Monetary Transmission in the New Economy: Service Life of Capital, Transmission Channels and the Speed of Adjustment

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Abstract

This paper evaluates the consequences of accelerated technical progress for monetary transmission and the speed of adjustment in the real economy. With a decreasing service life, the long term rate relevant to real demand will resemble more closely the money market rate. We make the investment decision explicitly dependent on a long-term rate for a credit contract of finite maturity. This, along with perfect foresight, leads to a differential-difference equation for the dynamics of transmission, which is new to the economics literature. Our analysis shows that a reduced service life of capital leads to an *increased speed of adjustment of the real sector,* which goes along with a *reduced volatility of the exchange rate*. Wherereas the interest channel becomes stronger, the exchange-rate channel loses importance. The grip of monetary policy becomes more direct: while demand will react more sharply at the beginning, the transmission process will be completed earlier. All in all, our answers as to the feasibility of monetary policy and the stability of the financial system are rather optimistic.

Key Words: Monetary Transmission, Interest-Rate Structure, New Economy

JEL Classification: E 50, E 43, F 41

Zusammenfassung

Diese Arbeit untersucht die Folgen eines beschleunigten technischen Fortschritts für die monetäre Transmission und die Anpassung auf den Gütermärkten. Mit abnehmender Kapitalnutzungsdauer wird der für die aggregierte Nachfrage relevante langfristige Zins dem Geldmarktzins ähnlicher. Wir betrachten die Investitionsentscheidung in Abhängigkeit von einem langfristigen Zinssatz bezüglich eines Kreditvertrags mit beschränkter Laufzeit. Dies, gemeinsam mit perfekter Voraussicht, führt zu einer neuartigen Differenzen-Differentialgleichung für den Transmissionsprozess. Unsere Untersuchung zeigt, daß eine abnehmende Kapitalnutzungsdauer zu einer *erhöhten Anpassungsgeschwindigkeit auf den Gütermärkten* führt, was eine *verminderte Volatilität auf den Devisenmärkten* bedingt. Während der Zinskanal stärker wird, verliert der Wechselkurskanal an Gewicht. Die geldpolitische Wirkung wird direkter: Zu Beginn reagiert die Nachfrage stärker, und der Transmissionspozeß ist früher abgeschlossen. Insgesamt sind unsere Ergebnisse bezüglich geldpolitischer Kontrolle und Stabilität der Finanzmärkte recht optimistisch.

JEL-Klassifikation: E 50, E 43, F 41

Schlüsselwörter: Monetäre Transmission, Zinsstruktur, New Economy

Table of Contents

1.	Introduction and Summary	1
2.	Expectation Theory and the Mean Value Effect	7
3.	The Macroeconomic Platform	9
4.	The Characteristic Equation for the Speed of Adaptation	11
5.	Service Life, Speed of Adustment and Exchange-Rate Overshooting	12
6.	Inflation Dynamics and Conclusion	14
References		16

List of Charts and Figures

Chart 1:	Average depreciation rates of total capital stock in the United States and Germany	2
Chart 2:	Average depreciation rates of equipment and software in the United States and Germany	2
Chart 3:	Estimated average service life of new equipment in Germany	3
Fig. 1:	The mean value effect - long term interest rate and short term interest rate	4
Fig. 2:	Graphical determination of the exponent λ	12
Fig. 3:	Negative sign of $\partial G/\partial\Omega$	14

Monetary Transmission in the New Economy: Service Life of Capital, Transmission Channels and the Speed of Adjustment*

1. Introduction and Summary

During the past decade, the structure underlying monetary transmission in Europe and the world has changed considerably. Globalisation has made the international repercussions of monetary policy more important. EMU has transformed a system of national markets interlinked by exchange-rate bands into a single monetary area with a unique and flexible exchange rate with respect to the outside world. And a series of technological breakthroughs, especially in the IT, telecommunication and biotech industries, has left many people wondering how much confidence they can place in the received ideas about the workings of monetary policy.

In this paper, we mainly want to address some aspects of the last issue, adopting a distinctly European perspective with respect to the others. We will investigate monetary policy under the conditions of accelerating technological progress, from the point of view of an open economy that features a flexible exchange-rate system, well-developed financial markets, sluggish commodity markets and an important exchange-rate channel. We will evaluate the implications of higher depreciation rates for the speed of adjustment, for financial stability, and for the relative strength of two important channels of monetary transmission, the interest-rate channel and the exchange-rate channel.[1]

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[1] Currently, the workings of monetary transmission in the newly emerged European Monetary Union is the object of intensive investigation. According to research done in the Monetary Transmission Network of the Eurosystem (MTN), the interest-rate channel figures rather prominently in the transmission mechanism, whereas the role of the credit channel is not as strong as expected. For an overview of the project, see Angeloni et al (2002). Macroeconomic simulation exercises also seem to indicate a strong role for the exchange rate channel, see McAdam and Morgan (2001) and van Els et al (2001). A thorough empirical investigation of the effects of monetary policy on investment demand using firm-level data is presented by Chatelain et al (2001) for the major countries in the Euro area, and by von Kalckreuth (2001) for Germany alone.

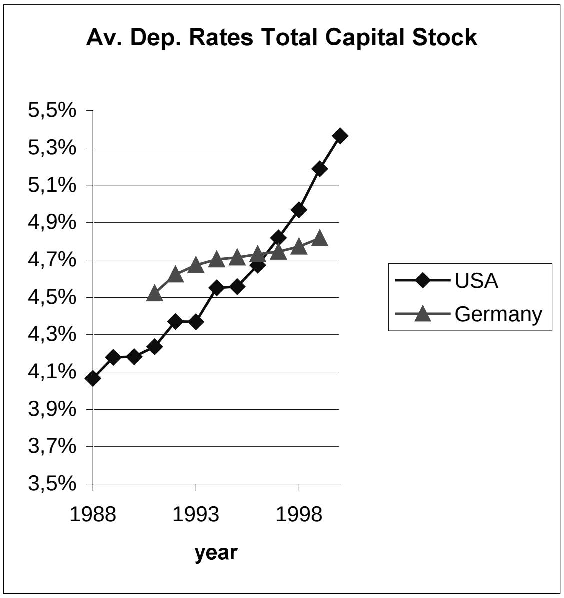

Chart 1: Average depreciation rates of total capital stock in the United States and Germany. Source: BEA, Statistisches Bundesamt, own calculations

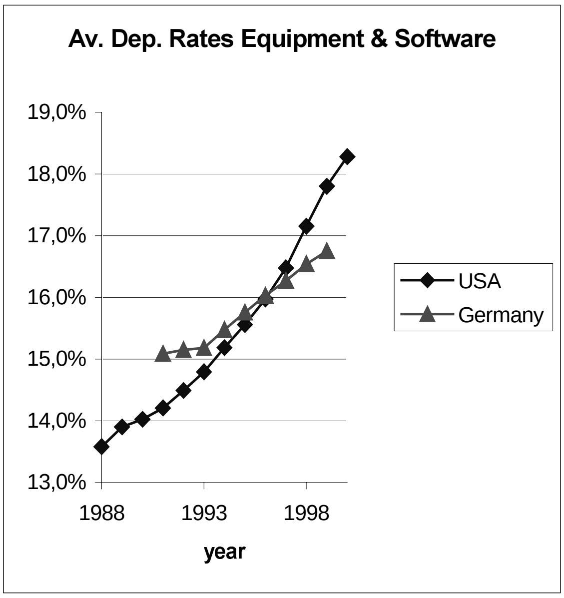

Chart 2: Average depreciation rates of equipment and software in the United States and Germany. Source: BEA, Statistisches Bundesamt, own calculations

The service life of capital in industrialised countries is shrinking. According to a statistical survey by Stephen Oliner (1989), between 1948 and 1987 the average service life of capital in the United States fell from about 30 years to under 25 years. This refers to the gross stock of private non-residental fixed capital. The change in the service life at the actual "frontier" (new capital goods) must have been even more marked. Oliner offers two explanations: an increasing share of the shorter-lived equipment in the stock and a falling average service life within the aggregate of equipment, both owing to the great expansion in the use of computer technology and other high-tech equipment. For these new types of capital goods, the rate of technologically-induced depreciation is exceptionally high.

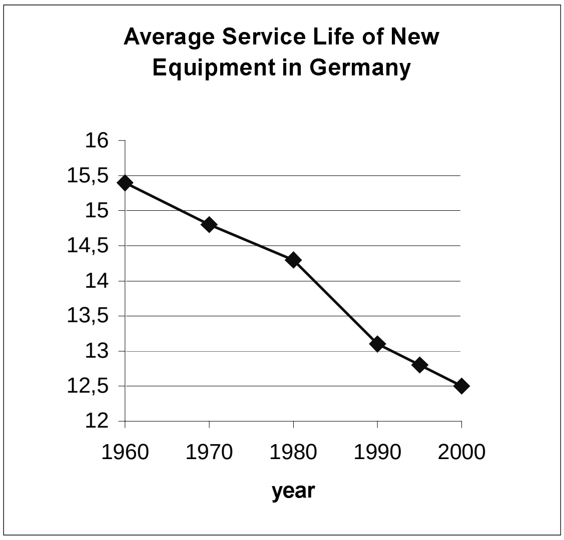

Chart 3: Estimated average service life of new equipment in Germany.
Source: Statistisches Bundesamt

It is informative to track the average depreciation rates for the last decade by dividing real depreciation from income account data by real capital stocks. Chart 1 plots the average depreciation rates for the entire capital stock in the US and in Germany, being a large European country. Overall depreciation rates in the US rose from 4.1% in 1988 to 5.4% in 2000. In Germany, the increase at this aggregation level is barely visible.[2] We get a clearer picture, however, by looking specifically at depreciation rates for equipment goods and immaterial assets in Chart 2. Here, the increase of the US rate was even more marked, from 13.6% in 1988 to 18.3%. But also in Germany, the depreciation rates have accelerated: Within the shorter time span between 1991 to 1999, they rose from 15.1% to 16.6%. It is important to note that for *new* investment goods, the change will necessarily have been more intense in both countries. Chart 3 plots the average service life of capital for new equipment goods in Germany during the last four decades: in a rather continuous way, average service life fell from 15.5 years to 12.5 years.

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[2] Unfortunately, it is hard to obtain comparable data for the whole Euro area, as the national statistical systems are not harmonized. The European Commission made an attempt at calculating depreciation rates for the total capital stock by aggregating unharmonized data from the national statistical offices. The resulting time series looks very similar to the graph for Germany in our Chart 1: Depreciation rates for the total capital stock have slightly increased, but much less dynamically so than in the US. See European Commission (2001), p. 96.

It is evident that this decrease in average service life affects the time to maturity of the interest rate relevant to real demand. Consider a project characterised by one single expenditure at the beginning, and one single, certain return at the end of its lifetime Ω. This project would be a perfect substitute for the purchase of a zero bond with a time to maturity equal to Ω. The opportunity costs[3] of this project at time t are given by the continuous internal rate R_Ω of such a bond. Thus, the time to maturity of the capital-market interest rate entering in the costs of capital will rise or fall in line with the service life of capital. How will this affect the ability of monetary policy to influence investment decisions and real demand? And will a shorter service life make the economy unstable?

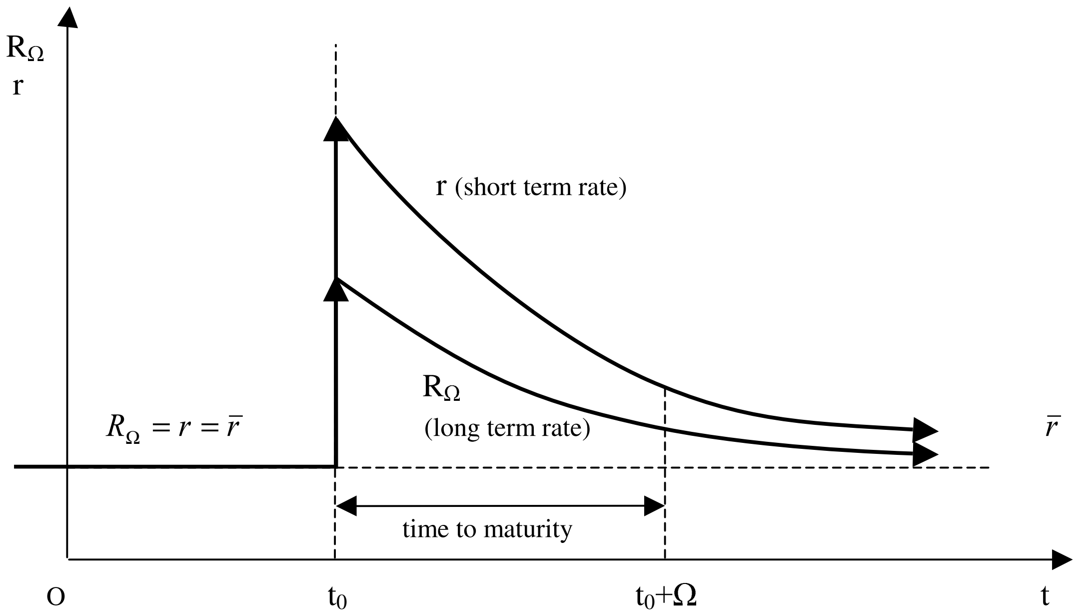

Fig. 1: The mean value effect - long term interest rate and short term interest rate

In order to get an intuition for our answer, consider Fig. 1. It shows a time path of the short term real interest rate r, which returns to its long run equilibrium, $\bar{r}$, after a contractionary monetary shock in t_0. According to the expectations hypothesis of the interest rate structure[4], the long term interest rate of a zero-bond with a time to maturity Ω will always be equal to the mean value of the (instantaneous) short term rates within the horizon given by its time to maturity. This is true for both nominal and real rates. Thus, with a short term real

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[3] If the pattern of payments is modelled in a more realistic way, the cost of capital will also include (expected) interest rates of shorter terms, see Hartman (1980).

[4] The expectations hypothesis was pioneered by Irving Fisher as early as 1930. See the classic exposition by Meiselman (1962) for a comprehensive summary.

interest rate converging to its equilibrium, the movement of the long term real rate R_{Ω} will be dampened as the future return to equilibrium of the short term real rate is anticipated in the contemporaneous long run real rate. We call this the "mean value effect" of the term structure.

Let us consider now the rate $R_{\Omega*}$, characterized by the shorter time to maturity $\Omega* < \Omega$ of the underlying bond. As the average for this bond is calculated over a shorter time horizon, the mean value effect is weaker. The anticipated future return of the short term rate is less important for the long term rate $R_{\Omega*}$ – therefore, in effect, the long term real rate $R_{\Omega*}$ is *closer to the short term real rate* than R_{Ω}.

The effect of a general shortening of the service life of capital on the interest rate channel can be regarded as making final demand depend on a rate with the shorter maturity $\Omega*$ instead of Ω. As $R_{\Omega*}$ is more responsive to movements in the money market rate than its counterpart with the longer time to maturity, this gives more immediate power to the impulse of a monetary shock of a given size. Hence, the adaptation process toward the new equilibrium will be speedier.

As it stands, however, our argument only considers the partial equilibrium on the domestic bond market. In a macroeconomic context, the shape of the time path for the real interest rate after a disturbance is endogenous, and it depends on all the other parameters. Therefore, we have to repeat our thought-experiment within the framework of a fully worked-out macro model. Aggregate demand must be made dependent on the real long-term rate of a given maturity which is linked to the short term rate by an interest rate structure relationship. In this way, the service life of capital can be introduced as a technological parameter that is allowed to vary.

For this task, the well-known exchange-rate-overshooting model by Dornbusch (1976), Wilson (1979) and Gray and Turnovsky (1979) turns out to be the ideal vehicle. Before us, Turnovsky (1986) investigated an overshooting model augmented by an interest-rate structure. Along the lines of Blanchard (1981), investment in his model depends on the real interest rate of an eternal bond. Although this paper contributes a lot towards understanding the problem, using an eternal bond makes it conceptually impossible to investigate the consequences of a changing maturity relevant to investment decisions. We will therefore use an interest-rate structure with finite time to maturity and perfect foresight.

In a partial equilibrium framework, Ehrmann and Ellison (2001) assume that the new technologies imply lower costs of adaptation. They show that this might induce firms to react later to a monetary impulse, because firms can afford to "wait and see". This argument implicitly takes the magnitude of the underlying demand impulse as given. We show, however, that a shortening of service life can increase the size of the macroeconomic demand impulse.

The rest of this paper is organized in the following way: In Sect. 2, the interest rate structure relationship is developed and discussed. In Sect. 3, the complete model is presented. The dynamics can be reduced to a differential-difference equation with advancing argument. Sect. 4 deals with the transcendental characteristic equation and its graphical solution. In Sect. 5, a formal relationship between the service life of capital, the speed of adjustment and the exchange-rate overshooting is derived. Sect. 6 is concerned with the economic interpretation of the results. These can be summarised as follows:

a) *As a reaction to monetary shocks, the deviation of real long-term rates from equilibrium becomes more marked when the time to maturity decreases.* With perfect foresight, capital-market arbitrage ensures that, at any point in time, the yield of every long-term investment is equalised to the yield of a series of short-term investments with regard to the same time horizon (expectation hypothesis). With stable adjustment, the real long-term rate will always stay closer to its steady-state level than its short-term counterpart. This is the mean value effect, and it becomes weaker with decreasing time to maturity.

b) *The interest-rate channel becomes more powerful with any decline in the time to maturity relevant to investment. The speed of adjustment of the dynamic system will increase. In that sense, the dynamic equilibrium of the economy becomes more stable.* Short term interest rate movements have a higher effect on demand if the time to maturity is shorter and the interest rates on the money market and on the capital market become more closely interlinked. As the reaction of real demand will be stronger, the speed of adjustment increases.

c) *A shorter service life of capital within the economy leads to a smaller exchange rate overshooting owing to monetary shocks.* This result is based on the inverse relationship between the speed of adjustment and the amount of overshooting in Dornbusch-type models. If the adjustment process accelerates, the amount of overshooting necessary to maintain a permanent equilibrium on the international asset market will be reduced.

d) *With decreasing service life of capital, the burden of adjustment shifts from the sectors sensitive to exchange-rate movements to the interest-sensitive sectors. Whereas the volatility of the costs of capital increases, the stability of a flexible exchange-rate system is enhanced.* A shorter time horizon of the *national investors* implies greater fluctuations in their basis for decision-making, i.e. the relevant long-term real interest rate. Somewhat surprisingly, however, the sectors depending on *international* market conditions, that is, the real exchange rate, will at the same time benefit from a lower degree of volatility. Thus, an accelerated speed of technical progress will *not* destabilise international financial markets. In fact, the exchange-rate channel loses importance relative to the interest-rate channel.

2. Expectation Theory and the Mean Value Effect

As it is central to our argument, we want to start by developing the interest rate structure relationship used in our model from first principles, as an arbitrage equation for bonds of finite maturity.[5] Complete foresight in a perfect asset market implies the equality of the instantaneous real rates of return on bonds and investments in the money market. Consider a zero bond of arbitrary time to maturity Ω, issued at time t. Let N be the issue price and $R_{\Omega,t}$ the real long-term rate for bonds with time to maturity Ω. At time $t+\Omega$, the holder of the bond receives a payment of $N\exp(\Omega R_{\Omega,t})$. Since there are no interest payments until maturity, according to the Hotelling rule, the arbitrage condition is given by:

$$\frac{\dot{K}_s}{K_s} = r_s \ , \tag{1}$$

with K_s as the real market value of a bond at any point in time s between t and $t+\Omega$. Taking into consideration the terminal condition that, at maturity, the real market value K_s is bound to be equal to the real value of principal and accrued interest, the general solution of (1) becomes:

$$K_s = N\exp\left(\Omega R_{\Omega,t} - \int_s^{t+\Omega} r_\tau \ d\tau\right). \tag{2}$$

At the date of issue, the value of this expression must be equal to *N*, which immediately yields the arbitrage equation:

$$R_{\Omega,t} = \frac{1}{\Omega}\int_t^{t+\Omega} r_\tau \ d\tau \ . \tag{3}$$

Equation (3) gives us the term structure of interest rates according to the expectation theory for the case of continuous interest compounding. The (continuous) real long-term rate R_Ω is determined as the arithmetic mean of the short-term rates within the relevant time interval.

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5 See, for example, McCulloch (1971). Fisher and Turnovsky (1992) also use this equation in the context of a dynamic macroeconomic model. The reasoning applies in the same way for nominal rates and for real rates. Given our interest in real long term rates, we derive the interest structure directly as a relationship between real rates

The former thus anticipates the movement of the latter. If the adjustment of r is monotonous and stable, this "mean-value effect" will make the long-term rate stay closer to the dynamic equilibrium than the contemporaneous short-term rate. The interest rate R_Ω, by definition, gives us the opportunity costs of an investment project characterised by one single payment in t and one single, certain return of V at the end of its lifetime Ω. Investigating the dynamic system for varying Ω thus permits us to describe the effects of a decreasing service life of capital, as a result of accelerated technical progress, on the dynamics of macroeconomic adjustment to various kinds of shocks.

Using equation (3), we are already in a position to make statements on the effect of a given deviation of the short term real interest rate from its long run equilibrium. Consider a contractionary monetary policy shock that raises the time path of the real interest rate r_r temporarily above its long run value, $\bar{r}$. If we compare two capital market rates, R_Ω and R_{Ω^*} that differ in their respective time to maturity, Ω and Ω^*, with $\Omega^* < \Omega$, it can immediately be gathered from eq. (3) that the reaction of the rate with the longer maturity, Ω, will be weaker whenever agents believe that the average deviation of the real money market rate in the time interval [t+Ω*, t+Ω] will be smaller than in the time interval [t, t+Ω].[6] This very general condition will always be fulfilled if the time path of the real money market rate is believed to be stable. It is a well known fact that yields for bonds with shorter time to maturity are more volatile than those with a longer one – their movements are closer to the money market rate.

Let us first assume that the central bank controls the real money market rate, and define a monetary disturbance as a *given time path* of the deviation of r_t from long run equilibrium. With the sensitivity of real demand to the real interest rate also given, this disturbance will have a larger impact on the commodity markets if the time to maturity relevant to demand is shorter. This first result, however, leaves some interesting questions open. Usually, the central bank is thought of as controling the *nominal* money market rate, whereas the *real* rate will be endogeneous. Second, it is not clear whether the typical time path of a deviation of the money market rate will look the same with the mechanics of transmission altered. Third, there is more to monetary transmission than just the interest rate channel. Therefore, we will embody our interest structure relationship into the well known macroeconomic framework of the Dornbusch overshooting model. The monetary disturbance we consider is a deviation of the growth rate of the monetary aggregates, and subsequently to the shock, we will look at both the real and the nominal money market rate as endogenous.

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[6] The formal condition is given by $\frac{1}{(\Omega - \Omega^*)} \int_{t+\Omega^*}^{t+\Omega} (r_\tau - \bar{r}) d\tau < \frac{1}{\Omega^*} \int_{t}^{t+\Omega^*} (r_\tau - \bar{r}) d\tau$.

3. The Macroeconomic Platform

Our macroeconomic model contains the following equations:

$$\overline{M} - P_t = \alpha_1 \overline{Y} - \alpha_2 i_t \tag{4}$$

$$r_t = i_t - \dot{P}_t \tag{5}$$

$$D_t = \beta_0 + \beta_1 (E_t - P_t) + \beta_2 \overline{Y} - \beta_3 R_{\Omega,\, t} \tag{6}$$

$$\dot{P}_t = \Gamma\left(D_t - \overline{Y}\right) \tag{7}$$

$$i_t = i^* + \dot{E}_t \tag{8}$$

$$\dot{R}_{\Omega,\, t} = \frac{1}{\Omega}\left(r_{t+\Omega} - r_t\right) \quad . \tag{9}$$

A bar denotes a steady-state value. All coefficients in (4)–(9) are strictly positive. Equation (4) is the Cagan-form money-market equation, with *M*, *P*, and *Y* as the logarithms of nominal money supply, price level and constant real income and i as the nominal money-market interest rate. While *P* is restricted to be a globally continuous function of time, all the other endogenous variables are allowed to jump discontinuously in response to an unexpected shock in $t = 0$. Equation (5) defines the real money-market interest rate *r* as the difference between the short-term nominal interest rate *i* and inflation. In (6), the logarithm of aggregate demand, *D,* depends on the logarithms of the real exchange rate $E - P$, the constant real income and the long-term real interest rate R_Ω, with maturity Ω. For simplicity, a uniform service life of capital is assumed. Whereas the dependence on the real exchange rate constitutes the exchange-rate channel in the model, the interest-rate channel is identified by the long-term real interest rate in the demand equation. Eq. (7) is a simple Phillips relationship, in which the rate of inflation, $\dot{P} = dP/dt$, is determined by the ratio of (variable) aggregate demand to (constant) supply. Equation (8) represents the open interest-parity condition, with i^* as the given nominal short-term interest rate in the international money market. Equation (9), finally, relates the change in the real long-term interest rate to the difference between future short-term rates and present short-term rates. It results form taking the time derivative of our interest-rate structure equation (3).

Long-run equilibrium is characterised by the conditions

$$\dot{P}_t = 0 \quad \text{and} \quad \dot{E}_t = 0 \quad . \tag{10}$$

Substituting these conditions into the system (4) – (9) readily yields a particular solution to the system, the steady-state solution.

$$\bar{i} = \bar{r} = \overline{R} = i^* \tag{11}$$

$$\overline{D} = \overline{Y} \tag{12}$$

$$\overline{P} = \overline{M} - \alpha_1 \overline{Y} + \alpha_2 i^* \tag{13}$$

$$\overline{E} = \overline{M} + \frac{1}{\beta_1}\left[(1-\beta_2-\alpha_1\beta_1)\overline{Y} + (\beta_3+\alpha_2\beta_1)i^* - \beta_0\right] . \tag{14}$$

Progressing from (11) to (14), we get the well-known classical long-run impact of an unexpected monetary shock:

$$\frac{d\overline{E}}{d\overline{M}} = \frac{d\overline{P}}{d\overline{M}} = 1 \text{ , and} \tag{15}$$

$$\frac{d\overline{D}}{d\overline{M}} = \frac{d\bar{i}}{d\overline{M}} = \frac{d\bar{r}}{d\overline{M}} = \frac{d\overline{R_\Omega}}{d\overline{M}} = 0 \ . \tag{16}$$

We can restrict our attention to the *deviations* of the endogenous variables from *steady-state* equilibrium. These are the general solutions to the homogeneous system of equation corresponding to (4) – (9). In the homogeneous system stated below, the levels of the variables have to be interpreted as deviations from the steady state. In order to facilitate interpretation, we will denote such deviations by using a tilde, e.g. $\tilde{P}_t = P_t - \overline{P}$:

$$\tilde{P}_t = \alpha_2 \tilde{i}_t \tag{4'}$$

$$\tilde{r}_t = \tilde{i}_t - \dot{P}_t \tag{5'}$$

$$\tilde{D}_t = \beta_1 \tilde{E}_t - \beta_1 \tilde{P}_t - \beta_3 \tilde{R}_{\Omega,\,t} \tag{6'}$$

$$\dot{P}_t = \Gamma \tilde{D}_t \tag{7'}$$

$$\tilde{i}_t = \dot{E}_t \tag{8'}$$

$$\dot{R}_{\Omega,\,t} = \frac{1}{\Omega}\left(\tilde{r}_{t+\Omega} - \tilde{r}_t\right) \quad . \tag{9'}$$

Repeated substitution yields the following dynamic equation for the price level:

$$\ddot{P}_t = -\frac{\Gamma\beta_3}{\Omega\alpha_2}\tilde{P}_{t+\Omega} + \frac{\Gamma}{\alpha_2}\left(\beta_1 + \frac{\beta_3}{\Omega}\right)\tilde{P}_t - \frac{\Gamma\beta_3}{\Omega}\dot{P}_{t+\Omega} - \Gamma\left(\beta_1 + \frac{\beta_3}{\Omega}\right)\dot{P}_t \, . \tag{17}$$

Equation (17) is a homogeneous differential-difference equation with an advancing argument. To date, differential-difference equations have not often been found in economic theory; one prominent application is Kalecki's (1935) theory of business cycles.[7] In our case, the advancing argument is a straightforward outcome of the perfect foresight assumption

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[7] For a brief introduction to the theory of mixed differential-difference equations, see Gandolfo (1980), pp. 519. Bellman and Cooke (1963) offer a comprehensive treatment. The present type of equation is analysed in Krtscha and von Kalckreuth (2002).

implicit in the arbitrage condition (3) for the national capital market. Future price levels, via future short-term rates and their influence on changes in the long-term rate relevant to investment decisions, explain changes in the aggregate demand and thereby act upon the *current* price level.

4. The Characteristic Equation for the Speed of Adaptation

In order to simplify our presentation, we want to focus on those time paths that are compatible with *adaptive expectations* on the financial markets. That means we add the equation:

$$\dot{P}_t = \lambda \tilde{P}_t . \qquad \lambda \in \mathbf{R},\ \lambda < 0 \ . \tag{18}$$

This is equivalent to restricting the solution to the system to a simple exponential, $\tilde{P}_t = \tilde{P}_0 e^{\lambda t}$. The parameter λ, being negative in a stable world, is to be interpreted as the speed of adaptation for the system. As will be discussed below, this assumption implies no loss in generality. The exponential trial solution leads to the following transcendental characteristic equation for the speed of adaptation, λ:

$$\frac{\lambda^2}{1-\alpha_2\lambda} - b = -\frac{a}{\Omega}(e^{\lambda\Omega} - 1) \ , \tag{19}$$

with constants *a*, *b* defined as:

$$a = \frac{\Gamma\beta_3}{\alpha_2} > 0, \qquad b = \frac{\Gamma\beta_1}{\alpha_2} > 0 \ . \tag{20}$$

Considering in Fig. 2 the graphs of the two functions,

$$\mathrm{G}(\lambda,\Omega) := -\frac{a}{\Omega}(e^{\lambda\Omega} - 1) \ , \ \text{and} \qquad \mathrm{H}(\lambda) := \frac{\lambda^2}{1-\alpha_2\lambda} - b \ , \tag{21}$$

the unknown value of λ is given by their point of intersection. $\mathrm{G}(\lambda,\Omega)$ is an exponential function converging to a/Ω for $\lambda \to -\infty$ and diverging for $\lambda \to \infty$. It has a horizontal intercept for $\lambda = 0$. As can be seen from its first and second derivatives, the function is globally concave and its slope is negative throughout. $\mathrm{H}(\lambda)$ is a fractional rational function. Its first two derivatives tell us that $\mathrm{H}(\lambda)$ has a local minimum in $(0,-b)$, a local maximum for $\lambda = 2/\alpha_2 > 0$ and a pole with a change in sign from positive to negative in $\lambda = 1/\alpha_2$. To the left of this pole, i.e. in particular for $\lambda \le 0$, $\mathrm{H}(\lambda)$ is convex throughout.

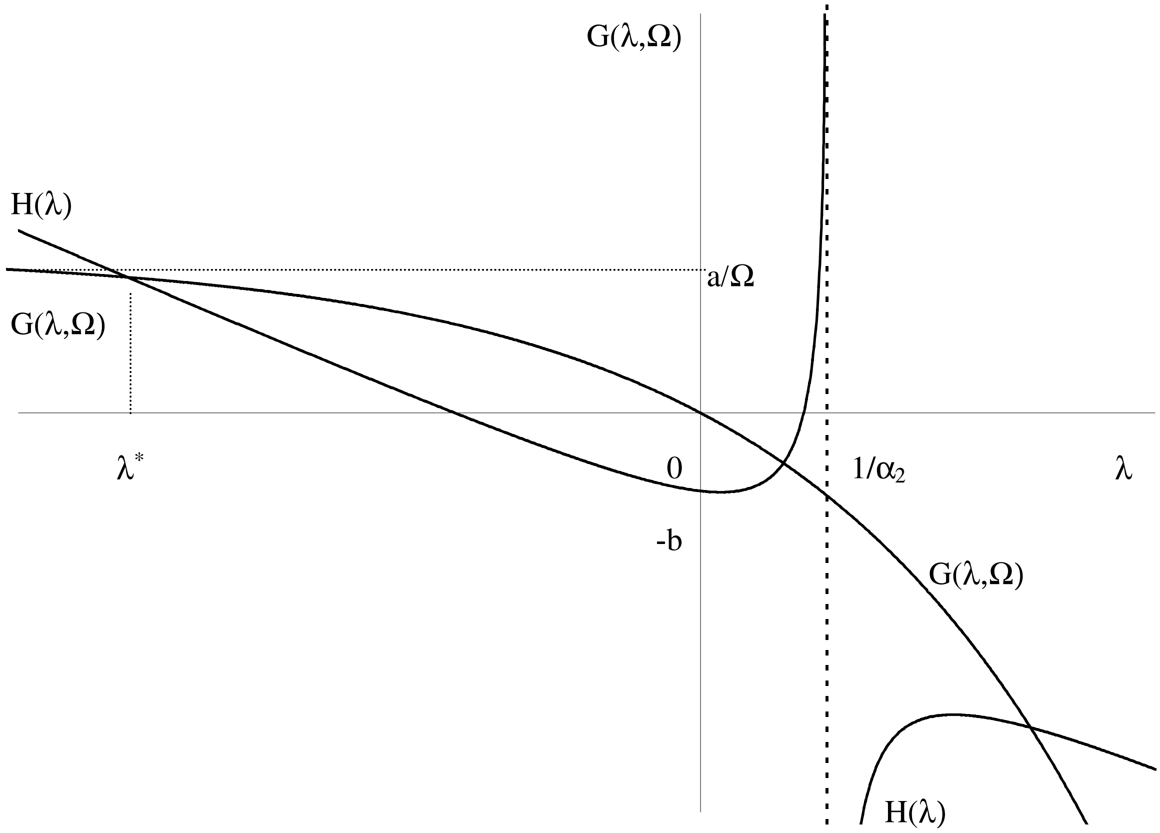

Fig. 2: Graphical determination of the exponent λ

As in Fig. 2, the characteristic equation always has three solutions.[8] One and only one of these three solutions is stable, i.e. negative. We have $G(0) > H(0)$. As $H(\lambda)$ diverges for $\lambda \to \infty$, whereas $G(\lambda, \Omega)$ converges to a positive constant, the intermediate value theorem for continuous functions guarantees the existence of at least one intersection. There can be no further point of intersection for $\lambda < 0$, as $G(\lambda, \Omega)$ is globally concave and $H(\lambda)$ is convex over all the negative half-plane. As is common in dynamic models with perfect foresight, it will be assumed that participants "opt" for the stable solution.

We have simplified the analysis greatly by restricting attention to exponential solutions for the differential-difference equation (17). In fact, equations of this type may have an infinite number of solutions that cannot be written as simple linear combinations of exponentials. In a companion paper, Krtscha and von Kalckreuth (2002) show that none of these additional solutions is stable – with respect to the question on hand, they can thus safely be ignored.

[8] We can exclude complex solutions, as these would lead to a complex time path for the price level in (18).

5. Service Life, Speed of Adjustment and Exchange-Rate Overshooting

After having shown the existence and uniqueness of a stable time path for any positive Ω, we are now in a position to investigate the implications of a change in Ω for the key variable, the adjustment rate λ. This can be done by applying the implicit-function theorem to the characteristic equation (19):

$$\frac{d\lambda}{d\Omega} = \frac{\partial \mathrm{G}/\partial\Omega}{\partial \mathrm{H}/\partial\lambda - \partial \mathrm{G}/\partial\lambda}. \tag{22}$$

The *numerator* of this expression is negative for any positive Ω:

$$\frac{\partial \mathrm{G}}{\partial\Omega} = \frac{a}{\Omega^2} e^{\lambda\Omega}(1-\lambda\Omega - e^{-\lambda\Omega}) < 0 \ . \tag{23}$$

Fig. 3 is a graphical analysis of the term in brackets; it shows that, for any negative value of λΩ, the inequality $e^{-\lambda\Omega} > 1-\lambda\Omega$ holds.

The *denominator* of (22) is the first derivative with respect to λ of the difference between $\mathrm{H}(\lambda)$ and $\mathrm{G}(\lambda,\Omega)$, at their point of intersection. As the graph of $\mathrm{H}(\lambda)$ cuts the graph of $\mathrm{G}(\lambda,\Omega)$ *from above*, the denominator is negative, too:

$$\frac{\partial \mathrm{H}}{\partial\lambda} - \frac{\partial \mathrm{G}}{\partial\lambda} < 0 . \tag{24}$$

The crucial result immediately follows:

$$\frac{d\lambda}{d\Omega} > 0 \ . \tag{25}$$

The exponent λ is a negative-valued and increasing function of Ω. *With a shorter service life of capital, the (absolute) speed of adaptation will increase*. This has immediate implications for the foreign exchange market. Overshooting has to take place *just because* the adjustment is sluggish, and continuing negative interest differentials have to be compensated for by appropriate exchange-rate losses. Analytically, it follows from (5) and (9), together with (15) and (18), that:

$$\tilde{E}_0 = \frac{1}{\alpha_2\lambda}\tilde{P}_0 = -\frac{1}{\alpha_2\lambda}\Delta M > 0 \ . \tag{26}$$

The higher speed of adjustment, associated with a decreasing service life of capital, will therefore reduce the amount of overshooting in $t = 0$.

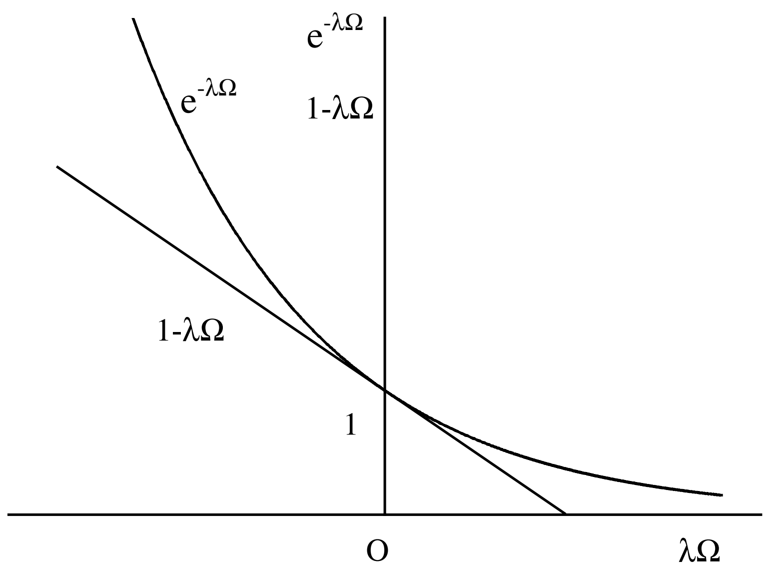

Fig. 3: Negative sign of $\partial G/\partial\Omega$

6. Inflation Dynamics and Conclusion

Discrete changes in the price levels are excluded. At the moment of initial disturbance in t=0, the nominal interest rate i is therefore the only variable on the demand side of the money-market equation which is free to move and restore monetary equilibrium. The speed of adjustment is determined by the magnitude of the inflation $\dot{P}$ induced in the commodity sector by the monetary shock. The higher this inflation, the faster the initial deviation $\tilde{P}_0 = \Delta M$ will be removed, and the greater will be the absolute value of $\lambda = \dot{P}_t / \tilde{P}_t$. This ratio of inflation to the deviation of the price level from equilibrium remains constant throughout the entire adaptation process. Thus it is sufficient to consider the magnitude of inflation $\dot{P}$ at $t = 0$.

There are two channels by which monetary disturbances act upon aggregate demand: the interest-rate channel, and the real exchange-rate channel. Now consider a shrinking service life of capital associated with a decrease in the time to maturity Ω relevant to investment decisions. If one presupposes, to start with, that the time path of the short-term real interest rate remains unaffected, then the reaction of the long-term rate $R_{\Omega,t}$ to some initial monetary disturbance clearly becomes stronger, because the mean value effect given by the interest-structure equation loses power. Via the interest-rate channel, the demand reaction on the market for commodities is enhanced, as is the resulting inflation and the speed of adjustment λ, by which adaptation is characterised. This is the basic idea, but there are several feedbacks to be taken into account. First, the short-term real interest rate itself depends on induced inflation: with a higher inflation, the gap between nominal and real rates of interest widens and the demand reaction is reinforced. A second feedback tends to mitigate the primary effect. A higher λ makes the short-term real interest rate converge more quickly. Hence the reaction of the long-term interest rate, as a mean value of future short-term rates, is weaker than it would be if there were no change in the time path of r.

Along the real exchange-rate channel, the rising speed of adjustment dampens the overshooting of the real exchange rate, with obvious implications for excess demand and inflation. This last feedback also mitigates the primary effect, again without being able to compensate completely for it: acceleration in adjustment is necessary for the overshooting to decrease.

The consequences of all this for economic policy can be summarised as follows: with the maturity relevant to decisions on the commodity market getting shorter, the interest-sensitive sectors will become increasingly sensitive to events on the money market. The acceleration of adjustment, however, removes part of the burden from the export and import competing sectors, as exchange-rate fluctuations dampen down. The effect of monetary policy becomes more "punctual": the impact is more intense at the moment of implementation, but it will subside sooner. The real side of the economy becomes more dynamically stable. Foreign exchange markets become less volatile, as less overshooting is necessary to maintain uncovered interest rate parity. The exchange rate channel loses power - in an absolute sense and relatively to the interest rate channel.

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