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Doubts on the Role of Disturbance Variance in New Keynesian Models and Suggested Refinements

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Summary:

Models with rational expectation have become quite popular in macroeconomics, particularly in the context of New Keynesian Models and DSGE models, respectively. These models are useful in many respects; however, they suffer from a serious problem which is discussed here in a very basic version: These models have equations with white-noise disturbance terms with finite variance where the size of this variance is assumed to have no impact on the behavior of economic agents and the equilibrium solution or the steady state values, respectively. This, however, is totally implausible – from a theoretical perspective, a disturbance term with a very large variance, for example, should have a crucial impact on consumption, investment and output, respectively. In the context of the Great Recession and the Transatlantic Banking Crisis as well as in the Euro Crisis – during which one could observe very high volatility of bonds prices pointing to a high variance of disturbance terms - one may therefore raise critical questions with respect to validity of policy recommendations derived from DSGE models. Hence these models should be refined adequately; institutions and regulations have an influence on the variance of white noise disturbance terms and thus various institutional regimes with differences in the variances of these disturbance terms should be discussed. Selected digital expansion and innovation aspects – e.g. related to the Corona shock - also are highlighted.

Zusammenfassung:

In der Makroökonomik sind Modelle mit rationalen Erwartungen sehr populär geworden, vor allem im Kontext der neukeynesianischen Modelle bzw. der DSGE-Modelle. Diese Modelle sind nützlich, aber sie leiden unter einer ernsten Problematik, die hier auf Basis eines einfachen Standard-Modells diskutiert wird: Diese Ansätze verwenden in Gleichungen normalverteilte (white noise) Störgrößen mit endlicher Varianz wobei die Größe der Varianz annahmegemäß keinerlei Einfluss auf das Verhalten der Akteure hat bzw. die Gleichgewichtslösung und die Steady state-Werte. Das jedoch ist völlig unplausibel – ein Störterm mit einer sehr großen Varianz sollte aus theoretischer Sicht einen deutlichen Einfluss z.B. auf den Konsum haben; oder auch die Investitionen oder die Produktion. Im Kontext der Großen Rezession bzw. der Transatlantischen Bankenkrise wie bei der Eurokrise – da konnte man zeitweise z.B. ungewöhnlich hohe Volatilitäten von Staatsanleihen beobachten bzw. liegt die Vermutung einer erhöhten Varianz der Störterme nahe – stellt sich daher die Frage, ob die Schlussfolgerungen herkömmlicher DSGE-Modelle relevant sind. Die Modelle sollten daher angemessen modifiziert werden. Institutionen und Regulierungen haben einen Einfluss auf die White Noise-Störterme und daher sollte die Rolle von entsprechenden „Institutionen-Regimen“ mit unterschiedlichen Varianz-Ergebnissen thematisiert werden. Zudem werden ausgewählte digitale Expansionseffekte und Innovationsaspekte – z.B. solche im Kontext mit dem Corona-Schock – thematisiert.

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1. Introduction

New Keynesian Macroeconomics (NKM) have become quite influential in the literature and for policy makers who typically use Dynamic Stochastic Genera Equilibrium (DSGE) Models for analysis and simulation studies. DSGE models are used by many central bankers, governments and researchers (e.g., GOODFRIEND/KING, 1997; CLARIDA/GALI/GERTLER, 1999; DEUTSCHE BUNDESBANK, 2008; SBORDONE/TAMBALOTTI/RAO/WALSH, 2010; BÖTTCHER/RACIBORSKI, 2019; BREDEMEIER/JÜSSEN/WINKLER, 2020). The advantages of NKM approaches are many: Counterfactual simulations, optimal policy, forecasting and historical decomposition analysis can be studied as well as issues of rules versus principles. One may argue that some DSGE models – based on the NKM approach – are not very realistic in the field of international economic relations as capital flows are not split between portfolio capital flows and foreign direct investment (FDI) flows: The latter could be greenfield investment or, more importantly in many countries, international mergers & acquisitions (M&A) for which the real exchange rate should play a crucial role if one follows the arguments of FROOT/STEIN (1991); FDI stock effects should also affect total factor productivity growth as well as the specification of the consumption, export and import functions: Consumption is not proportionate to Y (GDP) but to Z (GNP) which in a nutshell is Y + net factor income from abroad – and here, profits from foreign subsidiaries will matter.

In 2010, the US Congress held a hearing about DSGE models: CHARI (2010) defended DSGE models and he indeed pointed out some crucial advantages of DSGE approaches. Nevertheless, one may raise other critical points, including non-linearities in the adjustment process. Subsequently, however, one specific point will be addressed which thus far has not been thoroughly discussed and this concerns the problems linked to the white noise error terms typically used in various equations of DSGE models. The weakness emphasized subsequently requires an answer along with the question of whether or not national policy and economic system monitoring systems are adequate: National policy monitoring occurs on the side of the IMF in the form of Article IV missions every year for every member country. Financial Sector Assessment Programs (FSAPs), which were initiated after the Asian Banking Crisis, occur less regularly - before the Transatlantic Banking Crisis a member country could even refuse an FSAP; and the United States, under President George Bush Jr., did indeed refuse to be the subject of an FSAP. The FSAP on Ireland in 2006 was totally inadequate, inaccurate and showed poor analysis on the part of the IMF, while the FSAP on Switzerland a few years earlier noted outside the written statements – reflecting communications with Swiss authorities - that UBS was a strong bank which it obviously was not as the Transatlantic Banking Crisis has revealed.

Some authors (e.g., BRANCH/MCGOUGH (2009); HONKAPOHJA/MITRA (2006) have criticized NKM approaches on the ground that in reality there are heterogeneous expectations which make it difficult to easily use a rational expectations model (the standard approach in NKM models such that investors and trade unions base expectations on a model and use all publicly available information and not simply on weighted past realizations of, for example, the inflation rate as is the case under adaptive expectations). However, one may also raise a more general objection against DSGE models and the underlying class of models: The point which will be raised subsequently refers to the assumption that the error term has some fixed variance and that rational individuals should not care about the size of the variance; many entrepreneurs and workers in the real world would certainly argue that there is critical maximum variance which one may consider as neutral with regard to one's own behavior (this could affect e.g. international mobility of investors); if a mobile entrepreneur should move from a country with a low variance of the output disturbance term to a country with a very high variance of the output disturbance term, s/he might actually raise the question of whether or not a very high variance implies that there is a special liquidity risk against which one would have to seek insurance. This is just one case where the variance of error terms would affect the equilibrium solution in a way which is not considered in standard NKM models.

The debate about the role of sovereign debt ratings during the Euro Crisis and the problems of multiple equilibriums in foreign exchange markets and financial markets, respectively, also raise some unpleasant questions for rational expectations models (WELFENS, 2010; 2011; 2012; GÄRTNER/GRIESBACH, 2012). CALVO (1988) has suggested that the problem of multiple equilibriums in a debt crisis could be a serious problem and his theoretical approach has turned out to be quite useful.

As regards the analytical core of an NKM model one may at first look at a simplified macroeconomic approach with rational expectations; in a first step market rigidities and adjustment costs in markets, respectively, are ignored here, but a critical point related to white noise error terms already can be highlighted. Subsequently we will at first take a look at a standard model plus some NKM refinements (section 2), in the third section we will consider how the impact of a high variance of the disturbance term may crucially affect the model outcomes. Finally, I will suggest some key issues for further research.

2. A Standard Rational Expectations Model

A very simple New Keynesian Model (NKM) is based on an aggregate demand function and a Lucas aggregate supply function which basically says that the logarithm of real output Y^s is a positive function of the log of the long run equilibrium value Y# and the difference between the logarithm of the price level p_t and the expected price level (in logarithm) p'_t. Both the aggregate demand equation and the supply equation have a normally distributed stochastic disturbance term – u''_t for the demand equation, v''_t for the supply side equation - whose expectation value is zero and whose given standard deviation σ is finite. Denoting autonomous real demand, including government demand by G''_t, and the logarithm of the nominal stock of money by m''_t (p is the price level in logs) the demand equation may be expressed by

(1) $Y^d_t = G''_t + b(m''_t – p_t) + u''_t$;

By assumption, the parameter b>0. The supply side equation is given (with Y# denoting non-stochastic full employment output and p' the expected price level in logs) by:

(2) $Y^s_t = Y\# + h(p_t – p'_t) + v''_t$;

By assumption, the parameter h>0. For the sake of simplicity, it is assumed that the variances of the two disturbance terms are equal. In equilibrium we have $Y_t=Y^d_t=Y^s_t$ and get:

(3) $Y_t = G''_t + b(m''_t – p_t) + u''_t$

(4) $Y_t = Y\# + h(p_t – p'_t) + v''_t$

Assuming rational expectations, we can calculate the expectation values (E is the expectation operator) and obtain from applying the expectation operator:

(5) $Y^E_t = G''^E_t + b(m''^E_t – p'_t)$

(6) $Y^E_t = Y\#$

There is no disturbance term in equations (5) and (6) since the expectation value of the disturbance term is zero. From equations (5) and (6), we obtain as the expected price level p'_t (in logs):

(7) $p'_t = m''^E_t – (Y\# – G''^E_t)/b$

By substracting equation (5) from (3) and (6) from (4), we get the following two equations:

(8) $Y_t – Y^E_t = (G''_t – G''^E_t) + b(m''_t – m''^E_t) – b(p_t – p'_t) + u''_t$

(9) $Y_t – Y^E_t = h(p_t – p'_t) + v''_t$

Setting the equality sign ($Y_t = Y^E_t$) for the two equations above, we get (also using (4) $Y^E_t = Y\#$) the price level and the actual output Y_t are as follows:

(10) $p_t = p'_t + [1/(b + h)] [(G''_t – G''^E_t) + b(m''_t – m''^E_t) + u''_t – v''_t]$

(11) $Y_t = Y\# + [h/(b + h)] [(G''_t – G''^E_t) + b(m''_t – m''^E_t) + u''_t + b/h\ v''_t]$

The well-known result is that output is equal to equilibrium long run output Y# plus terms which reflect expectation errors (the difference $G''_t – G''^{Et}$ and the difference between m_t and m''^E_t) plus the error terms u''_t and v''_t. A similar equation is obtained for the price level (in logs) which is equal to the expected price level (in logs) plus expectation errors with respect to autonomous demand and with respect to the nominal money stock. The message is that only unexpected policy intervention matters, be it fiscal policy or monetary policy. Government intervention has no systematic effect. The white noise error terms will have no effect in the long run whether their respective variance is small or whether it is rather high (or indeed very high). This is a strange view of reality as people will implicitly care about the size of σ^2 – or of σ (standard deviation) - of the white noise error terms.

New Keynesian Model Perspectives

In a modern New Keynesian Model (NKM) some rigidities in goods and labor markets are explicitly considered - see the appendix for an NKM in a nutshell - so that even fully anticipated policy intervention has economic effects. A standard setting assumes differentiated intermediate goods produced by monopolistically competitive companies (DIXIT/STIGLITZ, 1977) and those companies are facing constraints in price adjustment (CALVO, 1983) so that not all firms can immediately adjust prices if some shock hits the respective sector (see also appendix 2). There is a share of firms (θ) which can adjust prices immediately; in a DSGE macro model – along the New Keynesian Macroeconomic modeling logic – the derivations for the price-setting bring the (log-linearized) New Keynesian Phillips curve which is a link between the current inflation rate and the expected inflation rate for t+1 as well as the marginal costs (mc; β" is the discount factor here; a hat denotes a percentage change):

$$(12) \qquad \hat{\pi}_t = \frac{(1-\beta''\theta)(1-\theta)}{\theta}\hat{m}c_t + \beta'' E_t \hat{\pi}_{t+1}$$

The Calvo approach leaves it somewhat unclear as to why firms are facing price adjustment costs and hence one may highlight here several critical aspects for the case of a negative shock and a digital shock, respectively:

- Firms producing consumer durables will have a limited interest to reduce the offer price since the price of used products – often considered to be an asset of the respective households – would fall in parallel; with portfolio investors/households emphasizing high yield, low risk (price volatility, possibly with asymmetric emphasis on avoiding price reductions) and liquidity of assets, respectively, the demand for new products (e.g., a Porsche car) as well as for used products would decline if price volatility for used product is rather high (the stock of used Porsches running on the streets worldwide by far exceeds that of annual production; and a Porsche indeed is both a consumer car and an asset so that it is a special "dual use" product). Hence, the larger the share of consumer durables in total household expenditures, the more rigid price reactions in markets for new products will be.

- Many new digital services and products are offered in markets in the Internet Economy. While adjustment speeds could increase for part of digital services and products – due to enhanced competition – part of the digital economy is characterized by high barriers to entry and hence rather high mark-up rates (ROEGER, 2019) - standing for modest intensity of competition. While for the former group of products ("internet-based products") price flexibility is rather high (CSONTO/HUANG/TOVAR, 2019), the price flexibility of the latter group of products – in markets with high mark-up rates - should be rather low. It is not fully clear which of the two effects will dominate in the medium and long run. One key aspect for the overall impact could be the range of product innovation and price differentiation, respectively.

- In open economies, pricing to market – related to the role of exchange rate changes – could also play a particular role, namely that, for example, a depreciation of the currency will not translate quickly (and fully) into a price reduction abroad.

- Product innovations and process innovations which is a distinction that has been not adequately considered in macroeconomics so far: In open economies one will have to consider sectors with current product innovations which, according to VERNON (1966), will bring about a temporary improvement of the current account as the new products are exported, namely at rather high prices in the innovation stage; later, in the expansion stage of the product cycle (partly emphasized by the Vernon approach), the product as well as the production process will become more standardized so that part of production is relocated internationally via outward foreign direct investment - say, from the US or Germany/France/Japan to some eastern European or Asian countries. Thus, the current account balance of the initial product innovation country will deteriorate as the price of new products still being exported is declining and since imports of the now established "new" product – and now being produced abroad – are rising and add to the import bill. Under flexible exchange rates – not considered in the Vernon approach – there should be a real appreciation of the currency of the country with the initial product innovation wave, followed later by a nominal and real depreciation of the currency. One may add that the speed of the price adjustment can be expected to be rather slow in the innovation stage, but should be faster in the subsequent stages of standardization and maturity, respectively (in the final maturity stage of the product cycle trade the initial product innovator country will only import from abroad, largely from developing countries and newly industrialized countries). The sectoral ratio of product to process innovations thus should be crucial for price responsiveness; that ratio, however, has not been much considered in the literature with the particularly notable exception (albeit not in the context of price adjustment speed) - in an early stage of the debate in the Economics of Innovation – of a contribution by UTTERBACK/ABERNATHY (1975) in Innovation Economics. These authors have argued that in new sectors, product innovations at first are typical while only in a later stage of the product cycle – to refer here to the approach of VERNON (1966) – the role of process innovations will play a bigger role so that the ratio of product innovations to process innovations would indicate the maturity of the respective sector. Product innovations are also considered in endogenous growth modeling where AGHION/HOWITT (1990, 2007) not only consider positive external effects of product innovations but also the effect of induced obsolescence in the loser sectors and for loser firms, respectively; an interesting Schumpeterian growth model extension – with innovation dynamics in the intermediate product market (under monopolistic competition) - is the enhanced Solow growth model with endogenous innovation (AGHION/HOWITT, 2007). MELITZ (2003) has emphasized the open economy aspects of innovation dynamics, namely that opening up – and thus further globalization – reinforces the role of innovative firms in the economic evolution process. The knowledge production function (GRILICHES, 1961, WELFENS, 2017b) is a concept which covers the link between R&D

investment/patenting and investment, namely in the sense that more patents of firms quoted on the stock market raise stock market prices which in turn stimulates investment (following the logic of the Q-approach of TOBIN (1969). New aspects of immaterial capital market accumulation (HASKEL/WESTLAKE, 2019) also are crucial. The Community Innovation Survey of the EU (EUROPEAN COMMISSION, 2020) gives some indication about the sectoral ratio of product innovations to process innovations for EU member states. As regards total factor productivity growth, there is some evidence – different for OECD countries and NICs – that outward FDI and inward FDI contribute to technological progress (AMANN/VIRMANI, 2015; VAN POTTELSBERGHE DE LA POTTERIE/LICHTENBERG, 2001). An important issue with respect to the variance of the white noise error term is whether or not innovation dynamics at home or abroad have an effect on the size of this variance. It is a kind of a portfolio-choice issue whether people, for example, would want to live in a country with relatively high innovation and growth – and therefore relatively high variance of disturbance terms (here linked to Schumpeterian dynamics) - while paying a price in the form of a higher variance of the disturbance parameters.

- In the context of the corona shock year of 2020, the digital economy has expanded through more digital services and products being used to support employees working from home in many firms in all OECD countries which amounts to an effective quasi-exogenous increase of the digital capital stock at nearly zero costs. In an open economy, the implication from the Rybczynski theorem is that the output of digital capital intensive goods will rise, while that of other goods will fall in absolute terms. Since more digital value-added can be expected to go along with more product differentiation (and possibly also product innovation), the average digital product price will increase. In an open economy therefore, following the Stolper-Samuelson theorem, the remuneration of the production factor which is used intensively in the production of digital products will increase: This therefore means that the skilled wage premium will increase; heterogeneous labor can, of course, be considered in open economy NKM models.

There are several elements of NKM models which are largely accepted as common analytical ground: (i) households are maximizing utility within an intertemporal optimization approach and firms are doing the same with respect to expected profits; there is full microeconomic foundation of aggregate behavior in the relevant markets. (ii) Expectations play a key role, and rational expectations is the standard approach used – and here all households adopt the same pattern of expectation formation. (iii) There is monopolistic competition of firms in an environment with frictions in markets where only a fraction of firms will be able to adjust prices in a way which is consistent with profit-maximization – as regards price adjustment dynamics on the supply side, many authors follow the CALVO (1983) model. The price adjustment approach of ROTEMBERG (1987) - using a quadratic term to model the cost of price adjustment - is an alternative but also assumes cost of price adjustment; (iv) there are stochastic disturbance terms on the supply side of the economy and possibly also on the demand side – e.g., the supply side may be stated as $Y_t = Y_\# + h(\ln P_t - E(\ln P_t)) + \varepsilon_t$ where h is a positive adjustment parameter, Y# is normal output, P_t is the price level and ε_t is a white noise disturbance term (with an expectation value of 0 and a finite variance; E is the expectation operator and t the time index).

NKM models emphasize nominal rigidity in intermediate products analysis: Differentiated goods are produced by monopolistically competitive firms (DIXIT/STIGLITZ, 1977) and companies are also facing limited price adjustment opportunities (e.g., CALVO, 1983). Households derive utility from consumption goods and leisure (over an infinite time horizon) where first order conditions give two equilibrium conditions, namely one for the ratio between current consumption and the following period's consumption; moreover, there is an intra-temporal decision about consumption and labor input/leisure. Firms in the setting with monopolistic competition apply mark-up pricing over marginal costs and inflation is covered indirectly through a log-linearized New Keynesian Phillips curve (often with an adjustment parameter from the Calvo model) while monetary policy is based on a standard Taylor rule: The central bank interest rate is based on the past central bank interest rate plus terms for the inflation deviation from the inflation target and for the output target deviation. It is noteworthy that the real economy is described by an equation (GALI, 2008) which depends on the deviation, x', of output from the equilibrium output: More specifically, current output deviation is given as $x'_t = E(x'_{t+1}) - vr_t$ where v is a positive parameter and r is a real interest rate term in which the next period's expected inflation rate enters; the real interest rate r= nominal interest rate i minus the expected inflation rate. The NKM approach leads to hump-shaped impulse response functions and the Taylor rule brings about stability if the Taylor principle is fulfilled, namely that the central bank reacts to inflation target deviations over-proportionately.

The introduction of rigidities is a realistic improvement of modern macroeconomic models, however, the key question considered here remains: Why would it be irrelevant how large the variance of the disturbance terms is? This is the question discussed subsequently. It will be argued that consumers as well as investors normally are not indifferent with respect to the size of variance terms (unless they are risk-neutral). Implications will be considered in this context.

3. Considering the Critical Role of the Variance of Disturbance Terms

The traditional stochastic modeling approach is not convincing since (a) it is unrealistic to assume that an economic or political system could survive any system dynamics – read: set of equations – with potentially very high temporary changes in system output: if σ exceeds a critical value $\underline{\sigma}$ the system will collapse; and (b) traditional modeling ignores that economic agents will prefer institutional setups which limit the variance of disturbance terms; explicitly or implicitly, risk-aversion has to be considered; only under risk-neutrality will the size of the variance of the white noise error term not play a role. Incidentally, one should not rule out that leading big banks or hedge funds actively create "noise" in financial markets – having insider information in these banks or funds, there will be opportunities for the respective managers to share insider information with major clients whose loyalty to the respective bank thus is reinforced.

The very purpose of economic systems and modern institutions is to avoid critically high variances of variables. To catch this basic idea, one should consider households and firms which care about the variance of the disturbance term(s) and hence the behavior of economic agents has to be modeled accordingly. The very purpose of government intervention is to limit the variance of output or output growth. Thus, in the view proposed here, it is not plausible that we have a stochastic environment in which neither consumers nor investors nor government nor the central bankers are assumed to react to σ whatever its size in the real world is. Rather, it is realistic to assume that consumers will buy less if the world is rather unstable, read: is characterized by a high σ.

A natural analytical step is to consider the role of uncertainty in a theoretical perspective. Indeed with specific parameters, assumed instability of the yield on investment will raise consumption (more specifically, will increase the consumption wealth ratio), while a different parameter set has the consequence that a higher variance of the stochastic yield on investment reduces the consumption wealth ratio: DIXIT (1990, p. 174) considers a representative household which maximizes (with $\varepsilon>0$) the mathematical expectation of the discounted present value of utility $U(C) = C^{1-\varepsilon}/(1-\varepsilon)$ under the constraint that s/he consumes C, saves real wealth (A"- C) and faces a random yield r on investment; his/her random wealth increase at the beginning of the next period will be r(A"-C).

(13) $$U(C) = C^{1-\varepsilon}/(1-\varepsilon)$$

Households maximize this function over an infinite time horizon and discount future utility by the discount factor δ". The solution of the optimization problem (with δ" denoting the time preference) is

(14) $$C/A" = 1- \delta" E(r^{(1-\varepsilon)})^{1/\varepsilon}.$$

Assuming that $\delta" E(r^{(1-\varepsilon)})^{1/\varepsilon}$ is close to zero, we can use the approximation:

(15) $$\ln(C/A") \approx - \delta" E(r^{(1-\varepsilon)})^{1/\varepsilon}$$

Obviously, the optimum consumption wealth ratio depends on the parameters ε and δ" of the utility function and the distribution of the stochastic yield variable r. For the special case of a lognormal distribution of r we get:

(16) $$E(r^{(1-\varepsilon)}) = (E[r])^{(1-\varepsilon)} \exp(-\varepsilon(1-\varepsilon)\sigma^2/2)$$

For the case $\varepsilon<1$, we can see that a rise of E(r) – holding variance fixed – reduces the ratio C/A" whereas an increase in σ raises this ratio. If, however, the parameter $\varepsilon>1$, the opposite results will hold. From this perspective it is not plausible to assume that an individual living in a stochastic environment would ignore knowledge about the size of the variance of disturbance terms – even if their expectation value is zero. If one assumes that - with respect to the variance of disturbance terms - households have in mind a critical value σ'* beyond which they classify their environment as highly risky, they could be expected to adjust their decisions on consumption and investment in DSGE models. As regards game theoretical experiments, one could indeed study whether or not individuals adjust behavior once they get information about a switch in the size of variance of disturbance parameters.

With these insights, we return to the task of stating a modified equation system where it will be assumed that investment will be smaller if σ is high. As regards the supply side, one thus may assume that aggregate output is negatively influenced by instability (σ): Risk-averse managers will want to produce less and consumers – assuming a specific set of parameters - want to consume less if there is high instability (under specific conditions, one might instead assume that consumers want to raise current spending, e.g., if σ is associated with a shorter life expectancy: A phenomenon known from periods of war). The role of instability can be considered in both the demand equation - namely by the additional term b'σ – and in the supply-side equation, namely by the additional term b"σ (b' and b" are positive parameters). Finally, one may assume that the central bank will adopt a monetary policy rule which is positively reacting to a higher degree of instability (e' denotes the Euler number): $M_t = M_0\, e'^{[1+\phi(\sigma)\sigma]t}$ or $\ln M_t = \ln M_0 + [1+\phi(\sigma)]t$; $\phi(\sigma)$ is a positive function of σ. Hence the central bank wants to cushion potential shock effects on the real economy through the provision of more liquidity. An important aspect here is the impact of σ on the cost functions of firms; a standard approach – with risk-averse managers - suggests that a higher σ will shift cost functions upwards and this implies a fall of the real money supply. Here, one can also find an argument as to why the central bank should increase the supply of liquidity in periods during which the variance of disturbance parameters is increased. This holds all the more if one assumes (WELFENS, 2011) that the real stock of money enters the firms' production function on the basis of a positive external effect of households' holding of money.

The expected stock of money – from the perspective of the private sector - is $\ln M^E_t = \ln M_0 + [1+\phi'(\sigma)\sigma]t$ where the expected φ' is a positive function of σ; but φ' is, of course, not identical to φ(σ) at any point of time; φ is the central bank's reaction parameter where φ= φ' only under a perfect communication strategy of the central bank. Therefore, money matters since there will be transitory differences between $\ln M_t$ and $\ln M^E_t$; even if the central bank would try to lecture the public on the reaction function φ(σ), the private sector will be unable to fully understand this lesson; it is plausible that the learning process is all the more difficult and more costly the higher σ is. One might argue that a direct negative effect of the variance of the disturbance term occurs only if σ>σ'. For ease of exposition, we will consider a general role of σ in the subsequent equations.

The modified equations for the demand side and the supply side read as follows (with parameters b" assumed to be positive while b' could be – following the logic of the DIXIT model – positive or negative):

(1') $Y^d_t = G''_t + b(m''_t - p_t) + u''_t + b'\sigma$;

By assumption, the parameter b>0. The supply side equation is given by the equation:

$(2') \; Y^s_t = Y\# + h(p_t – p'_t) + v''_t – b''\sigma$

$(1'.1) \; Y^E_t = G''^E_t + b(m''^E_t – p'_t) + b'\sigma$

$(2'.1) \; Y^E_t = Y\# - b'\sigma$

From the above two equations the solution for p'_t now is:

$$(7') \qquad p'_t = m''^E_t – (Y\# – G''^E_t)/b + b'\sigma/b + b''\sigma/b = m''^E_t – (Y\# – G''^E_t)/b + (b' + b'')\sigma/b$$

Let us consider at first the case that $b'<0$: If the demand-side effect of risk dominates the supply-side effect of risk, a rise of the variance of the disturbance term(s) will reduce the expectation value of the price level; and in an open economy this also implies a long run nominal appreciation if one considers purchasing power parity. If, however, $b'>0$, the variance of the system has a positive effect on the expected value of the price level.

The systemic variance might be proxied in various ways. One simple measure would be to consider a weighted sum of the stock price volatility and the bond price volatility (one should note that the government bonds' price variance has increased enormously in several countries of the Euro Area in the period 2010-2012).

There is one more aspect to be considered here, namely that it is totally implausible to assume that natural output Y# is not affected by the size of σ; instead it is reasonable to assume that Y# (the steady state output in a deterministic world) is somehow affected by σ. Considering a production function $Y=K^{ß}(AL)^{1-ß}$ (with K capital, A knowledge and L labor; $0<ß<1$) a very simple neoclassical growth model – with savings $S= s(1-\tau)Y$, capital depreciations δK and the growth rate of knowledge (a) – yields as the steady state real gross domestic product the expression (with τ for income tax rate): $Y\#= L\{s(1-\tau)/(\delta+a)\}^{ß/(1-ß)}$. Again, the savings rate, according to the logic of the DIXIT model, is unlikely to be independent of σ; in an endogenous growth model, which would explain the growth rate of knowledge, the size of σ is likely to affect knowledge dynamics; for example, if the volatility would concern stock price dynamics, there might be a critical σ" beyond which the exit option for venture capitalist would be not attractive and, with stock markets considered as unattractive, venture capital activities would decline and hence a would become a negative function of σ. A counter-argument might be that one should make a distinction between financial market volatility indicators and "real volatility"; if there is a surge in venture capitalism, more new firms will start which in turn means that there will be a rise of Schumpeterian activities in the future so that σ^R in the real sector will increase. A more general specification on the supply side – with positive parameters q' and q" - is $Y\#=Y'\# + q'\sigma – q''\sigma^2$; if there is some entrepreneurial activity, there will be a certain stochastic output term on the supply side and this type of "entrepreneurial variance" will raise output. Beyond a critical value of σ^2 the natural output will be reduced by σ. A straightforward specification of an enhanced Cobb-Douglas production function can be useful here, namely if one would assume that σ always negatively affects natural output Y#; the basis for the specification suggested here is WELFENS (2011) who assumes that real money supply is held by private households but that there are liquidity spillover effects to firms so that the aggregate production function is given by

(8’) $Y= (M/P)^{ß'}K^{ß}(AL)^{1-ß-ß'}$; $0<ß<1$; $0<ß'<1$

Specifically, $\ln Y\# = ß'(\ln M - \ln P) + ß\ln(K/(AL))$

In a simple monetary neoclassical model – assuming that savings $S= sY(1-\tau)$ - we have for the steady state output $Y\# =[(M/P)/(AL)]^{ß'/(1-ß)}LA[s(1-\tau)/\delta]^{ß/(1-ß)}$; here s is the deterministic savings rate, δ is the deterministic rate of capital depreciation and τ the deterministic income tax rate; we have assumed a constant population L as well as a constant level of knowledge A. The steady state output is derived from the equilibrium condition for the goods market, namely that $sY/(AL)= [(dK/dt) + \delta K]/(AL)$ and from $dk'/dt= sy' - \delta k'$ where $k':=K/(AL)$ and $y':= Y/(AL)$. Inserting in the condition that savings per unit of labor in efficiency unit (AL) is equal to gross investment $(dK/dt + \delta K)$, the production function $y'=(m'/P)^{ß'}k'^{ß}$ gives the steady state value $k'\#$ from setting $dk'/dt =0$;

(9’) $dk'/dt = s(1-\tau)(m'/P)^{ß'}k'^{ß} - \delta k'$

Hence, we get

(10’) $k'\#= [s(1-\tau)(m'/P)^{ß'}/\delta]^{1/(1-ß)}$

and therefore we get

(11’) $y'=(m'/P)^{ß'} [s(1-\tau)(m'/P)^{ß'}/\delta]^{1/(1-ß)} =[(M/P)/(AL)]^{ß'/(1-ß)}[s(1-\tau)/\delta]^{ß/(1-ß)}$

Therefore, one gets

(12’) $Y\#= AL[(M/P)/(AL)]^{ß'/(1-ß)}[s(1-\tau)/\delta]^{ß/(1-ß)} = (AL)^{(1-ß-ß')/(1-ß)} (M/P)^{ß'/(1-ß)}[s(1-\tau)/\delta]^{ß/(1-ß)}$

If (M/P)/(AL) exceeds unity, output in a monetary economy obviously exceeds the steady state value of the pure neoclassical economy (without real money balances in the production function).

Here, due to the stochastic nature of the price level, the equilibrium output is also now a random variable. Taking logs, we can write here $\ln Y\# = (ß'/(1-ß))\ln(m'/P) + (ß/(1-ß))[\ln(s/\delta) - \tau]$ where $m':=M/(AL)$. The policy variable of the central bank is M/(AL) which is the nominal stock of money relative to labor in efficiency units. Obviously, we have

(13’) $E(\ln Y\#) = (ß'/(1-ß))\ln m' - (ß'/(1-ß))p' + (ß/(1-ß))[\ln(s/\delta) - \tau]$;

The variance V(lnY#) of the steady state output in logs is

(14') $V(\ln Y\#) = -(ß'/(1-ß))[V(\ln m') - V(\ln P)]$.

One may emphasize that in reality A is a stochastic variable as is the depreciation rate.

How is natural output affected by the variance of the disturbance terms in this setting? In the spirit of simplicity, one may assume that K, A and L are all deterministic. However, the output elasticity of the real money stock is a stochastic variable here. The link to the degree of instability is easily introduced, namely if we define ß' as that output elasticity of the real money stock which exists in a deterministic world; in a stochastic world, we replace ß' by the expression $ß' = ß'' - \alpha'\sigma$; the parameter $\alpha' > 0$. Thus ß" denotes the output elasticity of real money balances in a deterministic setup. Note that one may assume that σ is directly related to the inflation rate π and the higher the expected level of the inflation rate – so a standard argument in the literature states – the higher is the volatility of the inflation rate and thus the higher the risk that nominal price changes and real price changes are confused: This, in turn, implies that the output variance σ is positively correlated with the expectation value of the inflation rate. In a broader sense, it has been assumed here that ß" is a negative function of σ. Hence the supply function for the log of real output reads now (with $ß'' = ß' - \alpha'\sigma$):

(15') $y^s_t = ß''\ln(M/P) + ß\ln K + (1-ß)(\ln A + \ln L) + h(p_t - p'_t) + v''_t - b''\sigma - [\alpha'\ln(M/P)]\sigma$

The solution for the log of the expected price level now becomes

(16') $p'_t = m''^E_t - [(ß'' - \alpha'\sigma)\ln(M/P) + ß\ln K + (1-ß)(\ln A + \ln L) - A''^E_t]/b - (b' - b'')\sigma$

The impact of $\alpha'\sigma$ on p'_t is positive. The net impact of σ thus depends on a specifically monetary risk effect and on the already established risk impact associated with the parameters b' and b". In a microeconomic optimization framework, it is easy to derive the case that profit-maximizing firms will reduce output if the variance of costs is increasing; lack of monetary policy control thus can be interpreted as an output-reducing variance of central banks' activity. In a broader perspective – taking into account the role of the banking system – one may consider a stochastic framework in which the money supply multiplier is characterized by a specific variance which is related to the types of banks operating and the type of prudential supervisory regime applied.

A critical test of financial market consistency is to analyze how much divergence of major rating companies exist for key markets. Periods of very high convergence could be dangerous - as over-optimism on the part of investors could be nurtured – as could periods of considerable divergence since "rating disagreement" suggests high uncertainty about adequate sovereign bonds or corporate bonds or company ratings. It would be useful to have a permanent monitoring research on ratings.

Finally, one might consider a setup in which the money supply is a stochastic variable and then the traditional Friedman-argument - according to which a stable monetary policy is desirable becomes valid – looks interesting: Much in contrast to the standard New Keynesian macro model. Moreover, one may indeed raise the question as to which extent the "system variance" σ^2 can be endogenized, for example, on the basis of the hypothesis $\sigma = \lambda\sigma^M + \lambda''\sigma^{A''}$ where the standard deviations on the right-hand side refer to the standard deviation of the nominal money supply and the autonomous aggregate demand, respectively; in an open economy there will also be the impact of the variance σ^* of the foreign real GDP where a simple specification could be hypothesis $\sigma = \lambda\sigma^M + \lambda''\sigma^{A''} + \lambda'\sigma' + \Omega$ where the latter reflects a co-variance term.

One promising way to bring the size of the variance into the white noise error term(s) could be as follows:

- Using a utility function in which consumption enters positively, but working time and the variance of the white error term negatively.

- One could also have a utility function with these three elements and the additional constraint that the individual does not want to have a regime where σ^2 is above a critical limit. To make sure that such a regime bringing the variance below the critical limit is realized, the political constitution would have to impose certain limits on risk-driving transactions; for example, a minimum level of prudential banking supervision has to be imposed.

- This, in turn, would have implications for policy choices since it would be consistent to argue that the hump-shaped response of certain variables – after certain policy interventions – would have to be limited in the transition stage; this would therefore also affect the choice of optimal policy.

- Agent-based modeling might also be useful to identify critical variance limits that could result in the transition period to the new equilibrium.

It is noteworthy that the run-up to the Transatlantic Banking Crisis prior to 2007 went along with many banks and hedge funds chasing for rather high returns and this resulted for some time in very high rates of return on equity of banks and hedge funds – with the latter setting the benchmark. It has been suggested that a tax on the variance of the rate of return on equity would be useful to avoid the chasing for very high short-term rates of return on equity in the banking system (WELFENS, 2012).

Risk Dynamics: Home Bias and Related Issues

Once we accept that it is not natural to assume that the variance of disturbance terms is constant and non-influential for economic behavior, one may address some other issues for which the size of variance and the respective information could be quite important. In the real world, it is well-known that there is a home bias, namely both in the field of buying goods and in the field of buying assets. A standard hypothesis for such a home bias is that the information costs in the home market are smaller than in foreign markets, but there could also be some political nationalism which implies a preference for domestically-produced goods over foreign goods and for domestic bonds over foreign bonds; there is, however, one well-known exception, namely the role of a reserve currency which will be held in relatively large quantities by foreign central banks and countries, respectively, which have pegged the exchange rate to that of the reserve currency (or want, for whatever reason, a rather stable foreign exchange rate). In a stochastic world, this has two crucial implications which have been ignored thus far:

- The correct anticipation of domestic policy variables should be easier than the correct anticipation of foreign policy variables. For small countries, this implies that the incentive for an active policy is smaller than in a large economy whose exposition to foreign economic variables and hence foreign policy shocks is much smaller than in small open economies.

- The reserve currency's policymakers enjoy the advantage that the policy chosen will be relatively well anticipated by both domestic investors and foreign investors – foreign investors might still have a certain home bias but the role of the reserve currency of an α'-country (this term is used to dub a foreign reserve currency) implies that the interest of foreigners to acquire information about the α'-country's financial market dynamics and the behavior of the policymakers of that country are relatively large. Maintaining the position of a reserve currency requires to adopt a relatively stable monetary policy and a rather conservative fiscal policy as otherwise confidence in the long run stability of the currency of the α'-country will be undermined.

In an open economy, one should assume that investment – and possibly also consumption - will depend both on the degree of domestic instability (σ) and the degree of foreign instability (σ*).

Limited Time Horizon and Health

A specific feature linked to mathematical optimization questions in the NKM framework (and many other economic approaches) is the assumption of an infinite time horizon which often helps making the mathematical handling of model building easier. In the context of the Corona shocks in 2020, I have considered some basic aspects of health insurance, infections and output in a macroeconomic context (WELFENS, 2020). With people facing a potentially deadly epidemic, it is – one may argue – not adequate to explicitly base economic modelling on equations with households standing for individuals who live ad infinitum. Instead, one should consider life time T to be an endogenous variable which can be influenced by the health insurance system and the health system, respectively. The optimization problem for individuals – and politicians/the political system – now looks different from standard NKM models with households with an infinite time horizon; one may still want to maximize discounted life time consumption. For certain macro problems, for example related to the health system/health insurance, one should indeed develop a modified macroeconomic approach which allows to analyze the relevant problems in a consistent new way.

4. Future Research and Policy Conclusions

There is little doubt that DSGE models are the most important type of macro model used by central bankers in OECD countries, by the European Commission and by several research institutions: DSGE models are quite influential in the policy sphere. One can easily show that DSGE models have been less able to generate adequate forecasts in crisis periods such as the US subprime mortgage crisis or the Euro Crisis and various authors have tried to remedy existing models through various refinements.

In the context of the Great Recession and the Transatlantic Banking Crisis as well as in the Euro Crisis – during which one could observe a very high volatility of bond prices pointing to a high variance of disturbance terms - one may therefore raise critical questions with respect to the validity of policy recommendations derived from DSGE models. Hence, these models should be adequately refined. To the extent that there are multiple equilibria in financial markets, it is also unclear how economic agents would behave; strong policy rules – e.g., emphasizing that government will stick to a policy which brings about a top rating from the leading rating agency – could possibly help to maintain the favorable stable equilibrium and to avoid that random shocks would lead to an unstable equilibrium. This, however, implies that policymakers face a much more restricted range of policy options than is generally thought.

In a Consistent New Keynesian model, one has a better understanding of the economy of the real world. The strange argument that monetary policy is irrelevant as all policies can be anticipated no longer holds in a CNK model. At the bottom line, it is also worth noting that the impact of expansionary monetary policy in specific settings – such as the increase of risk during the Transatlantic Banking Crisis – can be much better understood. DSGE models with adequate refinements concerning the role of the variance in disturbance terms on economic behavior will be quite useful for policymakers.

As regards rational expectations and financial market dynamics, the majority for BREXIT in the UK's referendum of June 23, 2016, raises some unpleasant questions as is shown in the appendix. Free capital flows and a referendum are not easy to reconcile since free international capital flows can signal to voters an anticipated referendum outcome which has an influence on voters' participation in the referendum. An unbiased referendum is desirable and this can be expected only if capital flows would be limited by government authorities in the weeks before the referendum – such limits were, however, not imposed in the UK in 2016.

The ratings of major rating agencies should be systematically monitored not just by capital market actors but also by institutions such as the European Systemic Risk Board and other policy institutions including the IMF. Such research – as a kind of standardized institutional monitoring - does not exist and this is somewhat surprising.

As regards consensus forecasts amongst the professional forecasters of central banks (e.g., the ECB), it would be useful not only to ask respondents about the value of certain variables in t+1 – or t+n – but rather one should add a question concerning how big the variances of other professional forecasters' values are expected to be. Such surveys might act as an early warning system and help to identify critical variances in a timely manner which could motivate policymakers to bring about a regime change through adequate institutional reforms.

Finally, there is a crucial need to discuss more broadly the role of the Calvo price adjustment parameter in DSGE models, particularly in the context of digital economic expansion and product and process innovations, respectively. In this context, the particular role of platform firms – such as Google or Amazon – should be analyzed. Their market power might be strong enough to impose a follow the leader pricing strategy on all firms listed on the platform where platform firms could have established a subsidiary to act as the leader in the respective sector itself. Such symmetric pricing adjustment behavior will differ from a more competitive setting of an asymmetric pricing behavior whereby the followers reduce prices whenever the big leading company does but will not raise prices if the leader has increased the price so that firms are facing a kinked demand curve which has been discussed in the literature many years ago in Competition Economics (SWEEZY, 1939; DRAKOPOULOS, 1992) – and one can test for symmetric versus asymmetrical pricing adjustment patterns empirically. In part of the digital economy one can observe a rather asymmetric market setting in which one leader dominates in part of the respective digital platform economy (e.g. Google in the field of search engines).

With respect to open economies, one may point out the especially interesting case where country I (e.g., the US) is the leader country in certain important sectors and firms in country II are the followers. In a broader context with many countries it should hold: Depending on symmetric versus asymmetric adjustment pricing behavior the medium- and long-term exchange rate behavior should be different – the US exchange rate behavior vis-à-vis Newly Industrialized Countries (with nearly all firms representing a follower position in the various sectors) therefore should be different from that of the US compared to leading European countries (with some sectors where European firms are in a leader position). Thus, the innovation – exchange rate nexus should show some new perspectives in an adequate empirical analysis.

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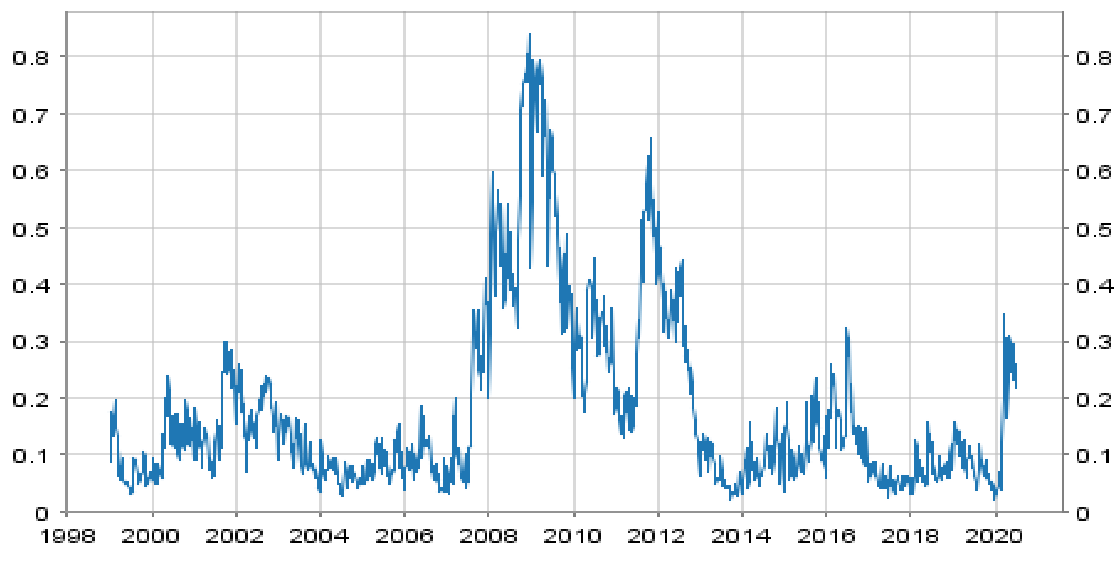
Appendix 1: Problems with Economic and Political Rationality

It seems obvious that error terms could have very high variances in periods of turbulence – say in the context of the Transatlantic Banking Crisis. The approach of the European Central Bank, as developed by HOLLO ET AL. (2012) and KREMER (2016), shows periods in which a portfolio-based set of indicators, summarized by the Composite Indicator of Systemic Stress (CISS), indicates periods of high risk or uncertainty, respectively. If these periods stood for uncertainty, an observer could not determine how big the variance is – or in the context of rational expectations, one would not agree on a consensus forecast, including an implicit consensus on the variance (usually not asked in surveys!). As regards Germany, one may note that all major professional forecasters had an overestimation of the actual inflation rate which could be understood as contradicting rational expectations: Across a group of forecasters, one would assume that certain forecasters underestimate the actual inflation rate while others overestimate the inflation rate. In a time series context, the rational expectations assumption implies that in some periods there were random overestimations while in other periods there were random underestimations – but never systematic overestimations or underestimations.

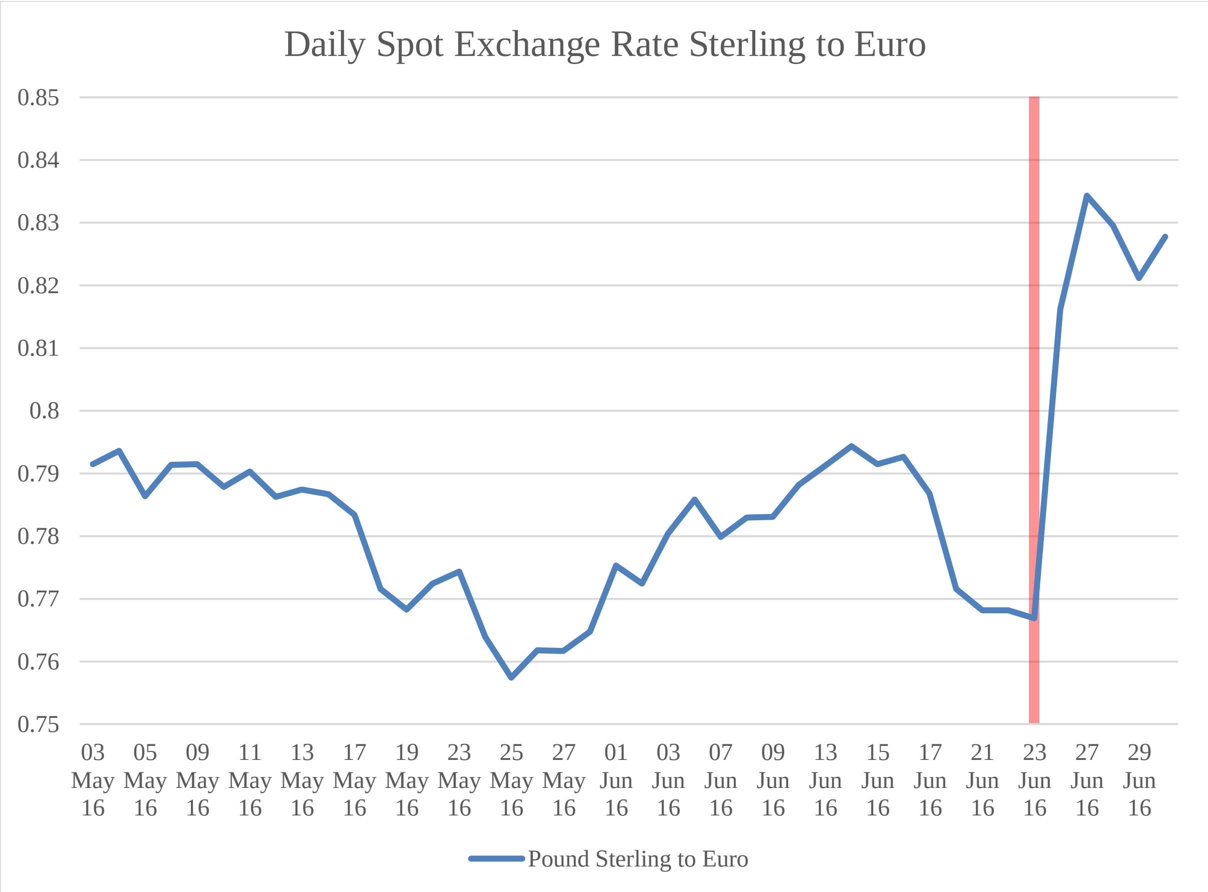
Figure 1: Composite Indicator of Systemic Stress (CISS) for the Eurozone, 08/01/99 – 03/07/20



Source: European Central Bank Statistical Data Warehouse – CISS – Euro Area (changing composition)

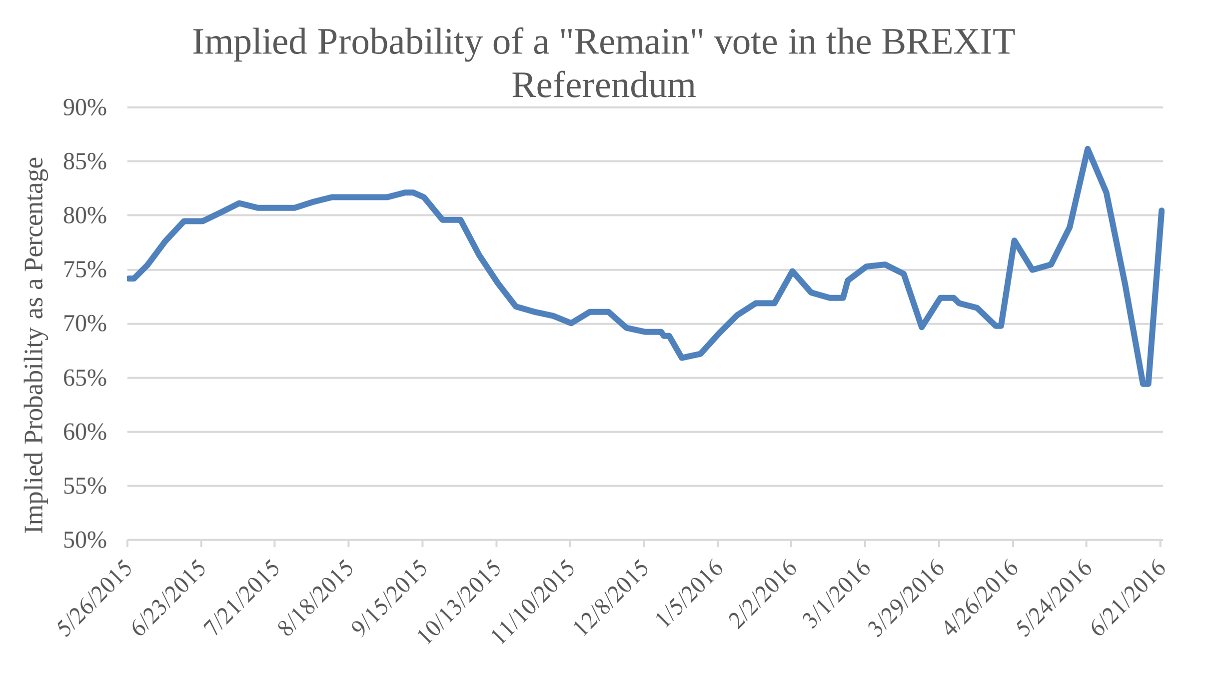
A rather complex problem emerges if expectations have an impact on policy regimes which in turn will subsequently have an impact on future expectation formation. Consider the case of BREXIT and the British referendum on EU membership of June 23, 2016. If the expectations of speculative investors in UK capital markets and foreign exchange markets, respectively, had been such that a major depreciation – driven by investors' fear of a BREXIT majority - of the British Pound would have occurred, then voters would have been so shocked by those developments that no pro-BREXIT majority would have occurred (WELFENS, 2016; 2017a); this is a self-fulfilling prophecy. If, by contrast, an appreciation of the Pound occurs (see Fig. 2) – as was the case in the week before June 23, 2016 – voters will get the perception that there are no major risks to be associated with the BREXIT referendum (a Remain majority is expected in capital markets) and less Remain voters will actually turn out to vote and thus the pro-Leave side achieves a majority; this is a self-destructing forecast, BREXIT itself will then lead to a Pound depreciation; the subsequent figure indicates the various exchange rate movements – driving by the respective net capital inflows/outflows – and the anticipated outcome of the referendum. It is unclear what the concept of rational expectations should mean in such a context. As regards the betting odds in the UK prior to the referendum, it seems obvious that investors from the capital market became quite active immediately prior to the referendum – thus the betting odds gave a biased signal which largely reflected the Remain-majority perceptions in capital markets which were self-defeating.

Figure 2: Daily Spot Exchange Rate, Pound Sterling into Euro, 01/05/16 – 30/06/2016



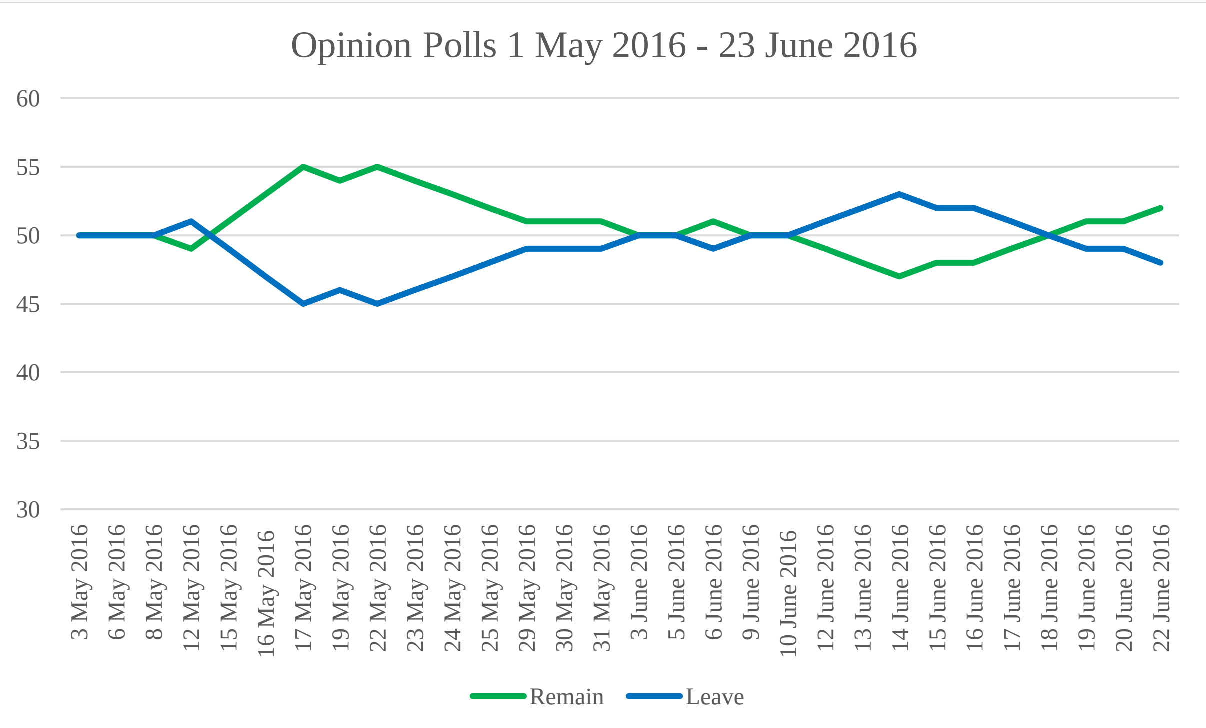
Note: The vertical red line marks the date of the referendum, 23 June 2016
Source: Own representation of data available from the Bank of England Database Historic Exchange Rates

Figure 3: Implied Probability of a Remain Vote in the June 23, 2016, Brexit Referendum



Source: Own calculations based on data available from www.oddschecker.com; implied probability based on daily betting odds from four major betting firms in the UK – Paddy Power, William Hill, Ladbrokes and Betfair

Figure 4: Summary of Opinion Polls on the Question "Should the United Kingdom remain a member of the European Union or leave the European Union?", 1 May 2016 – 23 June 2016



Source: Own representation of data available from whatukthinks.org, Poll of Polls, EU Referendum, https://whatukthinks.org/eu/opinion-polls/poll-of-polls/

Appendix 2: Some Reflections on the Standard NKM-Approach

There is an economy with rigidities in goods and labor markets, final products are offered in competitive markets while using intermediate products from differentiated products; the firms producing the latter act under monopolistic competition – and not all firms can change prices at any moment of time (CALVO, 1983). Households maximize utility in an intertemporal approach and households/firms maximize profits. Monetary policy is described by the Taylor rule which refers to deviations from the target inflation rate as well as the output gap. Finally, there is a pricing behavior based on mark-ups over marginal costs and expected inflation is also crucial, namely in the framework of rational expectations so that households/investors are forward-looking. The Calvo price adjustment frequency parameter is interesting for several reasons, particularly in the context of the digital economy – which has expanded during the course of the corona recession in 2020 as so many firms in industrialized and Newly Industrialized Countries have switched to home office activities so that there was an effective digital modernization of households/firms – typically at almost zero marginal costs. Thus, one could understand the corona shock related expansion of the digital economy as an effective fast increase of the digital capital stock in the economy (recall that marginal cost for internet services expansion is close to zero).

Rybczynski Theorem and Digital Modernization in the Context of the Corona Recession and in the Post-Corona Shock Recovery

If we follow the logic of the Rybczynski theorem, this means that the production of those goods which intensively uses digital capital goods will increase – the production of the other goods will decline in absolute terms. This aspect could become quite important also in the post-corona shock period since one may anticipate that the expansion of the internet economy and the digital capital stock will continue. This aspect is not included in the subsequent standard NKM model, but one could take into account labor market matching aspects in an enhanced model on the one hand, on the other hand one could consider changes in the Calvo price adjustment frequency parameter as the relevant point in a digital structural change context.

The New Keynesian Model in its Basic Version **(based on BRZOZA-BRZEZINA (2019), NKM Model, Warsaw School of Economics)**

The model assumes forward-looking individuals which maximize utility over an infinite time horizon; utility depends positively on consumption and negatively on working time (loss of leisure). Hence, the household's objective is to maximize the following utility function – with an infinite time horizon (ß'' is the discount rate):

$$\max U = E_0 \sum_{t=0}^{\infty} \beta^{"t} [\frac{c_t^{1-\eta}}{1-\eta} - \frac{N_t^{1+\varphi}}{1+\varphi}] \qquad (1)$$

where N_t is the working time and c_t is the final consumption good, subject to the budget constraint (B is stock of short term bonds, T is transfers, W is the nominal wage rate, P the consumption price index, R the nominal interest rate, t the time index; the exponent for c is assumed to be positive).

$$P_t c_t + B_t = W_t N_t + R_{t-1} B_{t-1} + T_t \qquad (1')$$

First-order conditions/FOCs: The following Lagrangean has to be considered

$$L = E_0 \sum_{t=0}^{\infty} \left[\beta^{\prime\prime\prime t} [\frac{c_t^{1-\eta}}{1-\eta} - \frac{N_t^{1+\varphi}}{1+\varphi}] + \frac{\lambda_t}{P_t} (W_t N_t + R_{t-1} B_{t-1} + T_t - P_t c_t - B_t) \right]$$

First order conditions are:

$$c_t : \quad c_t^{-\eta} = \lambda_t \qquad (2)$$

$$\frac{B_t}{P_t} : \quad -\lambda_t + E_t \beta^{\prime\prime} \lambda_{t+1} R_t \frac{P_t}{P_{t+1}} = 0 \qquad (3)$$

$$N_t : \quad -N_t^{\varphi} + \lambda_t \frac{W_t}{P_t} = 0 \qquad (4)$$

Households' equilibrium conditions

The first-order conditions thus give two equilibrium conditions for households, namely a choice between current and future consumption on the one hand, and the choice between consumption and leisure (work).

The intertemporal choice between consumption today and tomorrow is as follows:

$$c_t^{-\eta} = E_t \beta^{\prime\prime} c_{t+1}^{-\eta} R_t \frac{P_t}{P_{t+1}} \qquad (5)$$

The intra-temporal – choice between consumption and leisure (1 minus labor supply) is given by (w is the real wage rate):

$$\frac{N_t^{\varphi}}{c_t^{-\eta}} = \frac{W_t}{P_t} \equiv w_t \qquad (6)$$

$$N_t = w_t c_t^{-\eta} \qquad (6')$$

Households' equilibrium conditions:

Finally, the FOCs give two equilibrium condition:

Intertemporal – choice between consumption today and tomorrow (the hat stands for a relative change over time):

$$\hat{c}_t = E_t \hat{c}_{t+1} - \frac{1}{\eta}(\hat{R}_t - E_t \pi_{t+1}) \qquad (7)$$

Intra-temporal – choice between consumption and leisure (1 minus labor supply):

$$\varphi \hat{N}_t + \eta \hat{c}_t = \hat{w}_t \qquad (8)$$

Final good producers

The final good producers combine differentiated intermediate goods into final consumption goods. There is perfect competition and firms want to maximize profits and thus solve:

$$\max P_t y_t - \int_0^1 P_{j,t} y_{j,t} dj \qquad (9)$$

subject to:

$$y_t = \left[\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} \qquad (10)$$

where ε can be thought of as elasticity of substitution between the goods y_j. The higher the parameter ε is, the better substitutes are these goods.

FOCs and Lagrange equation:

$$L_t = P_t y_t - \int_0^1 P_{j,t} y_{j,t} dj - \lambda_t \left\{ \left[\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} - y_t \right\} \qquad (11)$$

The first-order condition is:

$$y_{j,t} = P_{j,t} - \lambda_t \frac{\varepsilon}{\varepsilon - 1} \left[\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}-1} \frac{\varepsilon - 1}{\varepsilon} y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}-1}$$

Demand function

This approach leads to the solution:

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\varepsilon} y_t \qquad (12)$$

where:

$$P_t = \left[\int_0^1 P_{j,t}^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}} \qquad (13)$$

is the aggregate output price level.

Pricing as mark-up phenomenon

After some mathematical transformations, one arrives at (with θ as the share of firms allowed/able to change the price in t):

$$E_t \sum_{i=0}^{\infty} (\beta"\theta)^i \Lambda_{t,t+i} \left(\frac{P_t^*}{P_{t+i}} - \frac{\varepsilon}{\varepsilon - 1} mc_{t+i} \right) y_{t+i}^* = 0 \qquad (14)$$

Note that under flexible prices (θ=0) and monopolistic competition, the price chosen in period t is set as a mark-up over nominal marginal cost (mc):

$$P_t^S = M' P_t mc_t \qquad (15)$$

where $M' \equiv \frac{\varepsilon}{\varepsilon - 1}$ is the gross mark-up. Hence, under monopolistic competition the price is set as a simply mark-up over marginal cost.

New Keynesian Phillips Curve

Further derivations bring the (log-linearized) New Keynesian Phillips curve – with a Calvo price adjustment parameter - which is a link between the current inflation rate and the expected inflation rate for t+1 as well as the marginal costs:

$$\hat{\pi}_t = \frac{(1-\beta"\theta)(1-\theta)}{\theta} \hat{m}c_t + \beta" E_t \hat{\pi}_{t+1} \qquad (16)$$

$\varepsilon_{i,t}$

Hence, inflation depends on marginal cost and expected inflation while the price adjustment parameter also plays a role. It should be pointed out that with an increasing digital share of the economy (in a post-corona shock setting) the Calvo parameter may be expected to rise which dampens inflation – such a view emphasized here would be in line with IMF research findings on the internet economy by CSONTO/HUANG/TOVAR MORA (2019). However, at the same time one may argue that the expansion of the digital economy goes along with a higher share of big digital firms with significant market power so that mark-ups will increase and the price adjustment frequency, respectively, will decline; RÖGER (2019) has pointed out the role of rising mark-ups in the US digital economy.

Monetary policy

To complete the model, monetary policy has to be considered where the standard assumption is that it follows a standard Taylor rule – this rule largely is in line with central bank responses observed in reality.

$$\hat{R}_t = \rho \hat{R}_{t-1} + (1-\rho)(\phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t) + \varepsilon_{i,t}$$

<u>Summary of the NK model</u>

As a rather complete NKM approach we thus have (with the hat sign indicating a growth rate):

- Basic Euler equation $\hat{c}_t = E_t \hat{c}_{t+1} - \frac{1}{\eta}(\hat{R}_t - E_t \pi_{t+1})$
- Consumption-leisure choice: $\varphi \hat{N}_t + \eta \hat{c}_t = \hat{w}_t$
- Marginal cost: $\hat{mc}_t = \hat{w}_t - \hat{a}_t$
- Productivity: $\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{a,t}$
- Production function (with growth of knowledge and population): $\hat{y}_t = \hat{a}_t + \hat{N}_t$
- NKM Phillips curve: $\hat{\pi}_t = \frac{(1-\beta''\theta)(1-\theta)}{\theta} \hat{mc}_t + \beta'' E_t \hat{\pi}_{t+1}$
- Basic Taylor rule: $\hat{R}_t = \rho \hat{R}_{t-1} + (1-\rho)(\phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t) + \varepsilon_{i,t}$
- Long run market clearing condition: $\hat{c}_t = \hat{y}_t$

The New Keynesian model (simplified approach)

- Derivation in GALI (2008), ch. 3
- The three-equation model:

$$\hat{\pi}_t = \kappa\hat{x}_t + \beta" E_t\hat{\pi}_{t+1} + \varepsilon_{c,t} \qquad (17)$$

$$\hat{x}_t = E_t\hat{x}_{t+1} - \frac{1}{\eta}\left(\hat{R}_t - E_t\pi_{t+1}\right) + \varepsilon_{a,t} \qquad (18)$$

$$\hat{R}_t = \rho\hat{R}_{t-1} + (1-\rho)(\phi_\pi\hat{\pi}_t + \phi_y\hat{x}_t) + \varepsilon_{R,t} \qquad (19)$$

- where x_t denotes here the output gap and

$$\kappa \equiv \frac{(1-\beta"\theta)(1-\theta)}{\theta}(\eta+\varphi)$$

In such an approach, the model shows hump-shaped impulse response functions as evidenced in simulation studies. As regards demand shocks, output and inflation move in the same direction. As regards supply shocks, output and inflation will move in opposite directions. Note also that the Taylor rule will guarantee stability only if the Taylor condition is fulfilled ($\varphi_\pi >$ 1). Thus, there is a rich set of parameters which one would have to consider for policy simulation studies.

A few thoughts beyond the above closed economy model: In an open economy context, several more equations will have to be added, namely the equilibrium condition for the foreign exchange market where an adequate modeling framework would look at overall net capital inflows Q= Q' (FDI) + Q" (portfolio capital inflows). To the extent that mainly international M&As are considered as the relevant form of FDI, one can write (with q* denoting the real exchange rate and V' as well as V" standing for positive parameters; * foreign variable, J is real imports and X is real exports): $Q = V'q_t^* + V''(R_t - R_t^*)$ and therefore the equilibrium condition for the foreign exchange market (with $J= jZ/q^{*ß'}$ and $X= xZ^*q^{*ß'*}$; ß' is the import elasticity in absolute terms, Z is real GNP, j and x are positive parameters in the interval 0,1; ß" is the profit share in GDP and a" is the share of the capital stock owned by foreign investors in country 1) can basically be written as:

$$V'q_t^* + V''(R_t - R_t^*) = j^*Y(1- a''ß'')/q^{*ß'} - x(Y^*+ a''ß''Y/q^*)q^{*ß'*} \quad (20)$$

Here, the definition of Z and Z* have been taken into account. For the DSGE model, one has to add again white noise disturbance terms. It should be noted that the term V'q* reflects the logic of the FROOT/STEIN (1991) analysis in a context of imperfect international capital markets; hence a real depreciation will bring about an increase in FDI inflows in the form of higher international mergers & acquisitions – for foreign investors, the real depreciation of the host country's currency means a real appreciation and hence an increase of equity capital expressed in units of the host country's currency. Thus, banks in the host country will be willing to more easily finance international M&As where the target company is in the host country so that more leveraged international M&As will take place.

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