve fulfillment.[5]

The objective of a central bank should be to provide a monetary system minimizing transaction costs in the real economy (by providing a medium of exchange, a store of value, and a unit of account) and which, at the same time, is not itself a source of destabilization and macroeconomic coordination failure. The central bank's instruments for achieving this purpose can be grouped into two categories, namely: (1) the design of the *monetary order* and (2) the design of a *reaction function* (a function which maps any observation by the central bank of the state of the economy into a monetary policy). There should exist one simultaneous specification of both groups of instruments which minimizes the macroeconomic coordination failure generated by instabilities of the monetary sector and which thereby maximizes economic welfare.

But why should it not suffice to choose an adequate reaction function in order to achieve optimum stability? Why should the monetary order as well be relevant for stabilization? It is again Hayek [1945, 524] (a committed opponent of the idea of a centrally planned economy) who gives the general answer to this question by stressing the fundamental relationship between the *dispersion of information* and the necessity of a *decentralization of economic decision taking*:

> "If we agree that the economic problem of society is mainly one of rapid adaptation to changes in the particular circumstances of time and place, it would seem to follow that the ultimate decisions must be left to the people who are familiar with these circumstances, who know directly of the relevant changes and of the resources immediately available to meet them... We must solve it by some form of decentralization."

The claim of the idiosyncratic relevancy of the monetary order for macroeconomic stability is related to this insight. If all information on the (monetary) state of the economy were concentrated at the central bank, stabilization policy could probably be reduced to the choice of an optimal reaction function. But if information about monetary conditions is dispersed among many agents, one should expect that the stability behavior of the

[5]The critique of any microfoundation of the theory of monetary policy and of monetary order that is not based on some incomplete and asymmetric information setting is in a sense similar to that of Coase [1960] concerning welfare economics. Coase showed that traditional welfare economics is built on shaky ground as it analyzes phenomena such as externalities and monopolistic price setting in a zero-transaction-cost (or complete information) framework, despite the fact that those types of coordination failure can be explained only *with* transaction costs (or incomplete information).

economy cannot be analyzed without looking at the monetary order and the way in which it shapes the disclosure of private information and its aggregation and transmission into financial prices and quantities.

The discussion of both stabilization aspects of reserve requirements will in this sense illustrate that (1) the stabilization of the real sector of the economy by shaping the monetary order has to be analyzed in the framework of an incomplete information approach and that (2) a dispersion of information is a necessary condition for the idiosyncratic influence of the monetary order (beyond the central bank's reaction function) for economic stabilization.

In the rest of the paper we proceed as follows: In section II, two aspects of minimum reserve requirements that are not of an informational economic nature in the narrow sense will be briefly reviewed. First, the question of whether or not minimum reserve requirements are needed in order to create a structural demand for central bank money is analyzed; secondly, it is examined what can be said about the efficiency of minimum reserve requirements from the point of view of the theory of optimal taxation (function 2). In sections III and IV, both stabilizing functions of (constant) minimum reserve requirements are discussed using approaches founded as far as possible on an incomplete information setting. Section III primarily reviews and classifies the literature about the stabilizing impact of the non-remuneration of minimum reserve requirements (regardless of averaging provisions). Section IV analyzes in the framework of a signal extraction model the implications of the granting of an averaging provision, regardless of the size and remuneration of the required reserves. In both sections III and IV, the crucial question is whether the reviewed institutional arrangements can enhance the information flows between the central bank, private banks and the general public and if they can thus contribute to a reduction of macroeconomic coordination failure in the form of fluctuations of economic activity originating in shocks in the monetary sector. In Section V, a summary of the results is given and some conclusions are drawn.

II. Short review of two functions of reserve requirements which are not related directly to a problem of incomplete information

In this section, we briefly review two aspects of minimum reserve requirements which cannot be interpreted directly as being related to some 'built-in stabilizing' effect due to the dispersion of information between the central bank and the private banking sector.

II.1 Creating an artificial structural demand for central bank money

In the older literature justifying reserve requirements, it was sometimes claimed that only such requirements would ensure that the creation of deposit money by private banks did not lead to an infinite monetary expansion and thus an undetermined price level.[6] The critical assumption for deriving this result is that currency and deposit money are perfect substitutes. This can be easily illustrated in the framework of the theory of the money multiplier (between the monetary base and, for example, M1): if the ratio of currency to transaction deposits is not well-defined and thus possibly zero (because of the perfect substitutability of both categories of M1), then the money multiplier will be undefined or even infinite (if the voluntary reserve holdings of the banking sector are zero). Then, a positive minimum reserve requirement limits the expansion of M1 and thus is a necessary condition for the existence of a finite price level.

In the present real world, deposits and currency are *not* perfect substitutes. If money holders have well defined preferences for different components of M1, banks will not be able to create an arbitrary quantity of deposit money, as their customers will transform a part of the bank money into currency. Even if banks hold no reserves at all, M1 will be well-defined and finite for any quantity of central bank money.

But this present stability is no guarantee that innovations in the private money supply will not introduce in the near future a greater instability of the money multiplier and, in the medium term, a far-reaching decline in the demand for central bank money.[7] These

[6]See for example Richter [1990, 327-331] for an overview of the older literature. The question of whether minimum reserve requirements are necessary is already discussed extensively for example by Keynes [1930] and Lutz [1936/1962]. Keynes [1930, I, 23-33] does not agree that banks could create any quantity of deposit money, but he nevertheless advocates the introduction of a minimum reserve requirement in Great Britain: "These regulations would greatly strengthen the power of control in the hands of the Bank of England - placing, indeed, in its hands an almost complete control over the volume of bank-money without in any way hampering the legitimate operations of the joint stock banks." (Keynes [1930, II, 77]). He also suggests that the reserve ratio should be variable and adjusted as a function of monetary conditions (Keynes [1930, II, 261]).

[7]Fama [1980] analyzes the relevance of minimum reserve requirements in a futuristic, currency-free

prospects are a strong argument in favor of generally keeping the minimum reserve instrument, even if, for other reasons, the reserve ratios would be reduced to zero for the time being. A raising of the reserve ratio in response to a substantial shrinking of the demand for central bank money would guarantee at least the rough stability of the monetary system. The private economic agents' knowledge of the fact that the central bank has a powerful instrument in its hand to guarantee a chosen scarcity of central bank money stabilizes expectations and secures the confidence of the markets in the monetary order, which is a crucial condition for the efficient work of any modern exchange economy.

How can the function of minimum reserves reviewed in this section be exactly separated from the one reviewed in section III? The potential shock assumed here (the shrinking of the natural demand for central bank money) is permanent and not transitory as the shocks in section III, where a constant reserve requirement is seen as a so-called built-in stabilizer. Another difference is that here it is ultimatively irrelevant what kind of good is subject to reserve requirements. In section III, it is decisive that certain kinds of bank deposits are subject to the reserve requirement. A third difference is that the function of reserve requirements discussed in this section can become a *necessary* condition for maintaining central bank money as the *numéraire* of the economy, whereby the function discussed in section III never becomes really fundamental for the preservation of the monetary order.

II.2. Allocative implications of the taxation effect of reserve requirements

Unremunerated or only partially remunerated reserve requirements are also a kind of tax on the bank deposits that are subject to the reserve requirement and are a source of income to the central bank. In general, taxes are related to some form of allocative distortions and related welfare losses.

A number of papers analyze in a rather abstract form the allocative effects of the taxation component of reserve requirements in the context of models of overlapping generations (Romer [1985], Sargent and Wallace [1985], Freeman [1987], Mourmouras und Russel [1992], Freeman und Haslag [1995]; Davis und Thoma [1995][8]). A related aspect is re-

economy. If in such a context, the central bank defines some good as the *numéraire* for which no natural demand exists, then a reserve requirement would be a necessary condition for having well defined prices expresssed in this *numéraire*. However, the best long-term solution in such a case would be to choose any real good as the *numéraire* for which scarcity is well defined without the creation of an artificial demand. For example, Browne [1996] analyzes concretely the current and expected innovations in the demand for currency and in payment systems and their implications for monetary stability.

[8]All these models are deterministic, such that potential benefits from reserve requirements related to their impact on information flows are not analyzed in their framework. Romer [1985] points out that

viewed by Baltensperger [1982b]: he thinks that the taxation effect of reserve requirements *compensates* for another distortion, namely the one implied by the non-remuneration of currency which is a substitute for deposit money. The non-remuneration of compulsory reserves would then neutralize the distortion by rendering currency *relatively* more attractive compared to deposit money.

Ultimately, one has to ask whether the tax effect of a non-remunerated reserve represents an optimal tax according to the theory of optimal taxation, which postulates the optimality condition that the marginal welfare cost of all kinds of tax income should be equal. Thus, the relevant question in the case of the central bank's (or the state's) income from reserve requirements is whether the marginal welfare cost (considering all benefits and distortions) equals the marginal welfare costs of other forms of taxes. Let us assume that the relevance of function 3 of minimum reserve requirements (discussed in the next section) can be neglected. Then the justification for the non-remuneration of reserves rests exclusively on taxation aspects, as function 1 and 4 are independent of remuneration.

In the case of open capital markets (and stable exchange rates), the international mobility of at least a part of deposits is relatively high, such that small differences in the tax on deposits (implicit in the reserve requirement) imply large outflows of certain types of deposits. The sensitivity of the tax basis regarding the size of the tax is thus rather high. In such a context, it is not efficient to tax the concerned deposits and it should be expected that the (national) marginal welfare cost of income generated by those unremunerated reserves is higher than the one of other forms of public income. To avoid the related inefficiencies, required reserves on the sensitive types of bank liabilities could be remunerated or the concerned reserve ratios could be reduced.[9]

reserve requirements are not exactly equivalent to a tax on deposits. He derives an optimal combination of public income from monetary expansion, minimum reserve requirements and debt expansion. Sargent and Wallace [1985] analyze the implications of paying interest on required reserves and reach the conclusion that such an arrangement would imply a continuum of equilibria. This result seems to be related to the assumption that all forms of money are perfect substitutes. Mourmouras and Russel [1992] analyze under which conditions an unremunerated minimum reserve and a deposit taxation are 'broadly equivalent'. Freeman and Haslag [1995] claim that the distortionary effects of reserve requirements are always larger than those of normal taxes.

[9]Remsperger and Angenendt [1995, 401-403] consider three kinds of distortions implied by minimum reserves: international distortions between different financial centers; distortions between financial intermediaries that are subject to reserve requirements and those which are not (or between deposits which are subject to reserve requirements and deposits which are not); distortions between different kinds of banks which differ for example in the amount of free reserves they would hold without any reserve requirement. The second type of distortions implies that there should be a permanent observation of whether substitutes for deposits subject to reserve requirements are created by banks to circumvent reserve regulations.

An alternative to the adjustment of a countries tax implicit in reserve requirements for the reasons mentioned naturally consists in an adequate adaptation of the reserve requirements in the other countries of the region of high mobility of deposits. The crucial point is that the implicit taxes on the more mobile types of deposits should be *harmonized.* In the case of such a harmonization, the sensitivity of the tax base (the volume of deposits) regarding the reserve ratio would be much lower and it would be difficult to prove that the marginal welfare cost of public income induced by a low reserve requirement on deposits is higher than the welfare costs of other types of tax income.

The emergence of such substitutes raises the marginal welfare costs of the reserve requirement tax and should eventually be prevented by some regulatory or legal action.

III. Unremunerated constant reserve requirements as a tool of macroeconomic stabilization (regardless of averaging provisions)

In this section, we review the problem of minimizing the impact of stochastic exogenous shocks on endogenous goal variables in the framework of Poole's [1970] method. In the basic specification, it is assumed that the reduced form of the macroeconomy can be represented by the following system:[10]

$$x_t = x_0 + A\epsilon_t, \tag{1}$$

where $x_t \in R^n$ is a vector of stationary economic variables (i.e. GDP growth, inflation, money supply growth, interest rates, etc), $x_0 \in R^n$ is the vector of natural or goal values, $\epsilon_t \in R^m$ is a vector of exogenous shocks which do not affect the natural (or goal) values of the endogenous variables and which are not anticipated by the central bank. The expected values of the elements of ϵ_t are zero and the variance-covariance matrix of ϵ_t is known. The matrix $A \in R^{n*m}$ describes the relationship between exogenous shocks and the endogenous variables. The central bank can influence the matrix A with its parameters $\phi = (\phi_1, \phi_2, ..., \phi_k)$. Those parameters can be divided into the two subcategories of instruments: (1) monetary order parameters (as the size and remuneration of minimum reserves), (2) parameters of the reaction function of the central bank (as the interest rate elasticity of money supply). Let the central bank have a quadratic utility function:

$$W_t = -\sum_{i=1}^{n} \delta_i (x_{ti} - x_{0i})^2 \tag{2}$$

The δ_i represent the weights of the endogenous variables in the central bank's utility function. The central bank determines the values of the parameters ϕ to maximize the expected value of this function (corresponding to a minimization of a weighted sum of the variances of the endogenous variables).

Only one part of the literature presented in this section explicitly analyzes the stabilization effect of reserve requirements. The other part looks at the choice of the reaction function and the central bank's instrument. But in both cases, the ultimate question is the one of shaping the matrix A in the reduced form (1). In fact, it does not make sense to have two parallel stabilization theories (one for the monetary order parameters and one for the reaction function) as both are closely interrelated.

[10] A variant of this model where the coefficients themselves are stochastic has also been discussed in the literature (Brainard [1967], Turnovsky [1975], Turnovsky [1977], Canzoneri [1979]). We will not consider this slightly more complex variant here. Another interesting extension of the model is the one by Kareken, Muench and Wallace [1973] and LeRoy and Waud [1977]. In these papers, the problem of signal extraction is introduced in a multiperiod specification of the stabilization model.

In the following, we give a short survey of parts of the related stabilization literature. The contributions are grouped into four categories. In a fifth section, we contribute another variant of the stabilization model illustrating the relevance of the dispersion of information for the significance of employing minimum reserves as an instrument of stabilization.

1. Kaminow [1977], Laufenberg [1979], Froyen and Kopecky [1983], Van Hoose [1986], Weiner [1992] and Brunner and Lown [1993a], [1993b] analyze the **stabilization impact of minimum reserves on intermediate targets as monetary aggregates or interest rates.**[11] The general conclusion of those papers is that the size and remuneration of reserve requirements is relevant for monetary stabilization which implies that reserve requirements are in principle useful to stabilize the monetary sector. However, none of the papers really shows that the destabilization induced by a lowering of reserve requirements from a low level (as for example the one prevailing in the US or Germany for the present) to zero would be substantial. On the contrary, Brunner and Lown [1993a, 204], who estimate their model, come to the following conclusion: "[O]ur work... suggests that lower reserve requirements are unlikely to have much impact on volatility in the reserve market. Although there may be other reasons for maintaining a certain level of reserve requirements, a significant increase in volatility of reserves and the funds rate does not appear to be one of them."

A general problem of this approach is that it is not well-motivated to focus on the stabilization of intermediate targets and not of final ones. It is assumed implicitly that both are equivalent, which is not necessarily true.[12] To criticize this assumption does not imply a critique of looking at intermediate targets as monetary aggregates at all. This may still be the best way to assure credibility and the ultimate goal of a low inflation rate. The point is that the stabilization of monetary aggregates by reserve requirements may theoretically end up raising the volatility of the real sector.

The rest of the literature reviewed here analyzes the stabilization impact of policy parameters **on the final goal variables of price level and GDP**.

[11]In the framework of models which are more differentiated in the time dimension, Kopecky [1988] and Lasser [1992] analyze the relative impacts on the stability of monetary aggregates of a lagged reserve accounting, a contemporaneous reserve accounting and an 'almost contemporaneous' reserve accounting. Polleit [1996] analyzes the relevance of a differentiation of reserve ratios with regard to different kinds of bank deposits on the stabilization of different monetary aggregates with reserve requirements.

[12]Canzoneri [1977] stresses this point. Siegel [1981, 1073], Baltensperger [1982a, 206] and the Bundesverband deutscher Banken [1996, 19] criticize the stabilization of intermediate targets in the case of minimum reserves.

2. Richter [1968] was the first author to analyze the role of minimum reserves as a macroeconomic built-in stabilizer in a comparative-static setting.[13] He concludes that the stabilization effect of reserve requirements ultimately depends on the coefficients of the model, but that the case in which minimum reserve requirements act as a "built-in destabilizer" is "by far the more plausible" (Richter [1968, 288]).

Siegel [1981] and Baltensperger [1982a] show in their models that the variability of the monetary aggregate is minimized by a 100% - reserve ratio. But the reserve ratio minimizing the variability of the *price level* depends on the coefficients of the model and the correlation structure of the shocks. It can take any value between zero and one. Baltensperger [1982a, 214] remains agnostic in his conclusions: "The fractional reserve system has a flexibility and elasticity that may be a disadvantage in some situations, but that may equally be an advantage in other situations. I conclude that it is difficult and probably not advisable to choose between a low and a high reserve requirement on the basis of this kind of stability considerations."

Siegel [1981] is more courageous and estimates his model for the US with quarterly data from between 1952 and 1973. He concludes that the optimal average reserve requirement would have been 7% instead of the actual 11.5%. On the other side, the difference in the standard deviation of the quarterly price level would only have been minor. For reserve ratios of 7%, 11.5% and 0%, the standard deviation would have been 0.452%, 0.485% and about 0.5% respectively. Thus, the consequence of a reduction of the reserve ratio from a high level (compared to the present one in Germany) to zero would have been rather minor.

3. The well known model of **Poole [1970]** focuses on the question of the optimal monetary instrument (a monetary aggregate, an interest rate or an intermediate solution) in a stochastic IS-LM model, without explicitly considering minimum reserves. He is one of the first authors to stress the relevance of the incompleteness of information for such problems: "The choice of instruments problem is clearly a consequence of uncertainty, and analysis of the problem requires a stochastic model" (Poole [1970, 214]). The stochastic IS-LM model contains the following two equations:

$$Y = a_0 + a_1 r + \mu \tag{3}$$

$$M = b_0 + b_1 Y + b_2 r + \nu \tag{4}$$

where Y is the GDP, M is a monetary aggregate, r is the interest rate, a_0, a_1, b_0, b_1, b_2

[13] Reserve requirements influence the multipliers of Richter's model, which is not explicitly stochastic, but which can be easily interpreted as such if the exogeneous variables are seen as random variables.

are coefficients with $a_1 < 0, b_1 > 0, b_2 > 0$. The random variables μ, ν both have an expected value of zero, variances σ_μ^2, σ_ν^2, and a covariance $\sigma_{\nu\mu}$. The realizations of these random variables take place such that the central bank is not able to react by adjusting its instruments.The model has two equations and three variables (Y, M, r). The central bank chooses between fixing M, r or the parameters M_0, h in the linear money supply function

$$M = M_0 + hr \tag{5}$$

In a deterministic framework (a framework of complete information) where $\sigma_\mu^2 = \sigma_\nu^2 = 0$, it is irrelevant which instrument the central bank chooses. Any intended (natural) value of Y can be realized with any instrument.

This is no longer true in the case of uncertainty. With a combined policy (5) (which includes the cases of a pure monetary and pure interest rate instrument as special cases), we obtain the following reduced form for Y:

$$Y = \frac{a_0(b_2 - h) + a_1 M_0}{b_2 + a_1 b_1 - h} - \frac{b_2 - h}{b_2 + a_1 b_1 - h}\mu + \frac{a_1}{b_2 + a_1 b_1 - h}\nu \tag{6}$$

The policy parameters h and M_0 are now relevant for the level and the variance of Y and thus for the expected value of the central bank's utility function. The central bank should set h at a level where it minimizes the destabilizing influence of the exogenous shocks, and in a second step it should choose M_0 such that it obtains the preferred expected value of Y.

How is Poole's observation related to the stabilization effect of minimum reserve requirements? In the papers by Richter [1968], Siegel [1981], and Baltensperger [1982a], the central bank uses the minimum reserve ratio instead of Poole's interest elasticity of money supply (h) to stabilize the economy. Both approaches can and indeed must be unified in one model. A separate analysis of the stabilization impact of the centrals bank's money supply function on the one hand and built-in stabilizers as minimum reserves on the other is not useful as the impacts of both types of policy parameters are interdependent. In addition, we are interested in the question of whether there are 'redundancies' in the sense that the central bank does not need as many policy parameters as available to achieve the highest possible stability. If some stabilization policies imply certain welfare losses (independently of the stabilization problem), a redundancy should be noted as it implies that the best stabilization result can be obtained without using the instrument(s) with bad properties. This is the insight of Horrigan [1988].

4. Horrigan [1988] shows in the framework of a macroeconomic model with rational expectations that the size and remuneration of required reserves are irrelevant from the point of view of stabilization of the price level and economic activity, as the impact of reserve requirements can also be obtained by an adequate adjustment of the interest rate elasticity of the money supply. He is the first author to explicitly merge the minimum reserve literature à la Baltensperger [1982a] with the general stabilization literature à la Poole [1970].

The redundancy hypothesis can be easily illustrated in the framework of an augmented model of Poole [1970] (Horrigan's model is slightly more complicated in its representation). A fixed money multiplier is introduced into the model and the supply of central bank money is modelled similarly to the money supply in the original model. Suppose that the relevant monetary aggregate M is related to the quanitiy of central bank money $Z = Z_0^s + gr$ by:

$$M = k(Z_0^s + gr), \tag{7}$$

where k is the money multiplier which can be determined by the central bank via the minimum reserve ratio. The central bank now has three policy parameters, but the redundancy of one of them is obvious. Any money supply function $M^s = M_0 + hr$ can be implemented for any value of k by choosing adequately the values of Z_0^s, g. Minimum reserve requirements are thus not necessary in this framework and should not be used for reasons of simplicity (even if minimum reserves do not imply any special welfare losses). The redundancy result of Horrigan [1988] thus includes this simple fixed money multiplier variant of the Poole model.

But how robust is this result? Are minimum reserves redundant in any reasonable model of the economy? It is easy to show that this is not the case. By small modifications of the model of Horrigan (including the introduction of additional noise terms), the redundancy result breaks down. Again, this can be easily illustrated in Poole's [1970] elementary setting by augmenting equations (3) and (4) by the following one:

$$M = k(Z_0^s + gr + \zeta), \tag{8}$$

where ζ is an additional random variable with $E(\zeta) = 0$, a variance σ_ζ^2, and covariances $\sigma_{\zeta\mu}^2$, $\sigma_{\zeta\nu}^2$. The reduced form for Y now becomes

$$Y = \frac{a_0(b_2 - kg) + a_1(b_0 - kZ_0^s)}{b_2 + a_1 b_1 - kg} + \frac{b_2 - kg}{b_2 + a_1 b_1 - kg}\mu - \frac{a_1}{b_2 + a_1 b_1 - kg}\nu + \frac{ka_1}{b_2 + a_1 b_1 - kg}\zeta \tag{9}$$

Again, the central bank minimizes the variance of Y by choosing k and g and then sets Z_0^s such that $E(Y) = Y^*$. The coefficient of ζ in (9) reveals that there is no longer any redundancy in the parameters of the central bank. All three are needed to obtain the optimal stabilization around a prefered expected value of Y.

In general one should expect that if the modelling of the economy is sufficiently complex and if sufficiently many exogenous shocks are included, then it becomes very unlikely that minimum reserves and the interest rate elasticity of the central bank's money supply are completely redundant. This is especially plausible if one considers that different subjects in the economy should have different information about the state of the economy (which is relevant for their optimization behavior). If, for example, the banks have private information about the monetary state of the economy, this should be a sufficient reason to make reserve requirements non-redundant as they shape incentives of a category of economic agents which have relevant information the central bank does not have.

Horrigan's [1988] contribution consists more in having demonstrated that the impact of minimum reserves on macroeconomic stability cannot be seen independently of other policy parameters of the central bank and that the question of the necessity of minimum reserve requirement has to be analyzed in conjunction with all other available monetary policy instruments. The redundancy result itself is probably not correct in a complex world. But that does not prove the necessity of minimum reserves as the insight on the theoretical relevance of reserve requirements for stability is only a first and relatively minor step towards the claim that a certain minimum reserve requirement is optimal for a certain concrete economy.

5. Now an additional version of Poole's [1970] model is presented illustrating how the dispersion of information between the central bank and the private banking sector can be seen as the crucial dimension of the redundancy question. This time equations (3) and (4) are completed by:

$$Z^s = Z_0^s + gr + c_1\tilde{\nu}_N \tag{10}$$

$$M = k(Z^s + c_2\tilde{\nu}_G) \tag{11}$$

The terms $\tilde{\nu}_N$ and $\tilde{\nu}_G$ represent the *ex ante expectations* of the realization of the monetary shock ν by the central bank and the private banking sector, respectively. It is assumed for both that the money market shock is relevant for their optimizing behavior. This implies that the degree of anticipation of shocks must play a role for the stability of the macroeconomic system. Equation (10) represents the supply of central bank money by the central bank. It is assumed that the central bank observes ex ante

$$\tilde{\nu}_N = \nu + \zeta_N \tag{12}$$

where ζ_N is a noise variable with an expected value of zero and a variance $\sigma^2_{\zeta,N}$. The parameter c_1 is another policy parameter of the central bank. By choosing c_1, the central bank decides on the relevance of prior information about the shock for its monetary policy. Equation (11) represents the creation of money by the private banking sector. It is assumed that the private banks observe a variable

$$\tilde{\nu}_G = \nu + \zeta_G \tag{13}$$

where ζ_G is another noise term with an expected value of zero and a variance $\sigma^2_{\zeta,G}$. The random variables ζ_G and ζ_N are assumed to be uncorrelated. If we assume that $c_2 \neq 0$, then the money market shock is indeed relevant for the private banks' money supply.

The central bank now has *four* policy parameters to achieve its goals, namely g, k, c_1 and Z^0_s. But how many parameters does the central bank really need for the stabilization of Y? The reduced form of Y now takes the following form:

$$Y = \frac{a_0(b_2 - kg) + a_1 k Z^s_0}{b_2 + b_1 a_1 - kg} + \frac{a_1(b_2 - kg)}{b_2 + b_1 a_1 - kg}\mu + \frac{kc_1 + kc_2 - 1}{b_2 + b_1 a_1 - kg}\nu$$

$$+ \frac{kc_1}{b_2 + b_1 a_1 - kg}\zeta_N + \frac{kc_2}{b_2 + b_1 a_1 - kg}\zeta_G \tag{14}$$

There are now four random variables influencing Y. In table 1, we distinguish nine combinations of ex ante knowledge of the central bank and private banks. For both, three cases can be distinguished, namely perfect anticipation of ν ($\sigma^2_{\zeta,G} = 0$; $\sigma^2_{\zeta,N} = 0$), partial anticipation of ν ($\sigma^2_{\zeta,G} > 0$ and finite; $\sigma^2_{\zeta,N} > 0$ and finite), and no prior information on ν ($\sigma^2_{\zeta,G} \to \infty$, $\sigma^2_{\zeta,N} \to \infty$). Let us assume that Z^s_0 is always used after the determination of the other parameters to implement the optimal value of $E(Y)$. Of the remaining three parameters two or three are necessary, depending on the information dispersion:

Table 1: Non-redundant policy parameters

	$\sigma^2_{\zeta,G} = 0$	$\sigma^2_{\zeta,G} > 0$, finit	$\sigma^2_{\zeta,G} \to \infty$
$\sigma^2_{\zeta,N} = 0$	2 of (c_1, k, g)	c_1 and k and g *	$c_1(= k/1)$ and (k or g)
$\sigma^2_{\zeta,N} > 0$, finit	c_1 and k and g *	c_1 and k and g *	c_1 and (k or g)
$\sigma^2_{\zeta,N} \to \infty$	$c_1 = 0$ and k and g *	$c_1 = 0$ and k and g *	$c_1 = 0$ and (k or g)

Minimum reserves are non-redundant in the combinations with a star '*'. Thus, the dispersion of information is a crucial dimension for the question of whether minimum reserves are redundant or not. Since the interactions between economic variables are very complex in the real world and knowledge about monetary conditions is widely dispersed, we should expect that minimum reserves and the interest rate elasticity of the reserve supply are ultimately *not* redundant.

Conclusion of Section III: In the real world, non-remunerated required reserves have a specific influence on macroeconomic stability and especially on the variability of real economic activity around its natural level. The redundancy result of Horrigan [1988] is a special case, which is especially unlikely in the case of differences between the knowledge of banks and the knowledge of the central bank about the monetary state of the economy.

As such differences certainly exist in reality, the minimum reserve instrument is in principle effective for stabilization purposes. The precise stabilization impact of reserve requirements depends on the size of the requirement. A wrong positive reserve ratio can lead to less stability than a reserve ratio of zero. The best reserve ratio from the point of view of stabilization depends on the economic structure, the information dispersion among the different economic agents and the variance-covariance structure of the exogenous shocks. The empirical implementation of this insight in the form of an estimation of the optimum mimimum reserve ratio has not been realized up to now in a convincing way. Moreover, according to the few empirical contributions which have been made so far, the estimated impact of low reserve requirements on economic stability is rather small.

IV. Averaging provisions and the information content of money market rates

IV.1 Some preliminary welfare economic remarks on the decentralization of monetary decision rights

The granting of averaging provisions in the fulfillment of reserve requirements to the private banks has been advocated in the literature as a means of smoothing short term interest rates (Poole [1968], Laufenberg [1979], Baltensperger [1980], Spindt and Tarhan [1984], Angeloni and Prati [1992], Feinman [1993], Vazquez [1995], Davies [1997]). The smoothing effect of reserve requirements with averaging provisions results from the fact that the banks can use the additional reserves for intertemporal arbitrage in refinancing. Finally, the intertemporal arbitrage activity of the whole banking sector implies that the interest rate effects of all anticipated temporary liquidity shocks are smoothed away.

Unfortunately, the literature does not explain the informational and real sector consequences of the smoothing of money market interest rates. This deficit has been detected by opponents of minimum reserve requirements. For example, the *Bundesverband deutscher Banken* [1996, 19] explicitly denies that more erratic money market rates in Germany (due to an abolishment of reserve requirements) would do any damage to the real economy.

Why should the smoothness of short term interest rates be an objective of the design of the monetary order? In answering this question, it is important to note that the central bank could always achieve a complete smoothing of interest rates by an infinite interest rate elasticity of money supply at a certain interest rate (which would be modified from time to time when the central bank would have received any news about the optimal interest rate for achieving its final goals). Such a supply function could be implemented by two standing facilities, a deposit facility and a lending facility offering and charging the same interest rate, respectively. The fact that central banks generally do not implement such a system shows that central banks do not really want to smooth *à tout prix.* They prefer certain market developments to be reflected in interest rate movements. What kind of developments does the central bank want to be smoothed out and what kind of developments does it want reflected in interest rates? Does an averaging provision smoothes out the 'bad' fluctuations and does it conserve the 'good' ones?

In this section the smoothing argument will be further developed to be able to answer such questions. In the framework of a simple signal extraction model, this section will illustrate that an averaging option may facilitate, for private market observers on the one hand and for the central bank on the other hand, *improved extraction of the permanent component in the money market interest rate* and thus enhance the aggregation of a certain type of dispersed information into prices according to Hayek [1945]. In this sense, an averaging provision can be seen as a decentralization of monetary decision rights reflecting the dispersion of knowledge about monetary conditions.

In traditional welfare economics, the regulation of a market (or a pigou tax or subsidy) has to be motivated by some externality. Which externality at the money market could motivate a regulation of banks' liquidity cushions (such as, for example, a minimum requirement)? Why shouldn't the cushions banks hold voluntarily be optimal from the point of view of society? In answering this question, one should be aware of the fact that money is a natural monopoly good because its consumption has positive network externality effects. The provision of natural monopoly goods is a public task or has to be at least regulated by the state. In the design of the monetary order, one therefore does not have anyway a classical market situation as the reference point of a regulatory analysis (Hayek [1976] denies this point by claiming that a private provision of money should be efficient). It thus does not make any sense to criticize minimum reserve requirements for being a regulation not in conformity with the principles of a market economy as it has sometimes been done by opponents of reserve requirements. On the other side, the lack of a pure market reference does not rule out a comparative welfare analysis. The welfare implications of two alternative regulations of the monetary order can always be compared.

This remark in mind, it is suggested here that the granting of an averaging provision can be interpreted as follows: the holding of liquidity cushions implies opportunity costs in the form of interest rates for the banks. In deciding about the size of liquidity cushions, banks compare their private marginal benefit to their private marginal costs. But beside the private returns of liquidity cushions, these have an important *positive* externality, as they enhance the information content of money market rates concerning the *longer-term* prospects of monetary and real interest rate conditions which are a basic variable for all intertemporal investment decisions of the economy.[14] Because of this positive externality, the cushions chosen by banks would be too small from the point of view of society. A subsidization of cushions or a prescription of cushions in the form of reserve requirements (with averaging) both influence the effective quantity of liquidity reserves. The additional capacity of intertemporal arbitrage in refinancing is the crucial element of averaging provisions. In general, it is not relevant whether the compulsory reserves are

[14]See Hirshleifer [1971] and Grossman and Stiglitz [1976] for a general analysis of the welfare aspects of the production and aggregation of information.

remunerated or not and whether the averaging capacities are created by a positive reserve requirement or by permitting the banks temporary overnight overdrafts as in the Bank of Canada's system of 'averaging around zero'. (Still another possibility to internalize the positive externalities of liquidity cushions would be to pay an interest rate on voluntary reserves.)

The choice of those details has some distributional implications. It can also have allocative implications if the banks can consider the costs of the regulation in some prior decision influencing the burden of the regulation, as for example in the case of an unremunerated reserve requirement when the banks can transfer deposits subject to reserve requirements abroad.

Another welfare effect of the smoothing of interest rates should be briefly mentioned: For money users, transitory scarcity shocks are relevant in so far as they imply that the marginal costs of borrowing money fluctuate. It is plausible under various settings that a constant interest rate corresponding to the average of fluctuating interest rates is better in welfare terms for money users than fluctuating rates. If banks have any information about the permanent/transitory decomposition of shocks the central bank does not have, then the banks' liquidity cushions implied by minimum reserves with averaging help to smooth the marginal costs of borrowing money and thereby raises welfare. This benefit of smoothing could be realized by standing facilities which would guarantee a fixed interest rate (which is not true for the signal extraction argument).

IV.2 The idea of a small signal extraction model

In the framework of a two period model, the 'informational efficiency of the money market' (which is defined here as the information content of the money market interest rate with respect to its permanent component) will be analyzed for the case of no averaging and the case of an averaging provision with an averaging length of two periods. Three independent shocks occur on the money market: two transitory shocks relevant only in the first and second period respectively and a permanent shock relevant in both periods and further on. None of the shocks is correlated with any other. The transitory shocks are viewed as short term liquidity shocks for which the interest rate is not relevant. Such liquidity shocks may occur at special transaction dates (as for example tax payment dates), at special currency withdrawal dates (as for example in Germany on Saturdays in December), in connection with very large single transactions, etc. The permanent shock can be interpreted as a variable reflecting the monetary policy stance of the central bank and/or as a variable reflecting structural developments on the side of money users, as changes in the domestic use of currency, changes in the currency demand of foreigners, innovations in payment systems, etc.

Different interpretations of the model can be given concerning the information flows on the money market. We distinguish three groups of agents: banks participating in the money market, market observers (all other private agents for which the interest rate is relevant) and the central bank. None of the agents has to have prior information about the permanent shock but it is assumed that the central bank and the private banking sector both have specific ex ante knowledge about the transitory shocks affecting the money market. It could be assumed, for example, that the transitory shocks are the sum of one transitory shock anticipated exclusively by the central bank and one anticipated exclusively by the private banking sector. For reasons of simplicity, we assume that the component of transitory shocks that is anticipated by the central bank is automatically neutralized by it, so that we can concentrate on the transitory shocks about which the private banks have some private advance information and the central bank does not.

Only in the case where the private banking sector had no specific advance information about transitory shocks at all would the argument of the model break down. In this unrealistic case, it would be sufficient to have the central bank smooth away all transitory shocks, or speaking in Hayek's [1945] vocabulary, as there would be no real dispersion of knowledge, no decentralization of decision rights would be necessary.[15]

In the choice of an order of the money market, one important goal should be to maximize the informational efficiency of the market in the sense of the information content of the interest rate concerning its permanent component. The extraction of the permanent component of the money market interest rate is of interest for all three types of economic agents: for the banks and market observers to be able to take better economic decisions and for the central bank to be able to implement a better monetary policy with the goal of price and output stabilization.[16] Some authors (Kasman [1993], Ayuso, Haldane and

[15]Even the Bank of England [1988, 13-14], which follows an activist strategy on the money market, writes about its possibilities of anticipating and neutralizing transitory money market shocks: "In order to plan and to undertake its operations efficiently, the Bank maintains running forecasts of the cash position of the banking system - daily for several weeks ahead, and on a weekly or monthly basis over a longer horizon... There is considerable unavoidable uncertainty in such forecasts. The factors which contribute to the market's position are known with varying degrees of certainty at varying stages in advance." It could also be the case that the central bank is in principle capable of collecting all the information the private banking sector has about transitory money market shocks by itself and of intervening correspondingly, but that the resource costs of such a data collection would be very high and that it is just more efficient to delegate the smoothing task to the private banks which are much closer to the necessary information.

[16]The estimation of the *permanent* component of the money market interest rate is important because

Restoy [1994], King [1994]) claim that a higher volatility of the short term interest rate has no impact on signal extraction problems as there is no significant positive correlation between the volatility of money market rates and the volatility of longer term (for example one year) rates. But this reasoning does not necessarily seem convincing: If the volatility of transitory liquidity shocks is less stable than the one of permanent shocks, then one should *not* observe a positive correlation between the volatility of the short term rate and the volatility of the long term rate. In periods of a large variance of the transitory shocks, economic subjects could learn only little about innovations in the permanent component. Thus, the correlation between short- and long-term rate volatility could even be negative and the low correlation between both volatilities does not prove the irrelevance of the signal extraction problem.

In the model, central bank money is lent for exactly one period. At the beginning of each period, central bank money (the only kind of money in the model) is alloted to banks for one period via an auction to which the private banks have to submit demand functions. After receiving the money, the banks lend money to their customers. If no averaging provision exists, the money lent by banks to customers must correspond exactly to the money received at the auction. At the end of the period, the customers return the money to the banks and the banks return the money received at the auction to the central bank.

One could ask how interest is paid on the money lent as there is no money in the system except that which is lent. We can assume that interest rates are paid in some real unit as ounces of gold. As the relative price 'units of money per ounce of gold' is well-defined, every interest rate payment can easily be expressed in ounces of gold.

In the following, three variants of the model will be presented. They differ with respect to the ex ante knowledge of private banks concerning transitory money market shocks. The two extreme cases of no averaging at all and unrestricted averaging will be analyzed in all three variants. In the sections following section IV.3, different partial restrictions to averaging will be discussed in the framework of the first variant.

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it is correlated (or even corresponds) to the long-term interest rate via some arbitrage equation.

IV.3 The information content of the money market interest rate with and without averaging

The three variants (a), (b), and (c) of the model each suppose a different anticipation of the transitory shocks by the private banks. If averaging is allowed, the competing banks (which are assumed to be identically informed) will participate to the first money market auction in such a way that the expected money market interest rates in both periods are equal (as long as this condition is not fulfilled, individual banks could lower their refinancing costs by some intertemporal reallocation of refinancing). We thus have to calculate the money demand functions of the banks which guarantee this condition. Assume that the money demand by bank customers is deterministic and constant in each period. The difference between the quantity of money allotted to the banks in the money market auction and the money passed on by the banks to their customers represents the banks' reserve holdings in the respective period.

For reasons of simplicity, the demand functions submitted by banks to the money market auction will be restricted to parallel shiftings of the money demand functions of the bank customers. Let the aggregated money demand function of the customers be, in both periods ($t = 1, 2$):

$$m_t^d = a - bi, \tag{15}$$

where a, b are constants with $a > 0, b > 0$ and i is the rate of interest to be paid. Let a small 'm' stand in general for quantities of money lent to customers and a capital 'M' for quantities of money at the level of the money market. The quantity of money available at the money market auction for the private banks is assumed to be, in the first and second period respectively:

$$M_1^s = \bar{M} - x - y_1 + di_1 \tag{16}$$

$$M_2^s = \bar{M} - x - y_2 + di_2 \tag{17}$$

where $d \geq 0$ is a constant and x, y_1, y_2 are uncorrelated random variables with $E(x) = E(y_1) = E(y_2) = 0$ and $Var(x) = \sigma_x^2$, $Var(y_1) = \sigma_y^2$, $Var(y_2) = \sigma_y^2$. This should be interpreted as follows: the central bank offers a quantity of money $\bar{M} + di$, but this supply is reduced (augmented) by demand shocks of $x + y_1$ (period 1) and $x + y_2$ (period 2). Various causes of the money market shocks can be imagined. In the variants (a) and (b) of the model, we can interpret the shocks as arising at the level of the banks just before the auction. In this interpretation, the banks would face two kinds of money demand by customers: one which is independent of interest rates, which cannot be influenced by the banks, and which occurs as realizations of a random variable before the auction ($x + y_1$ in the first and $x + y_2$ in the second period); and one which depends on the interest rate set by the banks and which is identical each period. Then, the banks would enter the first money market auction with a demand function $M_1^d = a_1 - bi_1 + x + y_1$ and would be confronted with the money supply $M_1^s = \bar{M} + di_1$. Keeping this possible interpretation in mind, we further develop the model by formally localizing the shocks on the money supply side. In the case of variant (c), it is more difficult to localize the shocks in the banking sector.[17]

Without an averaging option, the market equilibrium of both periods has to be calculated separately. With averaging, the model has to be solved in all variants in the following three steps:

1. The private banks submit money demand functions $M_t^d = a_t - bi_t$ to the auctions ($t = 1, 2$). The expected money market equations in both periods are thus:

$$a_1 - bi_1 = \bar{M} - E(x) - E(y_1) + di_1 \tag{18}$$

$$a_2 - bi_2 = \bar{M} - E(x) - E(y_2) + di_2 \tag{19}$$

   Then, the expected equilibrium interest rates are:

$$E(i_1^*) = \frac{1}{d+b}(a_1 - \bar{M} + E(x) + E(y_1)) \tag{20}$$

$$E(i_2^*) = \frac{1}{d+b}(a_2 - \bar{M} + E(x) + E(y_2)) \tag{21}$$

   In the intertemporal arbitrage equilibrium, those expected rates have to be identical.

2. The (identical) expected interest rates can be calculated from the condition that over both periods, the money demanded by bank customers must correspond to the money received by banks at the money market auctions, such that the bank reserves are zero on average (a positive reserve requirement could be treated correspondingly):

$$E(M_1^s(i)) + E(M_2^s(i)) = m_1^d(i) + m_2^d(i) \tag{22}$$

$$\Leftrightarrow 2\bar{M} - 2E(x) - E(y_1) - E(y_2) + 2di = 2a - 2bi \tag{23}$$

$$\Leftrightarrow E(i^*) = \frac{1}{d+b}\left(a - \bar{M} + E(x) + \frac{E(y_1) + E(y_2)}{2}\right) \tag{24}$$

[17] However, one could imagine a similar variant where the shock would occur at the level of the banks *after* the auction. Then, the banks would have to decide after the shock on the allotment of money to the regular customers' demand.

3. With this equilibrium interest rate, a_1 and a_2 can now be calculated by substituting into equations (20) and (21).

$$a_1 = a - \frac{E(y_1)}{2} + \frac{E(y_2)}{2} \tag{25}$$

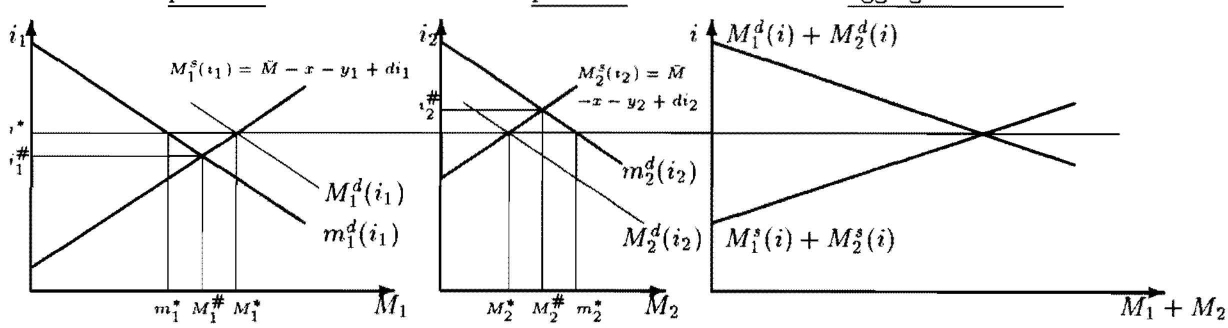
$$a_2 = a + \frac{E(y_1)}{2} - \frac{E(y_2)}{2} \tag{26}$$

With the a_1 calculated, the banks enter the first auction in each of the three variants (a), (b), and (c).

Variant (a) of the model

In this variant, the private banks exactly anticipate *both* transitory shocks y_1, y_2 *before the first auction*; interest rate differentials will be arbitraged away completely even ex post. This property permits a representation of the two periods' money markets and the aggregated market in a simple diagram. The equilibrium interest rate with averaging can be found as the intersection of the aggregated demand and supply functions. By drawing a line back to the individual periods' diagramms, one can determine the money transferred to the bank customers and the refinancing balances.

Figure 1



The variables have the following interpretation: $i_1^\#$ is the equilibrium interest rate in the first period, if averaging is not allowed; i^* is the equilibrium interest rate in both periods, if averaging is allowed; M_1^* ($M_1^\#$) is the quantity of money allotted on the money market to the banks in period 1, if averaging is (not) allowed; m_1^* is the quantity of money lent by the banks to their customers in period 1, if averaging is allowed; $M_1^\#$ is also the quantity of money lent by the banks to their customers in period 1, if averaging is not allowed. Corresponding variables are used for the second period. The reserve balance of the banks in the first period is $M_1^* - m_1^*$; in the second period the balance is exactly reversed and equals $m_2^* - M_2^*$.

Before the first auction, when the banks plan a_1, a_2, they anticipate perfectly the transitory shocks; therefore: $E(y_1) = y_1$ and $E(y_2) = y_2$, implying: $a_1 = a + (-y_1 + y_2)/2$ and $a_2 = a + (y_1 - y_2)/2$, so that:

$$i_1^* = i_2^* = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{y_1 + y_2}{2}\right) \tag{27}$$

The reserve balance of the banks in the first period is thus: $S_1 = M_1^d(i_1^*) - m_1^d(i_1^*) = a_1 - bi_1^* - (a - bi_1^*) = (-y_1 + y_2)/2$; in the second period it is $S_2 = -S_1$.

We are now interested in measuring the information content of the interest rate concerning its permanent component x, with and without averaging. The problem of estimating the realization of unobservable random variables of which an observed variable is a linear combination is treated in the theory of signal extraction (see for example Sargent [1979, 209] or Harvey [1993, 37-39]).

In the case of one observed variable, the linear least-square signal extraction model has the following structure: Let i^* be an observed variable and assume that it is known that $i^* = \alpha' X$, where $\alpha' = (\alpha_0, \alpha_1, ...\alpha_n)$ is a vector of known coefficients, $X = (x_0, x_1, x_2, ..., x_n)'$ is a vector of random variables, $x_0 = 1$ (deterministic) and for $j = 1...n$, $E(x_j) = 0$, $Var(x_j) = \sigma_j^2$ and $Cov(x_j, x_l) = 0, \forall j \neq l$. We are looking for a linear estimator of one of the unobserved random variables, x_k, using the observation of i^*. One has thus to calculate the two coefficients β_0, β_1 in the equation $\hat{x}_k = \beta_0 + \beta_1 i^*$, in order to minimize the squared error of the estimation:

$$min_{\beta_0,\beta_1} E(\hat{x}_k - x_k)^2$$

It is shown in appendix 1.1 that the optimal coefficients β_0, β_1 are:

$$(\beta_0, \beta_1) = \left(-\alpha_0 \frac{\alpha_i \sigma_i^2}{\sum_{j=1}^n \alpha_j^2 \sigma_j^2}, \frac{\alpha_i \sigma_i^2}{\sum_{j=1}^n \alpha_j^2 \sigma_j^2}\right) \tag{28}$$

By substituting those values of β_0, β_1, one obtains the expected squared error in estimating the unobserved variable x_k:

$$E((\hat{x}_k - x_k)^2) = \sigma_i^2 - \frac{(\alpha_i \sigma_i^2)^2}{\sum_{j=1}^n \alpha_i^2 \sigma_j^2} \tag{29}$$

Now, the quality of the extraction of the permanent component of the interest rate will be analyzed. The cases with and without averaging will be compared, both for the situation after the first and the second period's auction. It will be shown that temporarily the signal extraction is better with averaging than without.

- Information content of the interest rate in the first money market auction
  - **With averaging.** Here, the linear relationship between the interest rate and the unobservable money market shocks is:

$$i_1^* = \frac{1}{d+b}(a - \bar{M} + x + \frac{y_1 + y_2}{2})$$

By using the signal extraction formula (see appendix 1.1), we get the estimator for the permanent component x:

$$E(x|i_1^*) = -(a - \bar{M}) \left(\frac{\sigma_x^2}{\sigma_x^2 + \frac{1}{2}\sigma_y^2} \right) + (d+b) \left(\frac{\sigma_x^2}{\sigma_x^2 + \frac{1}{2}\sigma_y^2} \right) i_1^*$$

The expected squared error of the estimation is:

$$E((\hat{x} - x)^2) = \sigma_x^2 - \frac{(\sigma_x^2)^2}{\sigma_x^2 + \frac{1}{2}\sigma_y^2}$$

Let us now introduce a numerical example which will be used several more times in the course of the paper. Let $d = 0,5$, $b = 0,5$, $\sigma_x^2 = 1$, $\sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$. Then, when observing for example $i_1^* = 8$:

$$E(x|i_1^* = 8) = -5\frac{1}{1,5} + 8\frac{1}{1,5} = 2$$

The interest rate expected for the second period is also 8. The interest rate expected in the long run (for the time after the maintenance period) is 7. The squared error in estimating x (identical to the one of estimating the long run interest rate) is 1/3. For each additional interest rate point observed, the expectation concerning x, and in the specific example also the expectation concerning the permanent interest rate rises by 2/3. This 'slope coefficient' becomes smaller when the variance of y rises and larger if the variance of x rises. If a money market is exposed to a strong transitory shocks, the signal concerning the long-term interest rate given by a rise in the interest rate by one percentage point is weaker then on a money market with a low transitory volatility. Hence, if the transitory volatility rises, an adaptation of the interpretation of changes in the money market rate prevents the expectational errors rising proportionally. But this adaptation cannot prevent a certain deterioration of the extraction of the permanent component of the interest rate.

It should be noted that the information content of the interest rate concerning its permanent component (at the beginning of a reserve maintenance period) can be further increased by extending the maintenance period beyond two periods. The expected squared error in estimating x (after observing the first auction's interest rate) will be, expressed as a function of the length n of the maintenance period:

$$E((\hat{x}-x)^2) = \sigma_x^2 - \frac{(\sigma_x^2)^2}{\sigma_x^2 + \frac{1}{n}\sigma_y^2} \tag{30}$$

If the length of the maintenance periods goes to infinity, the expected squared error approaches zero. Of course, the supply of central bank money would no longer be well-defined with an infinite maintenance period.

- **No averaging.** In this case, the interest rate in the first period will be:

$$i_1^{\#} = \frac{1}{d+b}(a - \bar{M} + x + y_1)$$

Using again the signal extraction formula, we get the estimator for the permanent component:

$$E(x|i_1^{\#}) = -(a-\bar{M})\left(\frac{\sigma_x^2}{\sigma_x^2+\sigma_y^2}\right) + \left((d+b)\frac{\sigma_x^2}{\sigma_x^2+\sigma_y^2}\right) i_1^{\#}$$

The expected squared error is:

$$E((\hat{x}-x)^2) = \sigma_x^2 - \frac{(\sigma_x^2)^2}{\sigma_x^2+\sigma_y^2}$$

This error is always larger than the one in the case of averaging. In the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$) with $i_1^{\#} = 8$, the estimated permanent component is:

$$E(x|i_1^{\#} = 8) = -5\frac{1}{2} + 8\frac{1}{2} = 1.5$$

and the squared error is 1/2. The expected interest rate for the second period (which is identical to the interest rate expected in the long run) is $E(i_2^{\#}|i_1^{\#} = 8) = 6.5$.

- Information content of both periods' interest rates taken together.

  - **With averaging.** Both periods' interest rates are identical here, implying that the second period cannot add any information to the first one, meaning:

$$E(x|i_1^*, i_2^*) = E(x|i_1^*)$$

The expected estimation error is also unchanged relative to the situation before the second auction.

- **Without averaging.** In this case, the interest rate of the second auction contains additional information. As we observe now two independent interest rates, we have to apply the signal extraction model generalized to n observations as presented in appendix 1.2. The linear relationship between the shocks and the interest rate in the second period is:

$$i_2^\# = \frac{1}{d+b}(a - \bar{M} + x + y_2)$$

Thus, the matrix A which describes the relationship between all observed variables and the unobserved shocks $((i_1^\#, i_2^\#)' = a_0 + A.(x, y_1, y_2)'$, see appendix 1.2) is:

$$A = \begin{pmatrix} \frac{1}{d+b} & \frac{1}{d+b} & 0 \\ \frac{1}{d+b} & 0 & \frac{1}{d+b} \end{pmatrix}$$

By applying the signal extraction formula derived in appendix 1.2, we get the two coefficients $(\beta_1, \beta_2)'$:

$$\begin{pmatrix} \beta_1 \\ \beta_2 \end{pmatrix} = \frac{(d+b)\sigma_x^2\sigma_y^2}{[(\sigma_x^2 + \sigma_y^2)^2 - \sigma_x^4]} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

The identity of the weights of both interest rates follows from the symmetry of both lines of the matrix A. The estimated values of (β_1, β_2) have to be put into the signal extraction formula

$$E(x|i_1^\#, i_2^\#) = \beta_1[i_1^\# - \frac{1}{(d+b)}(a - \bar{M})] + \beta_2[i_2^\# - \frac{1}{(d+b)}(a - \bar{M})]$$

This estimator has to be substituted into the squared estimation error which yields a rather complicated expression. For the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$), we obtain the coefficients $(\beta_1, \beta_2) = (1/3, 1/3)$, and thus, for example:

$$E(x|i_1^\# = 7, i_2^\# = 9) = \frac{7-5}{3} + \frac{9-5}{3} = 2$$

The interest rate expected in the long run is 7. The squared estimation error is 1/3. Thus, after both periods, the information content of interest rates is *independent of whether averaging is allowed or not.* This result is not only valid for the specific example, but general.

In this variant (a) of our model, the information content of the money market rate can thus be raised by granting an averaging option, but only temporarily. At the end of a two-day maintenance period, observing the interest rates is equally informative with and without averaging. But since a temporary informational advantage is clearly useful for economic decision taking during the maintenance period, we can conclude for this variant of the model that averaging is useful.

Variant (b) of the model

In this variant, the banks only become informed about the second transitory shock *after* the first money market auction. Before the first auction (when choosing a_1), the banks expectations are: $E(y_1) = y_1$ and $E(y_2) = 0$. How does the uncertainty about the second transitory shock affect the relative quality of signal extraction with and without averaging? To assure the identity of expected interest rates, the conditions $a_1 = a - y_1/2$ and $E(a_2) = a + y_1/2$ have to be respected and thus:

$$i_1^* = E(i_2^*) = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{y_1}{2}\right)$$

Just before the second period's auction, the banks learn about the second transitory shock. From the first period, the banks have inherited a reserve balance $S_1 = -y_1/2$. The balance in the second period must be $S_2 = -S_1$. Beyond this necessary compensation of the first period's balance, the banks should submit the 'natural' demand functions $m^d(i)$ to the auction, as no opportunity of intertemporal arbitrage remains after the first auction has taken place. The market equilibrium condition in the second period is thus:

$$a - bi_2 + \frac{y_1}{2} = \bar{M} - x - y_2 + di_2 \Leftrightarrow i_2^* = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{y_1}{2} + y_2\right)$$

Now we will again look at the information content of interest rates concerning the permanent component in money scarcity, x.

- Information content of the interest rate in the first money market auction
  - **With averaging:** In this case, the interest rate in the first auction is:

    $$i_1^* = \frac{1}{d+b}(a - \bar{M} + x + \frac{y_1}{2})$$

    The estimator of the permanent shock is thus:

    $$E(x|i_1^*) = -(a - \bar{M})\left(\frac{\sigma_x^2}{\sigma_x^2 + \frac{1}{4}\sigma_y^2}\right) + (d+b)\left(\frac{\sigma_x^2}{\sigma_x^2 + \frac{1}{4}\sigma_y^2}\right) i_1^*$$

    The squared error is:

    $$E((\hat{x} - x)^2) = \sigma_x^2 - \frac{(\sigma_x^2)^2}{\sigma_x^2 + \frac{1}{4}\sigma_y^2}$$

In the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$) the error amounts to 0.2 which is less than in the corresponding case of the variant (a). If for example the interest rate is 8, we have $E(x|i_1^* = 8) = 2.4$ and the rate expected in the long run is 7.4.

- **Without averaging:** See variant (a)

- Information content of both period's interest rates taken together

  - **With averaging.** The matrix A becomes:

$$A = \begin{pmatrix} \frac{1}{d+b} & \frac{1}{2(d+b)} & 0 \\ \frac{1}{d+b} & \frac{1}{2(d+b)} & \frac{1}{d+b} \end{pmatrix}$$

By substituting into the formula given in appendix 1.2, one gets the coefficients β_1, β_2. The coefficient β_2 is always zero. This result can easily be understood as the interest rate in the second period only contains additional noise relative to the one in the first period (see the matrix A). In the specific example ($d = b = 0.5$; $\sigma_x^2 = \sigma_y^2 = 1$; $\bar{M} = 5$; $a = 10$), we obtain (β_1, β_2)=(0.8; 0). The quadratic estimation error is unchanged relative to the first period, namely 0.2.

  - **No averaging.** See variant (a)

One can conlude for the variant (b) of the model that the information content of the interest rate concerning its permanent component *is strictly better with averaging*, independent of whether only the first period's interest rate or both periods' interest rates are considered.

Variant (c) of the model

In this variant, the banks only learn about the first and second periods' transitory money market shocks after the respective auction. Thus, when planning a_1 before the first auction, $E(y_1) = E(y_2) = 0$. As the banks have no useful knowledge about the transitory shocks before the first period to engage in intertemporal arbitrage, $a_1 = a$ will be chosen and the equilibrium interest rate is:

$$i_1^* = (a - \bar{M} + x + y_1)/(d + b)$$

Contrary to the two preceding variants, the auction itself reveals new information to the banks which is used to decide about the reserve balance S_1 and the quantity of money lent to customers m_1. It is assumed that the banks know y_1 exactly after the first auction.[18]

[18] This would be the case if the banks knew the value of x. An alternative assumption would be that the banks have to engage in signal extraction themselves after the auction to estimate y_1 (this would be a variant (d) of the model).

The quantity of money lent to customers, m_1, has to be determined after the first auction such that $E(m_2) = m_1$ and such that the marginal return of holding money (for the bank customers) corresponds to the expected refinancing costs in period 2:

$$E(i_2^*) = (m_1^d(i_1^*))^{-1} (= (m_2^d(i_2^*))^{-1})$$

$$\Leftrightarrow \frac{1}{d+b}(a_2 - \bar{M} + x) = \frac{1}{b}(a-m) \Leftrightarrow a_2 = \frac{d+b}{b}(a-m) + \bar{M} - E(x)$$

In addition, the condition must be fulfilled that the reserve holding balances in both periods balance out exactly:

$$S_2(m, a_2) = -S_1(m, a_1) \Leftrightarrow S_2(m, a_2) = -S_1(m, a)$$

$$\Rightarrow m - \left(a_2 - b\left(\frac{1}{d+b}(a_2 - \bar{M} + x)\right)\right) = -\left(m - \left(a - b\left(\frac{1}{d+b}(a - \bar{M} + x + y_1)\right)\right)\right)$$

$$\Leftrightarrow m = \frac{d}{2(d+b)}(a_2 + a) + \frac{b}{d+b}(\bar{M} - x) - \frac{b}{2(d+b)}y_1$$

By substituting and rearranging, we obtain:

$$a_2 = a + \frac{b}{2b+d}y_1$$

$$m = \frac{d}{d+b}a - \frac{b^2}{(d+2b)(d+b)}y_1 + \frac{b}{d+b}(\bar{M} - x)$$

Knowing a_2 we can calculate the interest rate of the second period:

$$i_2^* = \frac{1}{d+b}(a_2 - \bar{M} + x + y_2) \Rightarrow i_2^* = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{b}{2b+d}y_1 + y_2\right).$$

Now, we compare again the information content of interest rates with and without averaging.

- Information content after the first money market auction
  - **With averaging** This case corresponds to the one *without* averaging in the variants (a) and (b).
  - **No averaging** See variants (a) and (b).
- Information content of both periods' interest rates taken together.
  - **With averaging**. The matrix A now takes the following form:

$$A = \begin{pmatrix} \frac{1}{d+b} & \frac{1}{d+b} & 0 \\ \frac{1}{d+b} & \frac{b}{(d+b)(2b+d)} & \frac{1}{d+b} \end{pmatrix}$$

    By substituting into the signal extraction formula, one can calculate the coefficients β_1, β_2. In the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$) we have $(\beta_1; \beta_2) = (0.318; 0.273)$. The squared standard error amounts to 0.409.

- **No averaging.** See variants (a) and (b).

Interestingly, the information content of both periods' interest rates is now higher without averaging then with averaging. The first lines of the matrices A (the first period's interest rate equations) are identical. But in the second lines (the second period's interest rate equations) one can see an additional noise term in the case of averaging relative to the case without averaging. This noise term is related to the fact that the surprise in the first money market auction implies an inverse balancing need in the second period.

In the following table 2, the results of all three variants of the money market model are displayed for the cases of averaging and no averaging and for the situation after one and after two periods. The twelve cases reviewed are ranked (rank 1 to rank 4) concerning the information content of interest rates.

Table 2: Information content of money market rates[19]

	Variant a	Variant b	Variant c
knowledge about trans. shocks before first auction	y_1, y_2 known	y_1 known $E(y_2) = 0$ $Var(y_2) = \sigma_y^2$	$E(y_1) = E(y_2) = 0$ $Var(y_1) = Var(y_2) = \sigma_y^2$
knowledge about trans. shocks before second auction	y_1, y_2 known	y_1, y_2 known	y_1 known $E(y_2) = 0, Var(y_2) = \sigma_y^2$
Matrix A after first auction, A	$\frac{1}{(d+b)}(1\ \frac{1}{2}\ \frac{1}{2})$	$\frac{1}{(d+b)}(1\ \frac{1}{2}\ 0)$	$\frac{1}{(d+b)}(1\ 1\ 0)$
Matrix A after first auction, nA	$\frac{1}{(d+b)}(1\ 1\ 0)$	$\frac{1}{(d+b)}(1\ 1\ 0)$	$\frac{1}{(d+b)}(1\ 1\ 0)$
Information content, A	2	1	4
Information content, nA	4	4	4
Matrix A after second auction, A	$\frac{1}{d+b}\begin{pmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 1 & \frac{1}{2} & \frac{1}{2} \end{pmatrix}$	$\frac{1}{d+b}\begin{pmatrix} 1 & \frac{1}{2} & 0 \\ 1 & \frac{1}{2} & 1 \end{pmatrix}$	$\frac{1}{d+b}\begin{pmatrix} 1 & 1 & 0 \\ 1 & \frac{b}{2b+d} & 1 \end{pmatrix}$
Matrix A after second auction, nA	$\frac{1}{d+b}\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix}$	$\frac{1}{d+b}\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix}$	$\frac{1}{d+b}\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix}$
Information content, A	2	1	3
Information content, nA	2	2	2

The information content of the interest rate after the first money market auction is always at least as good with averaging as in the case without averaging. Hence, a clear advantage of averaging provisions can be etablished at this level. Only in the variant (c) of the model is the information content of the interest rate identical under both institutional arrangements.

[19]'A' = Averaging; 'nA' = no averaging

After the second money market auction no one arrangement clearly dominates. In variant (a), both have identical informational properties. In variant (b), the quality of signal extraction is better with an averaging option. In variant (c), observers of the interest rates can learn more about their permanent component if there is no averaging provision.

All in all, one may conclude that an averaging provision is certainly favorable to signal extraction at the beginning of a maintenance period and that its total benefits should be ceteris paribus higher, the better the banks participating in the money market anticipate transitory liquidity shocks.

After having analyzed the extreme cases of unlimited averaging and no averaging at all, we will review intermediate arrangements in the next section. Intertemporal arbitrage may be restricted by a limitation of the reserve balance, by a reserve balance fee (in the form of a difference between the overdraft and the surplus interest rate) or by the setting of an interest rate corridor implemented by a deposit and a lending facility. Only the variant (a) of the model will be considered, but the results in variant (b) would be rather similar.

IV.4 The effect of limiting the reserve balance

Existing minimum reserve arrangements with averaging provisions (as in the US or in Germany) have a limitation to the overdraft relative to the required average reserve holding: banks are not allowed to have a negative balance on their central bank account overnight. Therefore, the maximum allowed reserve balance corresponds to the size of the reserve requirement. This is not a general necessity. In principle, the limitation of the reserve balance (the allowed overdraft relative to the required reserves) is independent of the size of the reserve requirement. For example, the *averaging around zero* - arrangement of the *Bank of Canada* allows for overdrafts without having a positive reserve requirement at all.[20] With a positive reserve requirement, one could imagine granting an averaging capacity of one half, or double, or triple of the reserve requirement, and so on.[21] We will now analyze briefly in the framework of variant (a) of the model presented above the implications of a limitation of the averaging capacity for the information content of the interest rate concerning its permanent component.

Suppose that the aggregated averaging capacity (the allowed reserve balance) of the banks

[20] See Bank of Canada [1991], Freedman [1991], and Clinton [1996] for an overview of the Canadian system.

[21] If the averaging capacity is bigger than the reserve requirement, then banks should be required to provide collaterals for the net overdrafts.

is limited to S_{max}. We can then derive critical values of the difference between the first period's and the second period's transitory shocks, at which the averaging capacity is exactly exhausted. Pairs of shocks with bigger differences cannot lead to additional arbitrage. The information content of the interest rate thus must be interpreted by taking into account the fact that the interest rate can be the result of three different linear equations mapping the shocks into the interest rates. It has been shown above that the balance in period 1 in variant (a) of the model is: $S_1 = (-y_1 + y_2)/2$. Thus, the maximum averaging capacity will be exhausted if $|-y_1 + y_2| \geq 2S_{max}$. If the averaging capacity is exhausted, the linear relationship between the money market shocks and the interest rate is transformed into another linear relationship. We thus have to distinguish among three situations:

1. If $|y_1 - y_2| < 2S_{max}$, the linear relationship between the shocks and the observed interest rate is:
$$i_1^* = \frac{1}{d+b}(a - \bar{M} + x + \frac{y_1 + y_2}{2})$$
2. If $(y_1 - y_2) \geq 2S_{max}$, then $a_1 = a - S_{max}$ and thus:
$$i_1^* = \frac{1}{d+b}(a - S_{max} - \bar{M} + x + y_1)$$
3. If $(y_1 - y_2) \leq -2S_{max}$, then $a_1 = a + S_{max}$ and thus:
$$i_1^* = \frac{1}{d+b}(a + S_{max} - \bar{M} + x + y_1)$$

The bigger S_{max} is, the more often case 1 is the underlying one, and the more similar the signal extraction problem becomes here to the one with unlimited averaging. The smaller S_{max}, the more often cases 2 or 3 are relevant, and the more similar the signal extraction problem becomes to the one without any averaging.

In appendix 2.1, the calculations to obtain the information content of interest rates in the case of a limited averaging capacity are given. Here, we only look at the signal extraction problem in the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$) with normally distributed shocks and represent the information content of the interest rate as a function of S_{max} graphically.

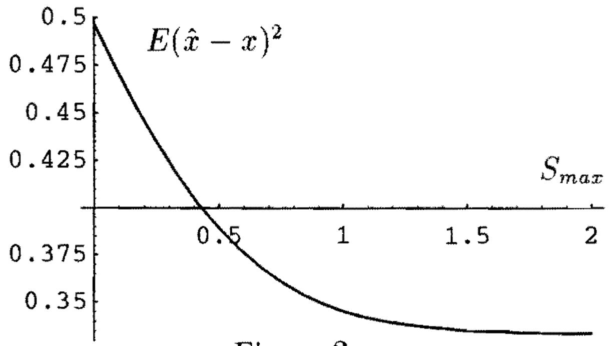


Figure 2

The expected estimation error falls as a convex function from 1/2 at $S_{max} = 0$ to 1/3 as $S_{max} \to \infty$. The marginal costs of narrowing the averaging capacity (with respect to informational efficiency) thus rise monotonously. If the central bank only has an aversion to very large reserve balances of the banks, it can forestall such balances by a sufficiently broad limitation without badly damaging the information content of interest rates.

IV.5 The effect of an averaging fee

It is costless for banks to undertake intertemporal arbitrage activity in the framework of a reserve averaging facility if reserve overdrafts and surpluses are rewarded and charged respectively with the same interest rate. This has not necessarily to be the case. The Bank of Canada's *averaging around zero* - system charges interest rates on overdrafts but does not remunerate the required compensating surpluses (Bank of Canada [1991, 26]).

Let i_h be the credit interest rate for positive balances and let i_s be the debit interest rate for negative balances with $i_s \geq i_h$. In our two-period model, the averaging fee then is, independently of whether the overdraft takes place in the first or second period, equal to $|S_1|(i_s - i_h)$. The competing banks will smooth the interest rate until the expected interest rate difference $|E(i_2) - E(i_1)|$ exactly equals $i_s - i_h$. Let us define $\lambda = i_s - i_h$ as the cost of averaging. Again, we will focus exclusively on variant (a) of the model. Similarly to the case of a limitation to the averaging capacity, three situations have to be distinguished:

1. If $|E(i_2) - E(i_1)| \leq \lambda \Leftrightarrow -\lambda(d+b) \leq y_1 - y_2 \leq \lambda(d+b)$ without any averaging

activity, then no averaging will take place, so that:

$$i_1^* = \frac{1}{d+b}(a - \bar{M} + x + y_1)$$

2. If $E(i_2) - E(i_1) > \lambda \Leftrightarrow y_1 - y_2 > \lambda(d+b)$ without any averaging activity, then the banks will have an overdraft in the first period, $S_1 > 0$, so that: $i_2 - i_1 = \lambda$, implying:

$$i_1^* = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{y_1 + y_2}{2}\right) + \frac{\lambda}{2}$$

3. If $-(E(i_2) - E(i_1)) > \lambda \Leftrightarrow y_1 - y_2 < -\lambda(d+b)$ without any averaging activity, then the banks will have a reserve surplus in the first period, $S_1 < 0$, so that: $-(E(i_2) - E(i_1)) = \lambda$, implying:

$$i_1^* = \frac{1}{d+b}\left(a - \bar{M} + x + \frac{y_1 + y_2}{2}\right) - \frac{\lambda}{2}$$

The higher the averaging fee, the more often the first situation is relevant and the more the signal extraction problem resembles to the one without any averaging at all. The lower the averaging fee, the more often situations 2 and 3 are relevant and the more the signal extraction problem resembles the case of unlimited averaging. The formal treatment of the signal extraction from the first period's interest rate in the case of an averaging fee can be found in appendix 2.2. Again, we will restrict ourselves here to looking at the information content of the interest rate after the first auction graphically in the specific example ($d = b = 0.5$, $\sigma_x^2 = \sigma_y^2 = 1$, $\bar{M} = 5$, $a = 10$) with normally distributed shocks. The expected squared error in estimating the permanent component x is plotted in the following figure as a function of the averaging fee. The squared error starts with 1/3 (no fee) and grows monotonously to 1/2 (infinite fee). The function is convex up to a certain value of λ and then becomes concave. By imposing a small averaging cost, the central bank can prevent averaging taking place in the case of small transitory shock differentials without badly harming informational efficiency.

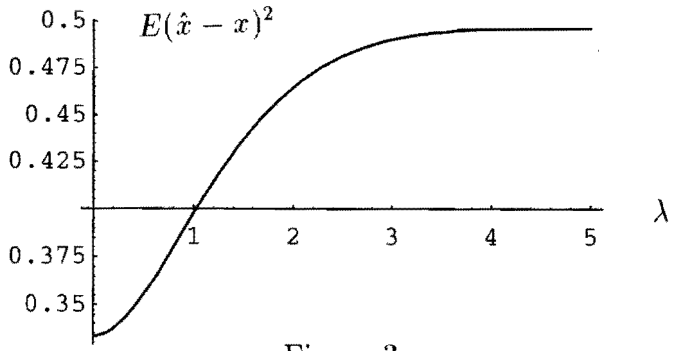


Figure 3

In the case of an averaging fee, the aspect of income generated for the central bank may be of some interest too. The expected quantity of averaging can be expressed as a function of the fee as follows:

$$U(\lambda) = \int_{-\infty}^{+\infty} \int_{-\infty}^{y_1-\lambda(d+b)} f_y(y_1) f_y(y_2) \left(\frac{|y_1 - y_2|}{2} - \frac{\lambda(d+b)}{2} \right) dy_2 dy_1$$

$$+ \int_{-\infty}^{+\infty} \int_{y_1+\lambda(d+b)}^{+\infty} f_y(y_1) f_y(y_2) \left(\frac{|y_1 - y_2|}{2} - \frac{\lambda(d+b)}{2} \right) dy_2 dy_1$$

$$= \int_{-\infty}^{+\infty} \int_{y_1+\lambda(d+b)}^{+\infty} f_y(y_1) f_y(y_1) \left(|y_1 - y_2| - \lambda(d+b) \right) dy_2 dy_1 \tag{31}$$

The fee income function $N(\lambda)$ is then $N(\lambda) = U(\lambda)\lambda$. Both functions are plotted for the specific example in the following two figures. If the central bank has well-defined preferences concerning informational efficiency on the one hand and income on the other, she can choose a corresponding optimal λ which has to be smaller or equal to the λ which maximizes income. Obviously, the central bank can come close to the income maximizing λ without seriously reducing the information content of the money market rate.

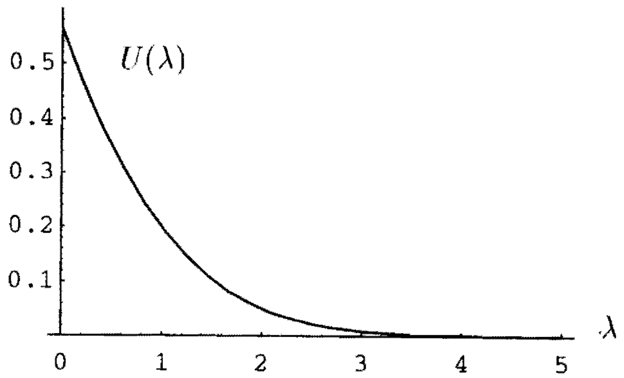


Figure 4

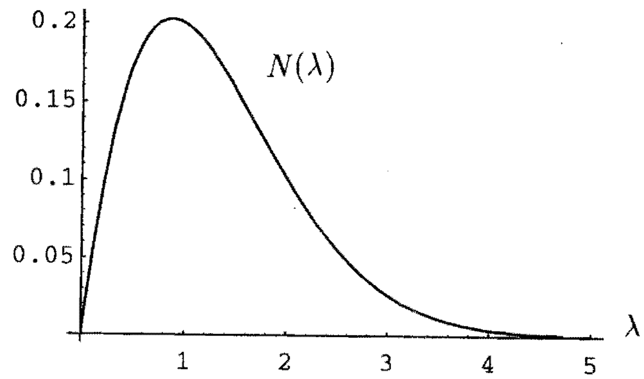


Figure 5

IV.6 The role of an interest rate corridor implemented by a deposit and a lending facility

If x, the permanent shock to the scarcity of money, is interpreted exclusively as a variable in the hand of the central bank, and if one thus interprets the problem of communicating information via the money market interest rate as a problem of revealing the intended central bank policy, then it would be best - in the framework of our model - to set a very narrow interest rate corridor implemented by two standing facilities. This way, the central bank could completely stabilize the interest rate and reveal x as precisely as desired. The fact that no central bank has chosen such a framework shows that the central bank wants the money market interest rate to reveal information about (permanent) developments coming from the central bank money *demand* side. The central bank may desire such an information revelation for itself (to use the information in its monetary policy decisions) and also for other market observers. In this section, we thus assume that x is exclusively a variable reflecting developments in the structural component of the scarcity of money coming from the side of the market.

If the interest rate is adsorbed by one of the corridor rates, some information about x is lost. The more narrow the corridor is, the more information is thus lost. If the interest rates of the deposit and lending facilities are identical, the observation of the interest rate is naturally worthless and $E(\hat{x}-x)^2 = \sigma_x^2$. There are critical values of $x + y_1/2 + y_2/2$ which lead to a corridor interest rate and beyond which the size of this sum is irrelevant for the observed interest rate. In the corridor implemented by the deposit rate i_{ez} and the lending rate i_{lz}, the interest rates i_1^* and $i_1^{\#}$ are distributed as if there were no corridor. Let j^* and $j^{\#}$ be the interest rate variables with and without averaging, as well as without any corridor. Then: $P(i_1^* = i_{lz}) = \int_{i_{lz}}^{\infty} f_j(i_1^*)di_1^*$, and $P(i_1^* = i_{ez}) = \int_{-\infty}^{i_{ez}} f(j_1^*)dj_1^*$, as well as $P(i_1^{\#} = i_{lz}) = \int_{i_{lz}}^{\infty} f(j_1^{\#})dj_1^{\#}$ and $P(i_1^{\#} = i_{ez}) = \int_{-\infty}^{i_{ez}} f(j_1^{\#})dj_1^{\#}$

Because of the higher variance of j without averaging, $P(i_1^{\#} = i_{lz}) + P(i_1^{\#} = i_{ez})$, the probability of the realization of a corridor interest rate without averaging is always bigger than $P(i_1^* = i_{lz}) + P(i_1^* = i_{ez})$, the corresponding probability with averaging. The density functions $f(i_1^*)$, $f(i_1^{\#})$ are plotted for the specific parameter constellation $a = 10; \bar{M} = 5; \sigma_x^2 = 1; \sigma_y^2 = 1; d = 0.5; b = 0.5$ and normally distributed shocks in the following figure.

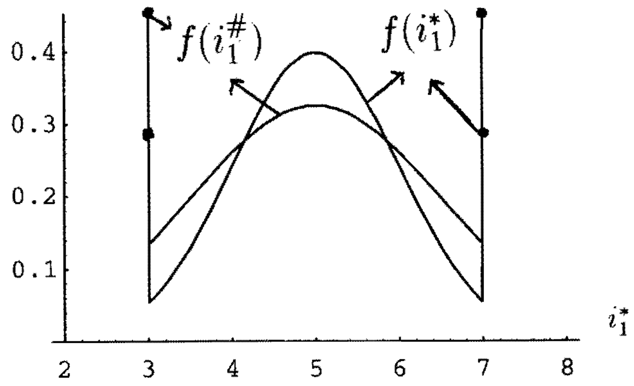


Figure 6

The density functions are drawn as thick points at i_{lz}, i_{ez} to express that they cannot be represented correctly here as a positive probability lies on a base of size zero. The figure illustrates that a narrowing of the corridor reduces the difference in the information content of interest rates between the cases with and without averaging: the narrower the corridor is, the more often the same interest rate occurs with and without averaging, namely a lending rate or a deposit rate.

The decision of the central bank about the width of the corridor may depend primarily on the idea it has about the direction of the information flows via the money market interest rate: from the central bank to the private banking sector or from the private banking sector to the central bank. The more the central bank itself uses the interest rate to assess the structural developments in the demand for central bank money, the wider the corridor should be. If the money market rate is primarily designed to reveal information about the central bank's policy intentions, the corridor should be narrow and the relevance of having an averaging option becomes small.

IV.7 Selection and combination of restrictions to averaging

Four possibilities to reduce the quantity of averaging can be considered: (1) limiting the allowed private banks' reserve balances, (2) charging an averaging fee, (3) implementing an interest rate corridor by two standing facilities, and, if one quits the framework of our two-period model: (4) the shortening of the length of the maintenance period.

How and to what extent the averaging activity should be restricted naturally depends on the motivations for this restriction. There is no extensive analysis of this question in the minimum reserve literature. Let us briefly discuss two possible motivations.

The *first* follows from the fact that the granting of an unrestricted averaging option implies the inability of the central bank to implement anticipated changes of money market interest rates in the course of an averaging period. In the medium term, there is an optimal nominal interest rate being a function of, among others, the inflation rate, the inflation rate relative to the target rate, the degree of capacity utilization, exogenous shocks, etc. The central bank tries to implement an interest rate path that follows as closely as possible the path of the optimal interest rate. Let us assume now that the central bank and the private banks know the path of the optimal interest rate. Then, the private banks will smooth out the anticipated changes of the nominal interest rate, independently of whether they are due to transitory shocks or to attempts of the central bank to have the interest rate follow changes in the optimal interest rate. Then the interest rate will not follow the optimal path but will move around this path in steps. In the following figure, this is illustrated for the case of an optimal interest rate following a path $i = 6 - t/4$ and maintenance periods of one and four months.

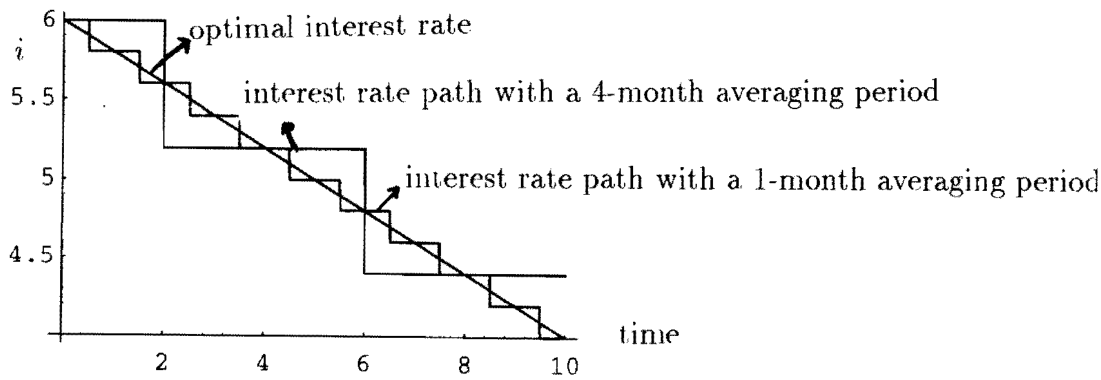


Figure 7

The deviations of the effective interest rate from the optimal one imply a suboptimal monetary steering of the economy with related welfare losses. The longer the maintenance period, the bigger the average deviation will be and the bigger the welfare losses due to the subotimal monetary steering will be: In the case of falling optimal interest rates $i_t = i_0 - a.t$ $(a > 0)$ and an n - month maintenance period, the average deviation of the interest rate from its optimal value is $na/2$.

An obvious reduction in this deviation can therefore be attained by shortening the maintenance period.[22] Other possibilities to reduce or eliminate this problem completely are

[22]Meulendyke und Tulpan [1993] (see also for example Spindt and Tarhan [1984]) discuss the pros and cons of *carry-over-provisions*, which allow to the banks to carry over reserve balances at the end of a maintenance period into the following maintenance period. Such provisions currently do not exist in Germany, but in the US, where banks can carry over up to two percent of their reserve requirement as a balance into the next maintenance period. The pros and cons of carry-over provisions should have some

to impose a maximum reserve balance S_{max} or a fee λ. If the averaging fee is bigger than $na/2$, there will be no smoothing out of anticipated optimal interest rate changes. If the fee is lower, the interest rate will be fixed close to the beginning and end of the averaging period. In the middle of the period, the interest rate will still follow the optimal path. If the central bank chooses a monetary quantity path consistent with the optimal interest rate path if no averaging is allowed, then the introduction of an averaging option with a maximum reserve balance implies a fixed rate in the middle of the averaging period and a parallel path to the optimum path close to the beginning and end of the period. It should be noticed that the central bank can ultimately implement any interest rate path if there is a limit to the reserve balance by varying the quantity of reserves supplied sufficiently in the course of the averaging period.

The *second* motivation for limiting the amount of averaging activity can be derived from the variant (c) of the two-period model presented in section III.3. It has been shown there that in the case of unanticipated transitory shocks, the anticipation errors that occured in the time span since the beginning of an averaging period add noise to the interest rate and thus do harm to the quality of signal extraction. The longer the maintenance period, the stronger this effect should become.[23] The beginning of a maintenance period is always a phase of a special purity of the interest rate signal: first, there is a relatively long time horizon for averaging, and second there is no noise ballast resulting from former unanticipated transitory shocks. It is thus in a certain sense advantageous to have frequent beginnings of maintenance periods. The optimal length of a maintenance period could be calculated in the framework of a model like the one presented in section III.2 generalized to n periods and to both anticipated and unanticipated transitory shocks.

Another question is whether an averaging fee or a limitation of the banks' balances is preferable if one wishes any restrictions to the averaging activity. With an averaging fee, all pairs of transitory shocks $(y_1, y_2) = (y_1, y_1 + e)$ with $e > \lambda(d + b)$ are mapped into the same interest rate. With a limitation to reserve balances, this is in a certain way reversed: if the difference between both transitory shocks is relatively small, all pairs of shocks are mapped into the same interest rate, namely all pairs $(y_1, y_1 + e)$ with

similarities with those of the lengthening of the maintenance period. The carry-over reduces the variance on the last days of the maintenance periods, but this variance may at least partially show up in the next period. The existence of a carry-over provision in the US has to be considered in relation to the length of the maintenance period of only two weeks. An argument for the German solution of a longer averaging period (one month) without the possibility of carrying over balances may be that it is somehow simpler. We do not intend to review the arguments for and against carry-over provisions in more detail here.

[23]Meulendyke and Tulpan [1993, 174-177] refer to a similar reason for restricting the amount of averaging.

$-S_{max}/2 < \epsilon < S_{max}/2$. We can conclude that, roughly speaking, with a fee, the large transitory shocks are better smoothed away than the weak ones, and with a limit to the reserve balance the weak transitory shocks are better smoothed away than the large ones (but we should keep in mind that weak transitory shocks are more frequent than large ones). Beyond those considerations, the following two arguments speak in favor of an averaging fee:

- The fee λ is a source of income for the central bank. If all other welfare effects of the fee are similar to those of a corresponding balance maximum, then the fee is preferable because in general, the marginal welfare cost of public income generated by taxes is positive.

- If a fee is imposed, it is irrelevant how the information about transitory shocks is spread among different banks. Even if only some few banks are informed, the amelioration of informational efficiency will be as good as if the whole banking sector had this information. If the balances are limited, this is not the case: the fewer banks are informed, the smaller the balancing capacity is. The assumptions that the dispersion of information varies from transitory shock to transitory shock and that in most cases only a minority of banks are informed seems realistic. Then the signal extraction problem becomes relevant for the whole banking sector, too, and the dispersed knowledge about a variety of transitory shocks not only has to be transmitted to other sectors of the economy, but also has to be aggregated (and revealed) in the banking sector itself. The theory of aggregation of various pieces of dispersed information into one price is another topic in the theory of information revelation as analyzed early by Grossman & Stiglitz [1976, 249-250].
  The argument may be expanded to the case in which it is costly for banks to become informed about transitory shocks. In the case of a fee, only a few banks have to invest in the production of the relevant information. In the case of a balance limitation, the quantity of resources spent for information production would have to be larger to attain the same degree of informational efficiency because more banks have to become informed to provide a certain volume of balances.

An advantage of a balance limitation may be that with such an arrangement the central bank can always implement any interest rate path if it sufficiently varies the reserve supply in the course of the averaging period.

What can be said about the interactions of a *corridor* with an averaging fee and with a limitation of the reserve balance? In the case of a combination of a corridor with a limitation of the reserve balance, from a certain narrowness of the corridor on, the maximum balances will never be attained, so that they are irrelevant and redundant. In the case of a combination of a corridor with an averaging fee, there will never be any averaging activity if the fee has a certain size relative to the width of the corridor. As in both cases, a money market with identical properties can be constructed with simpler rules, both cases should be avoided.

The systems in use in the US and Germany work with a balance limitation (corresponding to the volume of required reserves). In Germany, this limit is never used up by the banking sector as an aggregate. This could be interpreted as showing that there is no effective limitation to balancing in Germany. But that interpretation is not necessarily correct if one agrees that the ex ante information on shocks is not always widely spread among banks. The informed banks may have used up their balance while others do not use their balances at all because they do not have the relevant knowledge for averaging. The information content of the interest rate then could not reach the quality it would have with unlimited averaging.

V. Conclusions

In this paper, the contributions of reserve requirements to the stabilization of financial markets and economic activity were analyzed, stressing the role played by incomplete information. If one agrees that in a world of perfect information, money is a neutral veil, it becomes doubtful whether a theory of money which does not rely on the economics of information can be helpful. In the theory of economic policy, this view has generally been accepted since the introduction of the theory of rational expectations. In the theory of monetary order, it is also not new, but in many approaches, the underlying informational problems are still rather implicit. Especially section IV of the paper contributed to a more basic incomplete information foundation of one aspect of reserve requirements, namely averaging provisions.

Altogether, four functions of minimum reserve requirements were analyzed in varying degrees of depth in this paper:

1. A reserve requirement contributes to the structural demand for central bank money. This may be of interest to guarantee the existence of any demand for central bank money or to roughly neutralize a strong decline in the natural demand for it (section II.1). As important technological innovations have to be expected in the near future in the use of money as a means of payment by non-banks and in the area of payment systems, this function of reserve requirements could become relevant. Therefore, even if the reserve requirements are reduced for other reasons to zero for some while, the instrument should be preserved such that it could be reactivated any time. This would contribute to the confidence of economic agents into the capacity of the central bank to determine in all eventualities the scarcity of central bank money and thus to control indirectly its purchasing power.

2. A reserve requirement is in a certain way also a tax on bank deposits and thus has to be analyzed from the point of view of the theory of optimal taxation (section II.2). The high degree of international mobility of some of the banks' liabilities subject to reserve requirements speaks in favor of a *harmonization* of the concerned reserve ratios in the region of high mobility of capital. In the case of such a harmonization, it would be much more difficult to argue that the marginal welfare losses of a reserve requirement 'tax' are higher than those of other taxes generating public income. If harmonization were not possible, one could also think about remunerating reserves to reduce or eliminate any taxation aspect and thus any related distortion.

3. The incompleteness of the remuneration of required reserves should influence in the real world (where information is dispersed) in an idiosyncratic way macroeconomic stability and the variability of GDP around its natural (or goal) value (section III). On the other hand, it should be very difficult to estimate the corresponding optimal reserve ratios. Moreover, it is not clear at all *a priori* that a small reserve requirement should be better that none. Finally, the stabilization impact of a small reserve requirement (due to that function) like the one currently in effect in Germany is likely to be weak anyway.

4. If minimum reserves only have to be fulfilled on average over a certain maintenance period, banks can smooth away anticipated transitory money market shocks and thereby raise the information content of money market rates concerning their permanent component. For this function, it is not relevant (on an abstract, model-theoretical level) whether required reserves are remunerated or not, and, as the capacity of banks to build up temporarily reserve balances is not necessarily tied to the size of a reserve requirement, it is also irrelevant how large the reserve requirement is (section IV). This positive informational impact seemed to be relatively robust, such that one is tempted to conclude that an averaging option granted for a period that is not too long should be advantageous for informational flows and financial stability under the circumstances of the US or German money market, despite the fact that it seems difficult to derive empirically an optimal averaging system (in the sense of estimating a money market model and using the estimated parameters in some optimality conditions derived theoretically).

In Germany (and many other countries), the four functions have up to now been implemented together in the form of an unremunerated minimum reserve requirement with averaging. However, it has been argued here that the functions may be at least split into three groups that can be implemented independently. Only the functions 2 and 3 cannot be analyzed and implemented independently.

Certainly, many issues remain to be solved. To mention only a few: (1) It should be possible to integrate both stabilization arguments (the arguments of section III and IV) in the framework of one model. (2) The model of section IV could be enriched by the introduction of a reaction function of the central bank (taking into consideration the incomplete information the central bank has about the permanent component of the interest rate). The interest rate would change its time series properties but the structure of the signal extraction problem would in principle remain. A more general formulation of the transitory and permanent shocks and of the time structure of the model would be necessary. (3) Is it possible to analyze in a marginalistic framework the question of the optimal length of the averaging period and of the restrictions to averaging in the form of limitations to reserve balances and averaging fees and would it be possible to implement this model empirically?[24] (4) Is it possible to work out more precisely the nature of the positive externality of liquidity cushions of banks operating on the money market which was assumed to be the ultimate source of the benefits of averaging provisions?

It should be a general task of future research to further develop the idea that the theories of monetary order and of monetary policy are interrelated and should always be based on an analysis of a situation of strategic interaction of economic subjects with some explicitly defined informational incompleteness and asymmetry.

[24]Hamilton [1996] shows that it is possible to analyze empirically even relatively complicated institutional details of the money market.

Appendix 1: The basic least square signal extraction formula

Appendix 1.1 One observation and n unobserved shocks

Let i^* be the observed variable and assume that it is known that

$$i^* = \alpha' X \tag{32}$$

where $\alpha' = (\alpha_0, \alpha_1, ...\alpha_n)$ is a vector of known coefficients, $X = (x_0, x_1, x_2, ..., x_n)'$ is a vector of random variables, $x_0 = 1$ (deterministic) and for $j = 1...n$ $E(x_j) = 0$, $Var(x_j) = \sigma_j^2$ and $Cov(x_j, x_l) = 0, \forall j \neq l$. We are looking for a linear estimator of one of the unobserved random variables, x_k, using the observation of i^*. We therefore have to calculate the two coefficients β_0, β_1 in the equation $\hat{x}_k = \beta_0 + \beta_1 i^*$, in order to minimze the squared error of the estimation:

$$min_{\beta_0,\beta_1} E(\hat{x}_k - x_k)^2$$

The squared error is:

$$E(\hat{x}_k - x_k)^2 = E(\beta_0 + \beta_1 i^* - x_k)^2 = E(\beta_0 + \beta_1 \alpha' X - x_k)^2$$

$$= E(\beta_0^2 + 2\beta_0\beta_1\alpha' X - 2\beta_0 x_k + \beta_1^2(\alpha' X)^2 - 2(\beta_1)\alpha' X x_k + x_k^2)$$

$$= \beta_0^2 + 2\beta_0\beta_1\alpha_0 + \beta_1^2 \left(\alpha_0^2 + \sum_{j=1}^{n} \alpha_j^2 \sigma_j^2 \right) - 2\beta_1 \alpha_i \sigma_i^2 + \sigma_i^2$$

Setting the first derivative with respect to β_0 equal to zero and solving for β_0 yields:

$$\beta_0 = -\alpha_0 \beta_1$$

Setting the first derivative of the squared error with respect to β_1 equal to zero and solving for β_1:

$$\beta_1 = \frac{\alpha_i \sigma_i^2 - \beta_0 \alpha_0}{\alpha_0^2 + \left(\sum_{j=1}^{n} \alpha_j^2 \sigma_j^2 \right)}$$

Substituting both expressions and solving again for the coefficients yields:

$$(\beta_0, \beta_1) = \left(-\alpha_0 \frac{\alpha_i \sigma_i^2}{\sum_{j=1}^{n} \alpha_j^2 \sigma_j^2}, \frac{\alpha_i \sigma_i^2}{\sum_{j=1}^{n} \alpha_j^2 \sigma_j^2} \right) \tag{33}$$

By substituting those values of β_0, β_1, we obtain the expected squared error in estimating the unobserved variable x_k:

$$E((\hat{x}_k - x_k)^2) = \sigma_i^2 - \frac{(\alpha_i \sigma_i^2)^2}{\sum_{j=1}^{n} \alpha_i^2 \sigma_j^2} \tag{34}$$

Appendix 1.2 The case of m observations and n unobserved shocks

The linear relationship between the m observations $(i_1^*, i_2^*, ..., i_m^*)$ and the n unobserved components $(x_1, x_2, ..., x_n)$ is:

$$\begin{pmatrix} i_1^* \\ i_2^* \\ ... \\ i_m^* \end{pmatrix} = \begin{pmatrix} \alpha_{1,0} + \alpha_{1,1}x_1 + \alpha_{1,2}x_2 + ... + \alpha_{1,n}x_n \\ \alpha_{2,0} + \alpha_{2,1}x_1 + \alpha_{2,2}x_2 + ... + \alpha_{2,n}x_n \\ ... \\ \alpha_{m,0} + \alpha_{m,1}x_1 + \alpha_{m,2}x_2 + ... + \alpha_{m,n}x_n \end{pmatrix} \quad (35)$$

Written in matrix notation: $i^* = \alpha_0 + Ax$ with $i^* \in R^m, \alpha_0 \in R^m, A \in R^{m.n}, x \in R^n$. The problem can be simplified by defining: $z = i^* - \alpha_0$ and thus: $z = Ax$. We are looking for a vector $\beta \in R^m$ satisfying: $\beta = argmin(E(\hat{x}_k - x_k)^2)$ with $\hat{x}_k = \beta' z$. By substitution we obtain:

$$E(\hat{x}_k - x_k)^2 = E(\beta' Ax - x_k)^2 = E((\beta' Ax)^2 - 2\beta' Axx_k + x_k^2)$$

$$= E((\beta' Ax)(\beta' Ax)' - 2\beta' Axx_k + x_k^2) = E(\beta' Ax(Ax)'\beta - 2\beta' Axx_k + x_k^2)$$

Following Lütkepohl [1991, S. 470] (proposition 2), the derivative of the first term with respect to β is:

$$\frac{\partial \beta' Ax(Ax)'\beta}{\partial \beta} = (Ax(Ax)' + (Ax(Ax)')')\beta = 2Axx'A\beta$$

The derivative of the second term is, again following Lütkepohl [1991, S. 470] (proposition 1):

$$\frac{\partial 2\beta' Axx_k}{\partial \beta} = 2(Axx_k)$$

The derivative of the third term is zero. If the complete derivative is set equal to zero, we obtain after rearranging:

$$2AE(xx')A'\beta = 2AE(xx_k)$$

If this equation is multiplied from the left side by $(2AE(xx')A')^{-1}$, we obtain the vector β which minimizes the expected squared error:

$$\beta = (AE(xx')A')^{-1}AE(xx_k) \quad (36)$$

By substituting this best estimator in the squared error function, we obtain the minimum squared error:

$$E(\hat{x}_k - x_k)^2 = E(\beta' Ax - x_k)^2 = E(\beta' Axx'A'\beta - 2\beta' Axx_k + x_k^2) \quad (37)$$

$$= ((AE(xx')A')^{-1}AE(xx_k))'AE(xx')A'((AE(xx')A')^{-1}AE(xx_k))$$

$$-2(AE(xx')A')^{-1}AE(xx_k))'Axx_k + \sigma_x^2$$

Appendix 2: The information content of the money market rate with restriction to averaging

Appendix 2.1: The information content of the money market rate with a limitation to the reserve balance in variant (a) of the money market model

If the maximum reserve balance allowed is S_{max}, a certain observed interest rate can be the result of three different mappings of unobserved random shocks, depending on the difference between the two transitory shocks:

1. If $|y_1 - y_2| < 2S_{max}$, then the mapping is:
$$i_1^* = \frac{1}{d+b}(a - \bar{M} + x + \frac{y_1 + y_2}{2})$$
We shall define j_1 as the random variable corresponding to *this* random variable i_1^*.

2. If $(y_1 - y_2) \geq 2S_{max}$, then $a_1 = a - S_{max}$ and thus:
$$i_1^* = \frac{1}{d+b}(a - S_{max} - \bar{M} + x + y_1)$$
We shall define j_2 as the random variable corresponding to *this* random variable i_1^*.

3. If $(y_1 - y_2) \leq -2S_{max}$, then $a_1 = a + S_{max}$ and thus:
$$i_1^* = \frac{1}{d+b}(a + S_{max} - \bar{M} + x + y_1)$$
We shall define j_3 as the random variable corresponding to *this* random variable i_1^*.

The information content of the money market rate after the first auction can be calculated as follows as a function of S_{max}. To calculate the density function $f(i_1^*)$, one can sum up the three density function $f(j_1)$, $f(j_2)$, $f(j_3)$ while assuring by the choice of the limits of the integrals in the calculation of the marginal densities that the $(y_1 - y_2)$ are in the relevant range:[25]

$$f(i_1^*) = \int_{-\infty}^{+\infty} \int_{y_1-2S_{max}}^{y_1+2S_{max}} f_{(j_1,y_1,y_2)}(i_1^*, y_1, y_2) dy_2 dy_1$$
$$+ \int_{-\infty}^{+\infty} \int_{-\infty}^{y_1-2S_{max}} f_{(j_2,y_1,y_2)}(i_1^*, y_1, y_2) dy_2 dy_1$$

[25]A remark concerning the notation "$f_u(v)$" of the density functions: The variable in the index is the one determining the density function. The variable in the bracket is the one which is mapped into a probability. If both are identical, the variable in the index can be omited.

$$+\int_{-\infty}^{+\infty}\int_{y_1+2S_{max}}^{+\infty} f_{(j_3,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1 \tag{38}$$

The value of the realization of x is never relevant for the probability of being in one of the three cases. Thus, the impact of the transitory shocks on the interest rate can be analyzed in a first step independently of x. If x is set to be constant, then i_1^* (respectively j_1, j_2, j_3) is only a function of the two transitory shocks y_1, y_2. In the following, let $x = 0$. Then the relationship between j_1, y_1, y_2 is: $j_1 = (a - \bar{M} + (y_1 + y_2)/2)/(d + b)$. Whenever this equation is fulfilled, then $f_{(j_1,y_1,y_2)} = f_{(j_1,y_2)}$, else $f_{(j_1,y_1,y_2)} = 0$. Let us define $q(j, y_1, y_2)$ as a function equal to one if the equation is fulfilled and equal to zero if it is not. The first term of $f(i_1^*)$ then can be written as follows:

$$\int_{-\infty}^{+\infty}\int_{y_1-2S_{max}}^{y_1+2S_{max}} f_{(j_1,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1 = \int_{-\infty}^{+\infty} f_{(j_1,y_1)}(i_1^*,y_1)\int_{y_1-2S_{max}}^{y_1+2S_{max}} q(i_1^*,y_1,y_2)dy_2dy_1$$

The inner integral in this expression can only have either the value one or the value zero. It is one if $2((d+b)j_1 - a + \bar{M} - y_1/2) \in [y_1 - 2S_{max}, y_1 + 2S_{max}]$. But then, we can omit this integral if we make sure that we integrate only over the values of y_1 for which this condition is fulfilled. Thus:

$$y_1 - 2S_{max} < 2((d+b)j_1 - a + \bar{M} - y_1/2) < y_1 + 2S_{max}$$

$$\Leftrightarrow S_{max} + (d+b)j_1 - a + \bar{M} \geq y_1 \geq -S + (d+b)j_1 - a + \bar{M}$$

We shall designate the lower bound as Q_1 and the upper bound as Q_2. Then, the first term of $f(i_1^*)$ can be written as follows:

$$\int_{Q_1}^{Q_2} f_{(j_1,y_1)}(i_1^*,y_1)dy_1$$

Concerning the second term of $f(i_1^*)$: y_2 does not appear in the equation defining j_2. Thus, y_2 is statistically independent of the other random variables and the term can also be written as follows:

$$\int_{-\infty}^{+\infty} f_{(j_2,y_1)}(i_1^*,x,y_1)\int_{-\infty}^{y_1-2S_{max}} f_y(y_2)dy_2dy_1$$

But the density $f_{(j_2,y_1)}$ contains a linear interdependence, namely: $j_1 = (a - S_{max} - \bar{M} + y_1)/(d+b)$. Thus, the second term of $f(i_1^*)$ can be transformed similarly to the first one:

$$= \int_{-\infty}^{+\infty} q(i_1^*,y_1)f_{(j_2)}(i_1^*)\int_{-\infty}^{y_1-2S_{max}} f_y(y_2)dy_2dy_1$$

The restriction on one unique value of $y_1 \in [-\infty, +\infty]$ can be expressed by omitting the exterior integral and by substituting y_1 in the limits of the inner integral by the linear relationship in i_1^*. Let $R_1 = (d+b)i_1^* - a + S_{max} + \bar{M} - 2S_{max} = (d+b)i_1^* - a - S_{max} + \bar{M}$. Then the second term of $f_{(i_1^*)}$ finally becomes:

$$f_{(j_2)}(i_1^*)\int_{-\infty}^{R_1} f_y(y_2)dy_2$$

After similar transformations, one can express the third term of $f_{(i_1^*)}$ as:

$$f_{(j_3)}(i_1^*)\int_{R_2}^{+\infty} f_y(y_2)dy_2,$$

with $R_2 = (d+b)i_1^* - a - S_{max} + \bar{M} + 2S_{max} = (d+b)i_1^* - a + S_{max} + \bar{M}$. Finally, the density $f_{(i_1^*,x=0)}$ can be summarized as follows:

$$f(i_1^*) = \int_{Q_1}^{Q_2} f_{(j_1,y_1)}(i_1^*, y_1)dy_1 + f_{(j_2)}(i_1^*)\int_{-\infty}^{R_1} f_y(y_2)dy_2 + f_{(j_3)}(i_1^*)\int_{R_2}^{+\infty} f_y(y_2)dy_2 \quad (39)$$

In the two following figures, the specific example $a = 10; \bar{M} = 5; \sigma_x^2 = 1; \sigma_y^2 = 1; d = 0.5; b = 0.5$ with normally distributed shocks is illustrated. In the figure on the left, density functions of the interest rate are plotted for various values of S_{max} under the assumption that $x = 0$. The values S_{max} considered are 0 (corresponding to the case without any averaging); 0.2; 0.5; 1; 3; 20 (corresponds practically to the case of unlimited averaging). The variance of the interest rate caused by the transitory shocks can be chosen precisely in the range given by the two extreme arrangements of none and unlimited averaging. The variance of i_1^* under the assumption of a constant x is drawn as a function of S_{max} in the figure on the right side:

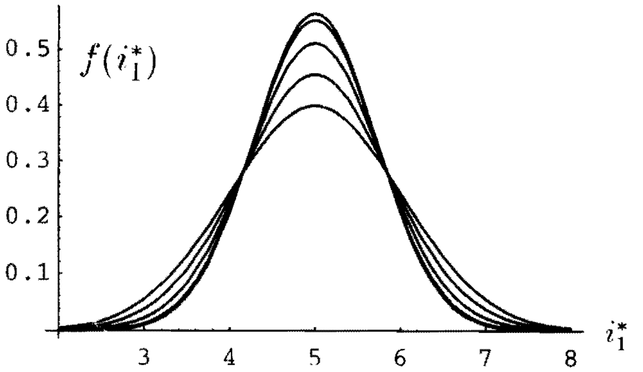


Figure 8

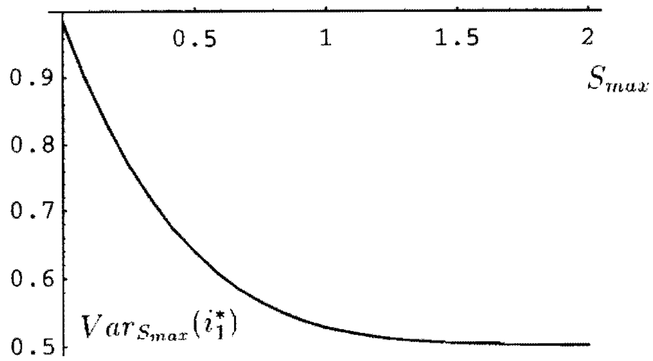


Figure 9

Now, x can be reintroduced into the analysis. The observed interest rate is a linear function in the random variable x and in a random variable which is composed from y_1 and y_2, depending on S_{max}. We shall designate the random variable composed from the two transitory shocks as z. Then, the expected squared error in estimating x when one observes i_1^* is:

$$E((\hat{x}-x)^2) = \sigma_x^2 - \frac{\sigma_x^4}{\sigma_x^2 + \sigma_z^2}$$

In the specific example (with $\sigma_x^2 = 1$), we obtain:

$$E((\hat{x} - x)^2) = 1 - \frac{1}{1 + \sigma_z^2} = \frac{\sigma_z^2}{1 + \sigma_z^2}$$

Appendix 2.2: The information content of the money market rate with an averaging fee in variant (a) of the money market model

Similarly to the case of a limitation to the reserve balance, in the case of an averaging fee λ, three situations have to be distinguished:

1. If without any intertemporal arbitrage of the banks, the condition $|E(i_2) - E(i_1)| \leq \lambda \Leftrightarrow -\lambda(d + b) \leq y_1 - y_2 \leq \lambda(d + b)$ is fulfilled, then no arbitrage activity takes place and the interest rate equation in the first auction is:

   $$i_1^* = \frac{1}{d + b}(a - \bar{M} + x + y_1)$$

   We shall define j_1 as the random variable corresponding to *this* random variable i_1^*.

2. If without any intertemporal arbitrage activity $E(i_2) - E(i_1) > \lambda \Leftrightarrow y_1 - y_2 > \lambda(d + b)$, then the banks will build up a refinancing balance $S_1 > 0$ such that: $E(i_2) - E(i_1) = \lambda$. Then the interest rate equation in the first auction becomes:

   $$i_1^* = \frac{1}{d + b}\left(a - \bar{M} + x + \frac{y_1 + y_2}{2}\right) + \frac{\lambda}{2}$$

   We shall define j_2 as the random variable corresponding to *this* random variable i_1^*.

3. If without any intertemporal arbitrage activity $-(E(i_2) - E(i_1)) > \lambda \Leftrightarrow y_1 - y_2 < -\lambda(d + b)$, then the banks will build up a refinancing balance $S_1 < 0$ in the first period, such that: $-(E(i_2) - E(i_1)) = \lambda$. In this case the interest rate equation in the first auction becomes:

   $$i_1^* = \frac{1}{d + b}\left(a - \bar{M} + x + \frac{y_1 + y_2}{2}\right) - \frac{\lambda}{2}$$

   We shall define j_3 as the random variable corresponding to *this* random variable i_1^*.

To calculate the density function $f(i_1^*)$, we must once again summarize three different density functions while assuring by properly chosen limits of the integrals that $(y_1 - y_2)$ is always in the relevant range:

$$f(i_1^*) = \int_{-\infty}^{+\infty} \int_{y_1 - \lambda(d+b)}^{y_1 + \lambda(d+b)} f_{(j_1, y_1, y_2)}(i_1^*, y_1, y_2) dy_2 dy_1$$

$$+\int_{-\infty}^{+\infty}\int_{-\infty}^{y_1-\lambda(d+b)} f_{(j_2,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1$$
$$+\int_{-\infty}^{+\infty}\int_{y_1+\lambda(d+b)}^{+\infty} f_{(j_3,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1 \tag{40}$$

If x is a constant, then i_1^* becomes a linear function only in the two random variables y_1 and y_2. The realization of the *permanent* shock is again irrelevant for the probabilities of the three different cases, so that again, the stochastic influence of x can be neglected in a first step. Again, set $x = 0$. Then the linear relationship between the variables j_1, y_1, y_2 is: $j_1 = (a - \bar{M} + y_1)/(d + b)$. The random variable y_2 does not appear in the equation determining j_1. Thus y_2 is statistically independent of the other random variables and the first term can also be written:

$$\int_{-\infty}^{+\infty}\int_{y_1-\lambda(d+b)}^{y_1+\lambda(d+b)} f_{(j_1,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1 = \int_{-\infty}^{+\infty} f_{(j_1,y_1)}\int_{y_1-\lambda(d+b)}^{y_1+\lambda(d+b)} f_{(y_2)}(y_2)dy_2dy_1$$

The density $f_{(j_1,y_1)}$ now still contains the linear relationship mentioned above. Let $q(j_1, y_1)$ be a function which takes the value 1 if the relationship is fulfilled and zero if it is not. Then the first term may be written as follows:

$$\int_{-\infty}^{+\infty} f_{j_1,y_1}(i_1^*,y_1)\int_{y_1-\lambda(d+b)}^{y_1+\lambda(d+b)} f_{(y_2)}(y_2)dy_2dy_1 = \int_{-\infty}^{+\infty} q(i_1^*,y_1)f_{j_1}(i_1^*)\int_{y_1-\lambda(d+b)}^{y_1+\lambda(d+b)} f_{(y_2)}(y_2)dy_2dy_1$$

But this restriction by q on one unique value of $y_1 \in]-\infty,\infty[$ can also be expressed by omitting the exterior integral and by substituting y_1 in the limits of the inner integral by the linear relationship in i_1^*. Define $R_1 = (d + b)j_1 - a + M - \lambda(d + b)$ and $R_2 = (d + b)j_1 - a + M + \lambda(d + b)$. Then the first term of $f(i_1^*)$ can finally be written:

$$f_{(j_1)}(i_1^*)\int_{R_1}^{R_2} f_{(y_2)}(y_2)dy_2$$

In the second term, the linear relationship between j_2 and y_1, y_2 is (for $x = 0$):

$$i_1^* = \frac{1}{d+b}\left(a - \bar{M} + \frac{y_1+y_2}{2}\right) + \frac{\lambda}{2}$$

Whenever this equation is fulfilled, $f_{(j_2,y_1,y_2)} = f_{(j_1,y_1)}$, otherwise $f_{(j_1,y_1,y_2)} = 0$. We shall define $q(i_1^*, y_1, y_2)$ as a function which takes the value one if the linear relationship holds and otherwise takes the value zero. Then the second term of $f(i_1^*)$ can be written as follows:

$$\int_{-\infty}^{+\infty}\int_{-\infty}^{y_1-\lambda(d+b)} f_{(j_2,y_1,y_2)}(i_1^*,y_1,y_2)dy_2dy_1 = \int_{-\infty}^{+\infty} f_{(j_2,y_1)}(i_1^*,y_1)\int_{-\infty}^{y_1-\lambda(d+b)} q(i_1^*,y_1,y_2)dy_2dy_1$$

But the inner integral of this expression can only take the value one or the value zero. It takes the value one if and only if $2((d + b)j_2 - a + \bar{M} - x - y_1/2 - (d + b)\lambda/2) \in$

$]-\infty, y_1 - \lambda(d+b)]$. We can thus omit this integral if it is assured that the exterior integral only integrates over values of y_1 for which the following relationship holds:

$$2((d+b)i_1^* - a + \bar{M} - y_1/2 - (d+b)\lambda/2) < y_1 - \lambda(d+b) \Leftrightarrow y_1 > (d+b)i_1^* - a + \bar{M}$$

We shall define this bound as V_1. Then the second term can finally be written as:

$$\int_{V_1}^{+\infty} f_{(j_2,y_1)}(i_1^*, y_1)dy_1$$

The third term of $f_{i_1^*}$ can be treated similarly to obtain:

$$\int_{-\infty}^{V_1} f_{(j_3,y_1)}(i_1^*, y_1)dy_1$$

Summing up, the density function $f_{(i_1^*, x=0)}$ can thus be written:

$$f(i_1^*) = f_{(j_1)}(i_1^*) \int_{R_1}^{R_2} f_y(y_2)dy_2dy_1 + \int_{V_1}^{+\infty} f_{(j_2,y_1)}(i_1^*, y_1)dy_1 + \int_{-\infty}^{V_1} f_{(j_3,y_1)}(i_1^*, y_1)dy_1 \quad (41)$$

In the following figure on the left side, the density functions of i_1^* are plotted in the specific example $a = 10; \bar{M} = 5; \sigma_x^2 = 1; \sigma_y^2 = 1; d = 0,5; b = 0,5$ (for $x = 0$) and normally distributed random variables for various values of the arbitrage fee λ. The values of λ used are 0 (corresponding to the case of unrestricted averaging); 0.25; 0.5; 0.75; 1; 2; 8 (corresponding practically to the case of no averaging). As in the case of a limitation of the reserve balance, the variance of i_1^* generated by the transitory shocks can be precisely chosen in the range given by the two extreme arrangements of no averaging at all and unrestricted averaging. The figure on the right side plots the variance of i_1^* with a constant x as a function of λ.

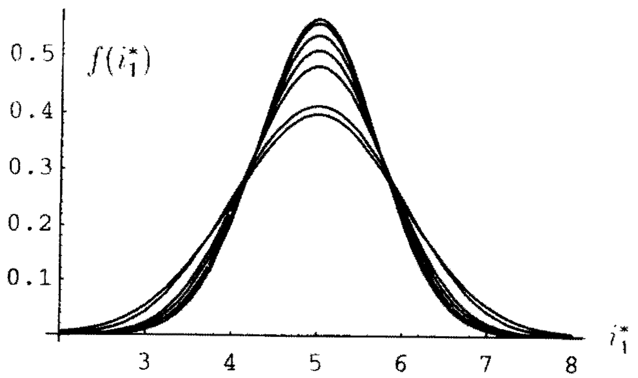


Figure 10

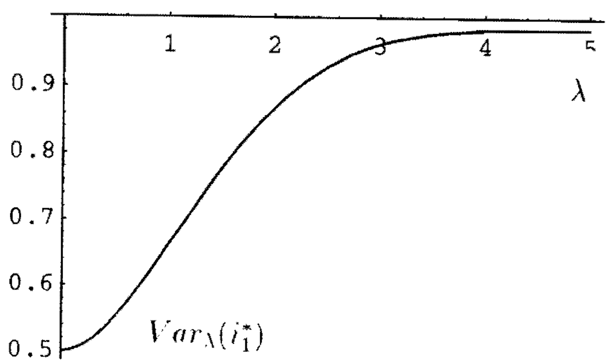


Figure 11

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