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E-mail address: Sandra.Steindl@wifo.ac.at
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Business Cycles and Growth: A Survey*

PAUL GAGGL†
SANDRA STEINDL‡

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Abstract

The paper surveys the evolution of modern macroeconomic models with the focus on the interrelations between endogenous growth and cyclical fluctuations. After reviewing models of the business cycle and endogenous growth, the paper discusses literature combining elements of both of them.

I. Introduction

Until the 1980s most of the mainstream macroeconomists used to regard short-term economic fluctuations (or *business cycles*) as deviations around a smooth and stable trend growth path of GDP.[1] These two phenomena, *trend* and *cycles* (around it), were considered to be determined independently and for analyzing their behavior, two different types of macroeconomic models were used: while the trend component was explained by neoclassical growth models (emphasizing the importance of capital accumulation, labor and productivity growth), the cyclical component was analyzed with Keynesian macroeconomic models, considering the interaction of consumption and investment as key factors. This dichotomy was broken by the introduction of the socalled *Real Business Cycle* (RBC) theory initiated by Kydland & Prescott (1982) as well as Long & Plosser (1983). In their new models growth and business cycles were united in one framework by assuming stochastic technological growth which has two implications: First, as in the neoclassical growth model, the economy *on average* grows at a constant exogenous rate, and second, stochastic disturbances in technological growth make all major economic variables fluctuate around their long-run steady state growth path. In turn, this baseline setup became a point of departure for a host of new theories in which not only technology shocks play a central role. While early models exclusively focused on the *real* side of the economy, most recent theories incorporate var-

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†University of California, Department of Economics, One Shields Avenue, Davis, CA 95616, USA, email:pgaggl@ucdavis.edu

‡Austrian Institute of Economic Research (WIFO), Arsenal Objekt 20, 1030 Vienna, Austria, email:sandra.steindl@wifo.ac.at

[1] Some of the earlier literature which has investigated the interaction between trend-growth and business cycles is among others Wicksell (1898), Schumpeter (1942) and Kalecki (1968). Despite these early contributions there has not been much emphasis – at least within mainstream macroeconomic research – on the interrelation of trend growth and business cycles until very recently.

ious nominal rigidities supporting ideas of the traditional Keynesian perspective. These models analyze the relation between money, inflation and the business cycle, and in particular represent a framework in which the stabilizing effects of monetary and fiscal policy can be investigated within a unified framework. Since this setup is essentially an extension of static general equilibrium theory to a dynamic stochastic environment, models of this brand are nowadays referred to as so called *Dynamic Stochastic General Equilibrium* (DSGE) models and represent the major building block of most modern macroeconomic research.

This paper reviews the evolution of modern macroeconomic theory and in particular tries to highlight the interrelation of (endogenous) growth- and business cycle theory. We outline the basic RBC model and review its extensions up to state-of-the-art DSGE models and try to relate them to the endogenous growth theory. There are several surveys that analyze the development of both areas of research: Stadler (1994), Cooley & Prescott (1995) and Rebelo (2005) are excellent references for RBC theory, Gordon (1990) and Gali (2002) give an outline of the various techniques of monetary policy analysis in a New Keynesian framework and Kremer, Lombardo, von Thadden & Werner (2006) discuss DSGE models as a tool for both monetary- and fiscal policy analysis. The various endogenous growth theories are discussed in Saint-Paul (1997) and Aghion & Howitt (1998). In contrast to earlier work our survey tries to give an overview of these strands of research in a unified manner and, more importantly, highlight the interrelation of long-term growth and business cycles. For obvious reasons this survey is far from comprehensive, but it tries to contribute to the understanding of the interdependence of long-run trend growth and short-term cyclical fluctuations, and in particular, wants to highlight the fact that economic policy (be it fiscal or monetary) potentially has an effect on both, trend growth *and* the business cycle.

We observe that state of the art New Keynesian models are now able to explain (or at least reasonably approximate) the business cycle, but growth is exogenous by construction. In contrast, the endogenous growth literature emphasizes that long-run growth has numerous determinants (including R&D and human capital) and that transitory disturbances may have long-run effects on growth. The main finding of this line of research is that with incorporating elements of endogenous growth in a DSGE model any type of temporary disturbance (be it real or nominal) can have a permanent effect on the growth path of output as long as it changes the amount of resources on which productivity improvements depend.

In that sense, the belief that short-run fluctuations have long-run effects at the same time suggests that long-term economic growth does not only depend on the structural characteristics of the economy but could potentially be influenced by what was formerly referred to as *stabilization* policy. In other words, abandoning the idea of the (neo-)classical dichotomy would imply that a certain policy aimed to eliminate business cycle fluctuations may also affect the growth rate. Hence, if there indeed exists a connection between long-term growth and the business cycle, the chicken and egg question arises of whether growth causes cycles, or the other way around. Only the latter would make macroeconomic policy a tool for both, stabilizing short-run fluctuations and fostering long-term growth. Unfortunately, as of yet, there is no consensus on one or the other conclusion, neither on theoretical nor on empirical grounds.

The remainder of this paper is structured as follows. Section II outlines the development of business cycle models. The simple RBC setup is considered as a starting point for richer models up until modern New Keynesian macroeconomic theory. Stochastic endogenous growth models are reviewed in section III, which emphasize the relationship of business cycles and growth and the implications for stabilization policy. Section IV concludes.

II. Models of the Business Cycle

A. *The Basic RBC Setup*

Kydland & Prescott (1982) and Long & Plosser (1983) introduced the basic RBC model, a stochastic version of a basic intertemporal general equilibrium model with flexible prices and wages.[2] The model describes a perfectly competitive economy with complete markets and no information asymmetries. A stochastic exogenous technology process is considered to cause both, output growth and business cycles. The cyclical fluctuations of GDP, investment, consumption and hours worked are the outcome of maximizing decisions by individual agents responding to exogenous shocks in the productivity process. Stadler (1994) describes the process set off by shocks to technology as follows:

> ”First, agents generally seek to smooth consumption over time, so that a rise in output will manifest itself partly as a rise in investment and in the capital stock. Second, lags in the investment process can result in a shock today affecting investment in the future, and future output. Third, individuals tend to substitute leisure intertemporally in response to transitory changes in wages – they will work harder and compensate by taking more leisure once wages fall to their previous level. Fourth, firms may use inventories to meet unexpected changes in demand. If these are depleted, then, if firms face rising marginal costs, they would tend to be replenished only gradually, causing output to rise for several periods.”[3]

Although the RBC theory is not concerned with explaining the relationship of trend and cycle and the mean rate of output growth is set exogenously, RBC blends business cycle and growth theory in one framework. A model which was originally designed to explain long-run growth was found to be useful to produce the sort of fluctuations of business cycle frequency.

a. *A Typical RBC Model*

The basic model abstracts from both the government and monetary sector and amends the neoclassical growth model by stochastic technology growth. The economy consists of a large number of identical, infinitely lived price taking firms and households, which face the following optimization problems.

Households A representative consumer choses infinite sequences of consumption, $\{C_t\}_{t=0}^{\infty}$, labor, $\{H_t\}_{t=0}^{\infty}$, and investment, $\{I_t\}_{t=0}^{\infty}$, in order to maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t u(C_t, 1 - H_t), \qquad (1)$$

where $0 < \beta < 1$ is a constant discount factor, and $u(\cdot)$ is a concave period utility function, subject to the budget constraint

$$C_t + I_t = w_t H_t + r_t K_t, \qquad (2)$$

where r_t and w_t represent the real rental rate of capital and the real wage, respectively. Moreover, each period households inelastically supply capital to the firms and the capital stock, K_t, accumulates according to the following law of motion:

$$K_{t+1} = (1 - \delta)K_t + I_t, \qquad (3)$$

[2]There exists a number of surveys on RBC models including work by Cooley & Prescott (1995), Stadler (1994) and Rebelo (2005).

[3]See Stadler (1994), p. 1753.

where $0 < \delta < 1$ denotes the rate of depreciation.

Firms Firms have access to a technology represented by a neoclassical production function, $F(\cdot)$, which determines aggregate output

$$Y_t = F(K_t, H_t, A_t), \tag{4}$$

where A_t is stochastic productivity. The level of productivity is assumed to evolve according to the law of motion

$$A_{t+1} = \rho A_t + \epsilon_{t+1}, \quad 0 < \rho < 1, \tag{5}$$

where ϵ_t is an exogenous *i.i.d.* disturbance. The closer the autoregressive parameter ρ is to unity, the higher the degree of persistence of an exogenous technology shock.

Every period a representative firm choses the quantity of labor, H_t, and capital, K_t, in order to maximize (period) profits

$$Y_t - r_t K_t - w_t H_t, \tag{6}$$

subject to the technology (4) and the stochastic growth process of productivity (5), taking factor prices r_t and w_t and the output price ($p_t = 1$) as given.

Equilibrium A (rational expectations) equilibrium in this economy is then characterized by

(i) A set of optimal decision rules for the households,

(ii) a set of price functions,

(iii) and a value function (for the households),

such that

(a) firms maximize profits,

(b) households maximize their expected lifetime utility subject to the budget constraint (2),

(d) (aggregate) factor and final goods markets clear,

(e) capital obeys the law of motion (3), and the level of technology evolves according to (5).

This equilibrium concept was first proposed by Prescott & Mehra (1980) as a so called *recursive competitive equilibrium*. This basic dynamic equilibrium concept can easily be extended to allow for more general and complicated economies and is more recently referred to as a *dynamic stochastic general equilibrium* (DSGE). Rational expectations in this model are resembled by the fact that all agents expect prices to evolve according to stable, time invariant functions of the predetermined state of the economy in each period. Knowing the distribution of the exogenous technology shocks, they can then form expectations about all future prices, without *systematic* errors, in order to solve their maximization problem.

Using dynamic optimization techniques such an equilibrium can be characterized as a set of stochastic non linear first-order equations, reflecting households' and firms' optimal decisions, given their budget constraints and production possibilities, combined with the law of motion for capital (3) and the stochastic growth process (5).

Approximation Typically the system of nonlinear equations mentioned above does not have a (tractable) closed form solution but can be reasonably approximated in order to solve for a set of policy functions. The most common approximation is a first order Taylor series expansion around a stable steady state.[4]

[4] It's worth noting, however, that a first order approximation exhibits *certainty equivalence* and hence the effect of uncertainty on the equilibrium behavior loses importance. In particular, the slope of the optimal decision rules is invariant to uncertainty. Schmitt-Grohé & Uribe (2004) or Lombardo & Sutherland (2007) show how higher order approximations can be used to circum-

The approximate solution is then a set of *linear* decision rules together with the law of motion for capital (3) and the stochastic growth process (5), which only depend on the deep parameters of the model and all the exogenous shocks and predetermined variables:

$$X_t = \xi \left(X_{t-1}, B_t, G \right), \qquad (7)$$

where X_t is a vector of endogenous variables, B_t is a vector of exogenous shocks and G is a set of exogenous parameters, that capture the long-run properties of the economy and are unaffected by the exogenous shocks. $\xi(\cdot)$ represents some function approximating $X_t(\cdot)$.[5] The main idea of RBC theory as proposed by Kydland & Prescott (1982) is that the researcher can now *appropriately* choose numerical values for the set of long-run parameters G and use the approximate solution as a *laboratory economy* to analyze the business cycle.[6] In particular, policy experiments can be conducted by subjecting the model to certain *shocks*, e.g. productivity shocks, fiscal policy shocks, etc., and in turn analyze the approximated model's response to these shocks, e.g. by drawing impulse response functions and analyzing statistical properties of simulated time series.

B. *Features of the Basic RBC Setup*

Simulating a simple model as in Kydland & Prescott (1982) yields artificial time series which replicate many (statistical) features of the cyclical properties of post war U. S. data. Backus & Kehoe (1992) find that even when comparing different OECD countries the initial *stylized facts* about U.S. business cycles seem to be consistent and can be summarized as:

(i) Investment is about 2-4 times as volatile as output,

(ii) consumption is about as volatile as output[7],

(iii) investment and consumption are strongly pro-cyclical,

(iv) hours worked are as volatile as output,

(v) hours worked fluctuate considerably more than productivity,

(vi) and the correlation between hours worked and productivity is close to zero.

The basic RBC setup successfully replicates observations (i) through (iii), however, seems to fail with respect to (iv)-(vi). In particular the model predicts that hours worked are roughly half as volatile as output, hours and productivity seem to have the same volatility and appear to be perfectly correlated. Since the only source of uncertainty in the model are productivity shocks, it appears that in the model the short-run labor supply elasticity with respect to such a shock is too small.

Moreover, Cogley & Nason (1995) argue that the basic RBC setup lacks a strong *internal propagation mechanism*. This means that exogenous shocks do not lead to the observed persistence in output dynamics, and hence, the shock is not sufficiently *propagated* through internal features of the model structure.

Finally, since the basic RBC setup abstracts from money, and hence ignores the influence that monetary policy has on the business cycle,

vent the undesirable property of certainty equivalence.

[5] Although the basic setup from the previous section only has a single shock ϵ_t, we want to represent the solution in a more general form here, which for instance allows for several stochastic disturbances. Moreover, although in principal there could be more than one lag, depending on the structure of the model, we can usually reduce a system of higher order difference equations to a system of first order difference equations by introducing new variables.

[6] Different methods to evaluate parameter choices are discussed in section E.

[7] In U.S. post war data consumption is even less then half as volatile as output.

as well as the possibility of fiscal policy, which also potentially influences the business cycle, there is great potential to enhance the setup of the model in many dimensions. The following section reviews some extensions that attempt to fix or at least mitigate the shortcomings of the basic Kydland & Prescott (1982) setup.

C. *Extensions of the Basic RBC Setup*

In this section we consider the basic setup, as described in the previous section and outline some of the various modifications of particular components of the model, which were introduced in order to improve the model's *fit* to the data. The sample of extensions chosen here is not meant to be comprehensive but matches the set of assumptions made in very recent large scale New Keynesian DSGE models, which implement these modifications (discussed separately here) in a unified manner and are discussed in section D.

a. *Indivisible Labor*

Hansen (1985) argues that the key to the basic RBC model's failure in explaining labor market behavior is the way the labor/leisure choice is modeled. In the basic setup agents chose the optimal *amount* of labor $H_t \in [0,1]$, whereas Hansen (1985) considers the following modification. He notes that in reality, people usually face the choice between working a fixed amount of hours, say H_0, or to not work at all. Hence, in Hansen's model, people adjust labor along the *extensive* rather than the *intensive margin*. To illustrate the implications of this assumption Hansen (1985) considers the following example[8]: Suppose agents chose a lottery[9] (in essence a probability) $\alpha_t \in [0,1]$ of working H_0 hours in period t. Assume that household's instantaneous period utility in (1) has the form $u(C_t, 1-H_t) = \log(C_t) + \zeta \log(1-H_t)$. Although agents are homogeneous *ex ante*, and consequently all agents chose the same α_t, they are heterogeneous *ex post*, depending on the realization of their lottery. Therefore, assuming that agents are distributed along the interval $[0,1]$, on aggregate a fraction α_t of all the individuals will work H_0 hours and $(1-\alpha_t)$ individuals will abstain from work. This allows us to write expected utility as

$$\begin{aligned} u(C_t, \alpha_t) &= \log(C_t) + \alpha_t \zeta \log(1-H_0) \\ &= \log(C_t) + \eta L_t - \eta \\ &\Leftrightarrow \log(C_t) + \eta L_t, \end{aligned} \quad (8)$$

where we use the fact that aggregate hours are $H_t = H_0 \alpha_t$, $\eta = -\zeta \log(1-H_0)/H_0$, and we omit the constant term in the last line because it is irrelevant for the representation of preferences. Hence, the utility function in this example is linear in leisure L_t and consequently implies an infinite intertemporal substitution elasticity of leisure (on the aggregate level).

With this modification a model which is otherwise standard, as outlined in the previous section, implies a much higher volatility of labor relative to output and also the volatility of hours compared to productivity is closer to the data. However, even with indivisible labor the model still predicts much too high a correlation between productivity and hours worked.

b. *Government Shocks*

Another modification, considered among others by Christiano & Eichenbaum (1992) is the effect of government consumption shocks. In their approach they amend the standard RBC

[8] In particular this example is very convenient because it circumvents potential non-convexities introduced by the indivisibility assumption, and hence, the problem can be casted into a planner's problem to solve the model.

[9] This *lottery* can be viewed as a consumption insurance contract where the employer guarantees a certain amount of consumption and the employee works full time with probability α_t and abstains from work with probability $(1-\alpha_t)$. See Rogerson (1988) for details on this type of contract.

model by modifying the aggregate resource constraint to

$$C_t + I_t + G_t = Y_t, \tag{9}$$

where investment is defined as $I_t = K_{t+1} - (1-\delta)K_t$ and government consumption G_t follows some exogenous stochastic process[10], and hence (on top of productivity shocks) represents an additional source of uncertainty in this model. Government consumption is financed by lump-sum taxation and hence explicitly enters nowhere else in the model. In this setup there are two opposing effects and can intuitively be interpreted in the following way: First, fiscal shocks shift the labor supply curve along the demand curve and induce a negative relation between hours and productivity. Second, the technology shock simultaneously shifts the labor demand curve along the labor supply curve and in turn implies a positive relationship between hours and productivity. Overall, the net effect depends on the exact distributional properties of G_t. For a reasonable calibration one can find that the model is capable of reducing the correlation between hours and productivity but not enough to properly match the U.S data.

Alternatively, Braun (1994), McGratten (1994) and other authors consider the effect of distortionary taxation. They find that when agents have the possibility to substitute between taxable and nontaxable activities[11] the model is able to much better replicate the statistical properties of the U.S. business cycle in comparison to the basic Kydland & Prescott (1982) as well as the Hansen (1985) setup.

[10]An example would be $\log(G_{t+1}) = (1-\theta)\log(\bar{G}) + \theta\log(G_t) + \mu_t$, where $\theta \in (0,1)$ and μ_t is some *i.i.d* disturbance and is assumed to be independent of the technology shock.

[11]E.g. if there is a tax on capital income, agents might want to substitute away from capital investments to working more hours, and in turn gain in (untaxed) wage income.

c. *Investment Adjustment Costs*

While the first two extensions (indivisible labor and government shocks) primarily focused on the model's weak performance in replicating statistical properties of hours worked, and their relation to wages and productivity, costs of adjusting the capital stock try to address the model's lack of propagation. The idea behind this extension is, that it is costly to make new capital productive, either in terms of time or in terms of a real cost. So-called *time-to-build* models assume that it takes a certain amount of time until capital is productive (see Kydland & Prescott (1982)) and alternatively *q-theoretic*[12] models assume that the marginal cost of adjusting capital is increasing in the change in installed capital. Time-to-build simply changes the timing in the resource constraint and the production function, while a real adjustment cost can easily be incorporated into the basic RBC setup by, e.g., redefining the law of motion for capital as follows:

$$K_{t+1} = (1-\delta)K_t + \phi\left(\frac{I_t}{K_t}\right)K_t, \tag{10}$$

where $\phi(\cdot)$ is a convex increasing function and $\frac{I_t}{K_t}$ represents the rate of adjustment of capital. Although these mechanisms try to improve the model's ability to propagate shocks, Cogley & Nason (1995) argue that both, time-to-build and investment adjustment costs do not generate the desired hump shaped response to a productivity shock observed in U.S. GDP data. Hence, those two mechanisms alone cannot solve the persistence problems of basic RBC models, however, they prove to be useful in very recent New Keynesian DSGE models in combination with several other extensions of the basic setup.

[12]q-theory here refers to Tobin's q-theory, where q represents the shadow (or marginal) value of installed capital.

d. *Habit Persistence*

Besides the lack of consistency with certain business cycle features there is also concern about asset pricing behavior in RBC models. In particular, the issues addressed are the familiar *equity premium puzzle* and the *risk free rate puzzle* in Lucas (1978) type asset pricing models, as extensively discussed in Mehra & Prescott (2003). These two puzzles reflect the observation that consumption based asset pricing models, as introduced by Lucas (1978), cannot consistently replicate the observed premium of risky assets over riskless ones. With respect to these puzzles a central weakness of Lucas (1978) type models is the assumption of *constant relative rate of risk aversion* (CRRA) preferences, which imply a one to one inverse relation between agents degree of risk aversion and their willingness to substitute consumption over time, as captured by the *intertemporal elasticity of substitution* (IES). With iso-elastic CRRA preferences, e.g., $u\left(C_t\right) = \frac{C_t^{1-\theta}}{1-\theta}$, both risk aversion and the IES are captured by a single parameter, θ, which makes it impossible to disentangle the two properties of agents' preferences. It turns out that breaking up this one to one relation helps to improve the model's performance in replicating observed properties of asset prices. One way to achieve this separation is to introduce habit persistence, as very recently studied in Boldrin, Christiano & Fisher (2001) within an RBC framework.[13] A simple way of modeling habit persistence is to assume an instantaneous period utility function in (1) of the form

$$u\left(h(C_t - bC_{t-1}), 1 - H_t\right), \qquad (11)$$

where $h(\cdot)$ is some concave function and b is a positive scalar weighting the influence of *habits* on instantaneous utility. This assumption essentially reflects the idea that people, at least to some extent (as captured by b), want consumption in this period to be at least as high as it was last period.[14] Or stated more technically, the particular feature of habit utility functions is, that the discounted present value of utility of consumption is not necessarily monotonic in C_t because current consumption increases current period utility but at the same time decreases next period's utility. Consequently this assumption induces a strong desire to smooth consumption. In the context of asset pricing, habit persistence proves to be useful especially because it allows for a high equity premium and moderate degrees of agents' risk aversion at the same time. Moreover, as we will discuss in section D habit persistence turns out to be useful for generating hump-shaped consumption responses to monetary shocks, like the empirical evidence suggests.

e. *Money*

In the 1960s Milton Friedman and Walter Heller raised the question whether *money matters*, in the sense, that whether money and monetary policy influence the real economy, and in turn the business cycle.[15] Although models of the business cycle have dramatically changed since then the question by and large still remains the same. The basic RBC setup completely ignores the role of money by assessing that it behaves neutral, meaning that any change in money supply is completely offset by inflation and hence the value of real balances remains constant over time. More recently, however, economists began to introduce money in RBC models, starting with Cooley & Hansen (1989), trying to investigate the potential channels through which money may indeed effect on the business cycle. In

[13] Although these authors analyze a model with habit persistence in combination with a two-sector technology with limited intersectoral factor mobility we only focus on the assumption of habit persistence here.

[14] Technically households want to maximize the difference between yesterday's and today's consumption taking into account the effect of today's consumption on tomorrow's *habit stock*, bC_t.

[15] See Friedman (1968).

essence there are two ways of amending the basic RBC setup in order to incorporate money (as an additional asset) in a way that it influences agents' intertemporal choices. First, by assuming that agents gain no utility from holding money per se, but money is needed to make consumption purchases. This can be done by amending the aggregate resource constraint by the additional asset, e.g.

$$C_t + I_t + \frac{M_t}{P_t} = \frac{\bar{\mu}\bar{M}_{t-1} + M_{t-1}}{P_t} + \frac{W_t}{P_t}H_t + \frac{R_t}{P_t}K_t, \quad (12)$$

where P_t is the price of consumption in money units (euros say), C_t is consumption, I_t is investment in consumption units, $\frac{M_t}{P_t}$ are real balances and $\frac{\bar{\mu}\bar{M}_{t-1}}{P_t}$ is a periodical *helicopter drop* of money which grows at rate $\bar{\mu}$, i.e. $\bar{M}_t = (1+\bar{\mu})\bar{M}_{t-1}$. W_t and R_t represent nominal wage and rental rate on capital, respectively. Moreover, a so called *cash in advance* (CIA) constraint of the form

$$C_t \leq \frac{\bar{\mu}\bar{M}_{t-1} + M_{t-1}}{P_t} \quad (13)$$

is added. The CIA constraint simply says that current consumption purchases must not exceed the amount of real balances available at time t. In the basic model the CIA constraint introduces a *wedge of inefficiency* (as dubbed by Robert Lucas Jr.) by subjecting the individual to an *inflation tax*. The intuition is straightforward: In order to buy an additional unit of consumption tomorrow, one has to hold $\frac{P_t}{P_{t+1}}$ euros over night. Since prices might increase agents must pay inflation in order to be able to consume an additional unit tomorrow. Moreover, on top of the inflationary consequences, in the presence of interest bearing bonds, agents forgo interest payments by holding money over night in order to be able to pay for consumption tomorrow. Hence, a positive interest rate distorts people's consumption decisions if their choices are restricted by a CIA constraint and consequently, positive interest rates in this setup are inefficient from a social planner's point of view.

Alternatively one could assume that agents draw utility from the mere act of holding money (*Money in the utility function*). In particular this can be done by assuming an instantaneous period utility function of the form $u\left(C_t, \frac{M_t}{P_t}\right)$ and the aggregate resource constraint is (12). Because of the same reasons, also in this specification agents are subject to an inflationary tax, and hence uncertainty about the price level plays a crucial role for consumer optimization.

The implications of money and in particular the role of monetary policy are discussed in the next section focusing on so called New Keynesian DSGE models.

D. *New Keynesian DSGE Models*

Although the classic RBC setup and its numerous extensions, as outlined in the previous sections, is the major workhorse for most modern macroeconomic models and can account for many business cycle features it suffers from one major weakness: It is lacking strong internal propagation mechanisms as argued in Cogley & Nason (1995)[16]. A recent strand of business cycle models, called New-Keynesian DSGE models, tries to attack this particular weakness by introducing various nominal rigidities, in particular, by explicitly modeling price setting firms. Chari, Kehoe & McGratten (2000) thoroughly investigate the impact of staggered wage contracts on the business cycle[17]. It turns out that a combination of both staggered price and wage setting, as first introduced by Erceg, Henderson

[16]The internal propagation mechanisms refers to a high persistence in output's response to a low persistent technological shock.

[17]Also see Kimball (1995) and Yun (1996) for pioneering works on staggered Calvo (1983) style price setting in DSGE models.

& Levin (2000), is necessary for the model to generate the observed inertia in prices and persistent response in output fluctuations to a nominal shock. In particular, Huang & Liu (2002) find that staggered wage setting by itself has a great potential in generating real persistence in a model where the price- and wage setting rules are derived from the standard monopolistic competition framework. The key parameter for generating persistence and inertia in output dynamics is the elasticity of relative wage (price) with respect to aggregate demand in the wage (price) setting equation. They argue that for reasonable parameters the relative elasticity of wages is less then one and decreases both in the elasticity of substitution between differentiated labour skills (production side) and in relative risk aversion in labor hours (households). The relative elasticity of prices with respect to aggregate demand on the other hand is found to be greater than one and increases in the degree of risk aversion in labor hours. Consequently, staggered wage setting tends to induce persistence and staggered price setting alone cannot generate the desired features in output dynamics.

While the theoretic predictions of big scale New-Keynesian DSGE models are very tempting there is still an open question of how to consistently test these predictions against the data. While the calibration approach as proposed by Kydland & Prescott (1982) used to be the standard numerical evaluation method throughout the 1980s and 1990s a new strand of literature in the line of Christiano, Eichenbaum & Evans (2005)[18] focuses on formal econometric estimation of big scale DSGE models. These authors show how to use different approximation methods, to represent the solutions of a micro founded model in a vector autoregression (VAR) representation and characterize the well-defined distributional properties of all the endogenous macroeconomic variables. This VAR representation can then be used to address various normative issues, in particular optimal monetary and fiscal policy making, by conducting impulse response analysis to economic (policy) shocks. The next subsection outlines the basic setup of a state of the art New Keynesian DSGE model in the line of Christiano et al. (2005).

a. *A typical New Keynesian DSGE Model*

Production The main difference in the models setup compared to classical RBC models is a rich and detailed description of the production side of the economy. In order to implement sticky prices the supply side is usually divided into two sectors: final goods and intermediate goods. Final goods are produced from a variety of intermediate goods, typically using a Dixit-Stiglitz production function of the form

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{1}{\lambda_f}} \mathrm{d}i \right)^{\lambda_f}, \tag{14}$$

where $Y_t(i)$ represents is the amount of intermediate good i used for production. The representative firm maximizes profits, taking input prices as given.

Intermediate goods producers face monopolistic competition and hire capital and labor from households. In other words they set prices in order to maximize profits, given a production function

$$\max \left\{ F(K_t, L_t) - \gamma, 0 \right\}, \tag{15}$$

aggregate factor demand, and an aggregate price index. γ denotes fixed cost of production here. The key assumption, however, is that firms set their prices according to a mechanism described in Calvo (1983). At a particular point in time a firm can only reoptimize, and

[18]Also see Smets & Wouters (2003), Altig, Christiano, Eichenbaum & Linde (2004), Ratto, Röger, Veld & Girardi (2005) and Negro, Schorfheide, Smets & Wouters (2007) for state of the art formal econometric analysis of policy experiments in big scale DSGE models.

hence set a new price, with exogenous probability $(1 - \xi_p)$. In periods where a firm cannot reoptimize it is assumed to simply index its price to lagged inflation[19]. This implies that once a price is set, it cannot be changed for the next k periods – quarters say – with probability $(\xi_p)^k$. It turns out that this form of price rigidity has crucial implications for the cyclical behavior of most macroeconomic variables.

Households Another key innovation of modern DSGE setups is the assumption that households monopolistically supply a differentiated labor service. Consequently, they face a wage setting problem similar to intermediate firms. Again, there is an exogenous probability $(1 - \xi_w)$ with which a typical household can reoptimize his wage decision and with probability ξ_w it can only index it to inflation. Although this assumption is completely parallel to the price rigidities on intermediate goods markets the implications for the cyclical behavior of the economy are less dramatic.

Finally, households solve the usual dynamic optimization problem where they choose consumption, labor and various assets, in order to maximize

$$E_t^j \sum_{l=1}^{\infty} \beta^{l-t} \left[u(C_{t+l}, C_{t+l-1}) - z\left(H_{t+l}(j)\right) + v\left(\frac{M_{t+l}}{P_{t+l}}\right) \right], \tag{16}$$

subject to a resource constraint (essentially an extension of equation (12)) and a law of motion for capital (also an extension of equation (3). The function $u(C_{t+l}, C_{t+l-1})$ represents instantaneous utility from current and (potentially) lagged consumption, $z(H_{t+l}(j))$ captures disutility from working $H_{t+l}(j)$ hours, and $v\left(\frac{M_{t+l}}{P_{t+l}}\right)$ is utility derived from holding real cash balances[20]. It's worth noting that the expectations operator E_t^j captures individual j's ideosyncratic perception of risk at time t. The heterogeneity with respect to agents' risk perception comes from the assumption of monopolistic competition on the labor market in combination with staggered wage setting. Since each individual is a monopolist for its specialized type of labor service it does not know whether it will be able to reoptimize wages, independent of all the other agents in the economy[21].

The asset market (as captured in the households' budget constraint) is usually standard, except for one recent improvement, worth mentioning. Christiano et al. (2005) introduce variable capital utilization by allowing agents to chose what fraction of capital to supply for the use of intermediate goods production. This assumption has a crucial influence on the dynamic behavior of interest rates, since the supply of capital is flexible under this assumption and hence, interest rates are not necessarily immediately affected by nominal shocks.

Monetary and Fiscal Policy The monetary authority's actions are usually introduced by a Taylor (1993) type monetary policy rule of the form

$$\frac{R_t}{R^*} = \phi\left(\frac{R_{t-1}}{R^*}, \frac{\pi_t}{\pi^*}, \frac{Y_t}{Y^*}\right), \tag{17}$$

which reflects the choice of the optimal nominal interest rate R_t conducted by a monetary

[19]Various indexing mechanisms can be considered here.

[20]The assumption of money in the utility function seems to be standard in the current generation of DSGE models. See Yun (1996) for an alternative model with a cash in advance constraint. The main policy implications don't seem to hinge on the particular way of introducing money in the model economy. In either framework money is non-neutral once nominal rigidities are considered.

[21]Note that Woodford (1996) shows that the existence of a complete set of state contingent securities ensures that agents are homogeneous with respect to consumption and asset holdings. Hence household heterogeneity is restricted to wages and, in turn, work hours only.

authority that potentially pursues both, an interest rate target and an output target. This policy rule typically depends on last year's interest rate gap $\frac{R_{t-1}}{R^*}$, the current inflation gap $\frac{\pi_t}{\pi^*}$, and the output gap $\frac{Y_t}{Y^*}$[22].

Fiscal policy is modeled by introducing government spending, G_t, as a stochastic process (usually dependent on current output, Y_t) which has to be financed by lump-sum taxes T_t and government has to maintain a balanced budget.

Equilibrium An equilibrium in a modern DSGE model is reached if the following conditions are simultaneously satisfied:

(i) Households maximize expected lifetime utility (16),

(ii) households set their optimal wage (and are aggregated optimally),

(iii) intermediate goods firms set their optimal prices (and imply an optimal aggregate price index),

(iv) all budget constraints are satisfied,

(v) and all markets clear[23].

b. *Contribution of New Keynesian DSGE Models*

The findings implied by recent New Keynesian DSGE Models are twofold.

First, from a substantive point of view, those models are able to fill some important gaps in terms of successfully replicating the business cycle. A prominent example is the ability to generate high persistence in output's response to nominal shocks, and hence this class of models incorporates strong internal propagation mechanisms. In particular there are four components (assumptions) of the model, that crucially drive this result:

Monopolistic Competition One of the major contributions of new Keynesian DSGE models is an explicit model of a monopolistically competitive intermediate goods sector, within an otherwise standard RBC setup. The assumption of monopoly power hast two effects. First, monopoly power permits the explicit analysis of pricing behavior since firms have influence on the price of the goods they sell. In particular this allows for the introduction of complicated pricing mechanisms as outlined above and gives rise to a host of new possibilities to introduce nominal rigidities. Second, equilibrium prices set above marginal cost rationalize demand-determined output in the short-run, which essentially is the key assumption of the basic *Keynesian cross* model.

Sticky Prices Staggered price setting as described in the previous chapter crucially influences the evolution of inflation over time, which can be approximated by a log linear difference equation[24]:

$$p_t = \xi_p p_{t-1} + (1 - \xi_p)\tilde{p}_t, \qquad (18)$$

where $\tilde{p}_t$ is the newly chosen price, in case the firm is able to reopimize, and p_{t-1} is last periods price which is predetermined. It turns out that the optimal price-setting rule for a Calvo (1983) style price setting mechanism boils down to the log linear rule

$$\tilde{p}_t = \mu + (1 - \beta\xi_p) \sum_{k=0}^{\infty} (\beta\xi_p)^k E_t\{mc_{t+k}\}, \qquad (19)$$

[22] The term *gap* here refers to the deviation of the current realization of a variable X_t from its desired or *target* level X^*.

[23] Note that these equilibrium conditions are a straightforward extension of the equilibrium defined for the basic RBC model.

[24] To keep the exposition simple we abstract from inflation indexing at this point in time and simply assume that prices stay fixed until a firm can reoptimize.

where mc_t represents marginal cost and μ is a price markup which depends on deep parameters of the model[25]. The intuition behind this pricing relation is as follows: To find their optimal markup μ, and hence the optimal price $\tilde{p}_t$, firms not only take into consideration their current marginal cost mc_t, but also the marginal cost of all the future time periods where they don't have the chance to reoptimize. This type of price setting behavior implies an equilibrium relation between inflation and output that is characterized by

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa(y_t - \bar{y}_t), \qquad (20)$$

where π_t is the inflation rate at time t, $y_t - \bar{y}_t$ represents the output gap, and κ is a function of several model parameters. Equation (20) is referred to as the *new* Phillips Curve because it is a forward looking version of the *traditional* Phillips curve as used in traditional Keynesian models. Although there have been serious debates about whether the *new* Phillips Curve is not only theoretically appealing but also reflects empirical observations, most recent findings support the *new* (forward looking) Phillips Curve in both dimensions.

Moreover, equations (18) and (19) combined also imply that inflation does not depend on past inflation but only on future expected marginal costs. This insight is particularly useful when attacking the question of desired inertia in inflation. To have inflation change slowly (in response to an economic shock) marginal cost has to react slowly. Marginal cost is a function of productivity shocks, the rental rate of capital and the wage rate. Hence for marginal cost to react slowly to a nominal (or productivity) shock, there has to be sufficient inertia in the rental rate of capital and wages. This clearly implies that sticky prices a la Calvo (1983) provide an explicit theory for the evolution of inflation but cannot generate the interia in inflation observed in the data. Hence, to create persistence one also has to model rigidities for wages and interest rates.

Sticky Wages By assuming that individuals have monopoly power in the supply of their differentiated labor service, one can introduce a wage setting mechanism similar to the Calvo (1983) staggered price setting. This introduces wage rigidities which help to improve the propagation of nominal shocks as mentioned above.

Variable Capital Utilization Variable capital utilization has a very crucial role in generating persistence in the way it influences the response of short-run interest rates. In a model with full capital utilization, a shock that changes firms demand for capital would immediately change the rental rate of capital and hence inflation. However, in a model where individuals can chose the amount of capital they want to supply to firms, such a change in the demand for capital does not have to change the short-term interest rate immediately due to flexibility in the supply of capital.

Incorporating the assumptions outlined in the preceding paragraphs combined with habit persistence, investment adjustment costs and indivisible labor New Keynesian DSGE models incorporate many of the extensions of basic RBC models in a unified setup. Yet these models are simple enough to make transparent the various effects and propagation mechanisms from a theoretic point of view.

Second, on top of the theoretical insights and from a methodological point of view, recent large scale New Keynesian DSGE models allow the use of formal statistical methods in order to evaluate opposing model specifications. In particular, the various stochastic disturbances introduced in models in the line of Smets & Wouters (2003) allow the researcher

[25] In particular the markup directly depends on the substitution elasticity λ_f in the CES production function (14).

to statistically test the parameter restrictions implied by the theoretical model.

E. *Empirical Evaluation Methods*

Since in general hardly any of the models outlined in section II have a closed form solution, a major part of the positive as well as the normative analysis in DSGE models is of empirical nature. As outlined earlier the equilibrium is characterized by policy functions which are approximate solutions to the system of nonlinear stochastic first order equations. These policy functions can be used to simulate time series and analyze the distributional properties of the artificial data to describe equilibrium behavior. Moreover, for policy experiments the researcher cannot use conventional comparative statics analysis but has to, again, simulate data to characterize the *response* to a policy shock, also called *impulse-response* analysis.

In this context, it still remains an open question (and is subject to intensive research) how to test different parameter choices (i.e. particular model specifications) against each other and how to (formally) evaluate which model specification is *more appropriate* for approximating a particular economy. Calibration as proposed by Kydland & Prescott (1982) does not provide a very (statistically) formal mean of evaluating different model specification, and as a consequence, is not particularly useful for reasonable policy evaluation because it relies (at least in part) on the researcher's subjective preferences (as a measure of fit) with respect to the selection of a particular set of parameters. Very recent research (e.g. by Negro et al. (2007) and Smets & Wouters (2003)), however, use formal statistical methods to evaluate big scale DSGE models. They exploit the virtue that the representation of the solution to the DSGE model (i.e. equation (7)) is equivalent to a Vector Autoregression (VAR) and hence it is possible to view the estimates of an unrestricted VAR as a benchmark specification. Using the VAR parameter estimates one can then formally test the cross-parameter restrictions implied by the solution of the DSGE model. If the restrictions cannot be rejected the DSGE model seems to imply reasonable restrictions. An alternative approach is to estimate a restricted VAR, using the restrictions implied by the DSGE model, and comparing impulse response functions to the impulse responses of the unrestricted VAR.

III. Endogenous Growth and the Business Cycle

The line of research which generates models referred in the previous sections is basically interested in replicating the business cycle. The determination of long-run growth is not the question of research *per se*. Growth is exogenous by construction and therefore this kind of models does not account for explaining trend output in a causal relationship with the business cycle. Aghion & Howitt (1998) refers to these shortcomings stating that the basic RBC models are unsatisfactory in the following respects[26]:

> ”First they could not account for the existence of stochastic trends[27] evidenced in empirical studies by Nelson & Plosser (1982); second aggregate demand shocks could have no lasting consequence on technology and growth; third money had to remain neutral in the long-run with monetary shocks being completely dichotomize in the long-run from technological shocks.”

As outlined in the last section developments in the New Keynesian theory were successful in

[26]See Aghion & Howitt (1998), p. 235. The book provides an excellent and comprehensive examination of endogenous growth theory, with Chapter 8 referring to the relation of growth and the business cycle.

[27]That is aggregate output seems to have a greater-than-unit root.

order to improve the propagation mechanism of short-run shocks, but the long-run growth path is unaffected by the shock. In contrast, the endogenous growth literature emphasizes that long-run growth has numerous determinants, including investment in R&D and human capital.

Endogenous growth usually heavily emphasizes on Joseph Schumpeter. The idea of Schumpeter (1942) is that the creation and destruction of production units resulting from innovations is essential in understanding both, growth and the business cycle. He states that

> ”The fundamental impulse that sets and keeps the capitalists engine in motion comes from new consumers' goods, the new methods of production or transportations, the new markets, . . . [This process] incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of creative destruction is the essential fact about capitalism.”[28]

His idea allows for the linkage in both directions: *cycles-to-growth* and *growth-to-cycles*. The thought of *creative destruction* became central for modern theories of endogenous long-run growth referred to as *neo-Schumpeterian* growth theory (Aghion & Howitt (1992) and Grossman & Helpman (1991)).

In the present section we first state the two basic ideas of endogenous growth and following review a selection of models which combine elements of endogenous growth with business cycle theory.

A. *Two Controverting Ideas*

Broadly speaking there exist two contrasting ideas allowing business cycles to interact with long-run economic growth. The main difference refers to the perception of recessions as opportunity or as waste.

a. *Schumpeter and the Virtue of Bad Times*

Recessions may provide a *cleansing mechanism* for correcting organizational inefficiencies and for encouraging firms to reorganize, innovate or reallocate to new market conditions[29]. If market forces operate, firms which are unable to reorganize or innovate are eliminated and average productivity will increase. Thus small cyclical downswings can be productivity stimulating and foster long-term growth. Similarly according to the *opportunity cost* approach emphasized by Hall (1991) and Aghion & Saint-Paul (1998), technological change is the result of *internal (purposeful) learning*. Productivity improving activities are done during times of economic downswings. Recessions are considered as the right time for firms to engage in activities like restructuring, training and relocation to raise the productivity in the long-run. Endogenous growth models using the mechanism of internal learning tend to imply a positive relation between growth and volatility which would rather doubt the positive effect of stabilization policy on long-rung growth. But to put it in words of Aghion & Howitt (1992), p. 243:

> ”However, these effects should not be overemphasized. In particular, the idea that excessive macroeconomic volatility is an obstacle to growth appears to be largely supported by recent empirical evidence...”

The reverse causality from growth to fluctuations is examined with the so called *Schum-*

[28] The quote is drawn from Aghion & Howitt (1992), p. 324.

[29] See also Caballero & Hammour (1991) who builds on Schmupeter's idea of the *cleansing effect*.

peterian Waves, which explain the causality from productivity to fluctuations or *waves*[30]. The idea states, that the introduction of *General Purpose Technologies (GPT)* which are raising productivity and output in the long-run may cause fluctuations in the form of waves in the short-run. While in the simple RBC model the technological process directly affects productivity and leads to higher growth, the theory of GPT covers a more complex process. Unlike in the RBC approach, where a cyclical upturn arises in response to the shock, the effect here can work in the other direction as in the period between the discovery of a new GPT and its implementation, resources are taken out of production process and are used for R&D activities for a new product.

b. *Procyclical Productivity Enhancement*

The contrasting approach is the idea of *learning by doing* (or *external learning*, going back to Arrow (1962)), where during the production process, people gain in human capital and productiveness. An economic expansion may have positive long-run effects on total productivity growth as economic agents learn faster in cyclical upswing phases. Compared to the process of internal learning, learning by doing takes the form of a pure externality, where the learning process can be thought of as a by-product of the output process and technological change is pro-cyclical. Thus, even a temporary rise in output increases productivity and affects growth and employment in the long-run. This is the case for both, temporary real shocks and temporary nominal shocks in the presence of nominal rigidities (Stadler (1990)).

B. *Recent Models with Elements of Endogenous Growth*

Most of the recent and promising models covering endogenous growth and the business cycle are based on a RBC style approach. In order to endogenize productivity dynamics the idea of *learning by doing* by Arrow (1962) or a modification of the *innovation-based growth theory* going back to Romer (1990) and Aghion & Howitt (1992) is used. A selection of models will be reviewed here.

a. *Learning by Doing*

There exists a class of models possessing the structure of a stochastic growth model with endogenous technology via learning by doing[31]. In line with section II we outline the basic features of a model of this kind. Technology consists of an exogenous and an endogenous component, where the exogenous one is able to generate movements in the endogenous productivity component. As recent models focus on the effect of stabilization policy, the model's setup is New Keynesian, including features like indivisible labour, nominal rigidities and a preference shock.

Similar to equation (4) in the endogenous setup the aggregate production function can be written as:

$$Y_t = F(K_t, H_t, A_t, Z_t), \tag{21}$$

where Z_t denotes the index of knowledge which is acquired through external learning-by-doing. The representative household's lifetime utility function is defined similar to expression in (16), e.g.

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u(C_t) - z\left(H_t, \lambda_t\right) + v\left(\frac{M_t}{P_t}\right)\right], \tag{22}$$

where a preference parameter λ_t is included, which represents an exogenous *i.i.d.* demand (or preference) shock. Households maximize their utility in expression (22) subject to the budget constraint (12), with the modification

[30] Chapter 8.4 in Aghion & Howitt (1998) revisits *Schumpeterian Waves*.

[31] See for example Stadler (1990), Martin & Rogers (1997), Blackburn (1999), Blackburn & Pelloni (2004) and Blackburn & Pelloni (2005).

that the monetary growth rate, μ_t, which is an exogenous stochastic process in equation (12), represents here monetary authority's *feedback* to exogenous shocks.

The model described with the equations above is similar to Blackburn & Pelloni (2005). Some other authors abstract from physical capital and include only human capital in the production function[32]. The main feature of all these models is that besides the exogenous productivity process A_t in equation (21), endogenously generated human capital Z_t produces output. Using the concept of learning by doing, the accumulated technical knowledge Z_t is modeled to depend on factors like the physical capital stock, the level of the labour input and on the level of labour productivity:

$$Z_t = \Psi(Z_{t-1}, K_t, H_{t-1}, \frac{Y_{t-1}}{H_{t-1}}) \qquad (23)$$

A higher capital stock and greater level of employment offers a greater range of opportunities for learning and acquiring new skills. External learning acts as propagation mechanism for both demand side and supply side disturbances to output, a temporary shock can induce a permanent upward shift in the aggregate output. While producing people gain new ideas and are able to design more efficient ways of organizing production.

Blackburn & Galindev (2003) introduce both, an internal and an external learning mechanism in the knowledge function. The accumulated technical knowledge which is modeled similar like in equation (23), is extended by T_t, which denotes the amount of labour the agents are devoting in order to improve their productive efficiency (education and training):

$$Z_t = \Psi(Z_{t-1}, H_{t-1}, T_{t-1}), \qquad (24)$$

[32]See for example Stadler (1990), Martin & Rogers (1997) and Blackburn & Galindev (2003). But the main results do not hinge on this specification.

The model is set as planner's problem maximizing social welfare subject to the resource constraint. Aggregate output evolves similar to equation (21) and is totally spent for consumption. A positive preference shock in the utility function leads agents to devote more time to working and because of higher *opportunity costs* less time to learning. The idea of the latter is that activities like education and training are costly in terms of foregone current production. Depending on the parameters indicating the magnitude of internal or external learning in equation (24) Z_t decreases or increases after a temporary exogenous shock. The model further predicts that the correlation between growth and volatility can either be positive or negative according to whether technological change is driven predominately be internal or external learning. This has implications on the effect of stabilization policy on long-run growth, which will be dealt in section C a.

b. *Creative Destruction*

Creative destruction focuses on quality-improving innovations by entrepreneurs rendering old inventories, ideas, technologies, skills, and equipment obsolete. Aghion & Howitt (1992) develop a prototype model of growth through creative destruction based on the idea of Schumpeter. The model set-up builds on the *innovation-based growth theory* initiated by Romer (1990) who assumes that aggregate productivity is an increasing function of the degree of product variety[33]. Intellectual capital is regarded as the source of the technological processes. While physical and human capital are accumulated through saving and schooling, the intellectual capital depends on innovation. Output is produced by labour and a continuum of intermediate products using a *Dixit-Stiglitz-Ethier* production

[33]For a review on this topic see Durlauf & Blume (2008).

function of the form

$$Y = H^{1-\alpha} \int_0^A x(i)^\alpha \mathrm{d}i, \tag{25}$$

where H is the constant aggregate supply of labour, $x(i)$ represents the amount of intermediate good i in the according sector used for production and A denotes the different intermediate products which can be used. In the Schumpeterian theory the approach looks a bit different: it is not the variety of products but the quality improving innovations which is generating growth. Innovations create improved versions of old products. In the model the amount of product variety is normalized to unity, but each intermediate product has a separate productivity parameter $A(i)$, depending on the arrival rate of new innovations in the sector i:

$$Y = H^{1-\alpha} \int_0^1 A(i)^{1-\alpha} x(i)^\alpha \mathrm{d}i, \tag{26}$$

The model generates growth and volatility by a random sequence of vertical innovations that themselves result from research activities which are using labour as input (*quality ladder* approach). Each innovation in the line of a certain intermediate good i can be used to produce final output more efficient.

The representative firm maximizes profits, taking input prices as given. The realized amount of R&D in each sector i is determined by an economic decision process. The model incorporates two counteracting distortions. The first is *technology spillover*, which means that the already implemented innovation in the sector makes the work for other researchers easier. The other effect is called the *business stealing effect*. Every new innovation diminishes the surplus of the previous innovation by making it obsolete. Thus, the more research is expected to occur in the next generations, the shorter the periods of profits of the innovators will be and therefore the smaller will turn out the payoff to innovating.

Factors of production can either be used in the production process or in research activity. Thus, on the one hand firms are motivated to engage in research by the prospect to achieve profits when the innovation is successfully patented, but on the other hand with the arrival of the next innovation, these rents will be disturbed. Both, long-run growth and the variability of shocks is endogenized in the model, as their distribution depends on the economic decision of the involving agents. The authors show that the model possesses a unique balanced growth equilibrium in which the log of output follows a random walk with drift and is therefore in line with the empirical results by Nelson & Plosser (1982).

Recent models which are building on the quality ladder approach of Aghion & Howitt (1992) are by Comin & Mulani (2005) and Phillips & Wrase (2006). The former explains the source of volatility on the aggregate and firm level with Schumpeterian dynamics, whereas the latter incorporates the idea of creative destruction into basic RBC model in order to generate realistic volatilities for output.

c. *Medium-Term Cycles*

Alike the models referred above in section a which cover the idea of *learning by doing*, Comin & Gertler (2006) examine the interrelation between fluctuations in different frequencies where elements of endogenous productivity are used as propagation mechanism. The focus of this model, which will be described here only briefly, lies in the emergence of medium term cycles. The medium term cycle is defined as the sum of high- and medium-frequency variations, including frequencies between 2 and 200 quarters. In a two-sector version of a RBC model (with consumption and capital goods) medium term cycles arise as response of economic activity to high frequency fluctuations.

Aggregate output is modeled in a modification of Romer (1990) as the sum of output of all final goods firms, where the number of individual final goods firms is determined endogenously by an entry-exit mechanism. Additionally, the authors allow for an endogenous rate of adaptation of new technologies together with endogenous R&D which is modeled to behave procyclically. The model predicts that the latter permits disturbances to have permanent effects on productivity movements while the former accelerates the transitions of productivity to a new steady state.

d. *Opportunity Cost*

Following the work of Aghion & Saint-Paul (1998), where economic fluctuations are modeled as two-state stationary Markov model of recessions and expansions, the optimal choice for a representative firm to undertake production improvements is the trade-off of the implementation costs against the future gains due to the higher productivity. In order to increase its speed of productivity improvement, the firm must sacrifice a fraction of its production. The authors argue that the opportunity cost of productivity improvement is given by the marginal current forgone revenue, which is higher in expansions than in recessions. Symmetrically, the gain from the activity is higher in expansions than in times of economic downturns. But this is spread over the future, which also includes recession phases. Thus, the gain is less cyclical than the cost and the optimal productivity rate is counter-cyclical. The authors also show that, if on the other hand, the implementation cost of productivity improvements would be bought on the market (in the form of R&D services) by sacrificing a quantity of output instead of a fraction of production like above, the optimal productivity must not be counter-cyclical. This can be explained by the fact that the market cost of the productivity improving activities does not depend as strongly on the business cycle, whereas the firms future discounted revenues from the productivity behave strongly procyclical.

The models referred in section B use elements of endogenous growth to relate growth and business cycles. The sign of the relationship can either be positive or negative and affects the impact of stabilization policy on long-run growth. In other words it determines whether stabilization policy, designed to smooth the fluctuations, has also a beneficial effect on long-run growth. The next section will deal with this topic in more detail.

C. *Fluctuations, Growth and Policy*

The question how short-run fluctuations might affect the long-run trend depends besides values chosen for certain parameters and the types of disturbances considered in the model, on the mechanism responsible for generating technological change[34]. It is not surprising that different models find different results. The models of Stadler (1990), Martin & Rogers (1997) and Blackburn & Galindev (2003) find a negative relationship between long-run growth and volatility, whereas the work by Blackburn (1999) and Blackburn & Pelloni (2004) challenges these findings. Similarly, the existing empirical literature is ambiguous on this issue. Kormendi & Meguire (1985), Grier & Tullock (1989) and Zagler & Stastny (2007) find that a larger amplitude has positive effects on long-run growth. On the other hand work by Ramey & Ramey (1985), Kneller & Young (2001) and Döpke (2004) found a negative correlation between high-frequency fluctuations and long-term growth. Imbs (2007) explains the inconsistency in the theoretical literature by arguing that the positive effect, which is mentioned in the literature does indeed work on sectoral level but stay masked at the aggre-

[34] The two controversial ideas were outlined in section A. But as seen in the model of Blackburn & Galindev (2003) these two mechanisms must not necessarily exclude each other.

gate level. He empirically finds a positive effect of the sectoral volatility on growth, and moreover shows the irrelevance of this result on the relationship of growth and volatility at the aggregate level.

In this section we first review some model implications of stabilization policy on growth, and second examine the role of credit constraints in the relationship of fluctuations and growth.

a. *Stabilization Policy Implications*

Most models covering the idea of learning by doing or demand spill-overs, going back to Arrow (1962)), predict a negative relationship between long-run growth and economic volatility (Stadler (1990), Martin & Rogers (1997) and Blackburn & Galindev (2003)). The authors conclude that stabilization policy is desirable because of its positive impact on knowledge accumulation. Likewise, Martin & Rogers (1997) show that if cycles create fluctuations in employment and unemployed loose their skills in recessions, any type of temporary shock - be it either real or monetary, demand or supply shock - can persist for a long time. By subsidizing labour during recessions and taxing labour in cyclical upswing phases, the government eliminates the employment consequences of the cyclical fluctuations. Thus, learning can still take place in recessions and the authors show that a countercyclical policy of this kind is able to maximize the growth rate of output.

By contrast the models of Blackburn (1999) and Blackburn & Pelloni (2004) point out that in a stochastic endogenous growth model using the concept of learning by doing as outlined in section B a, the relationship of growth and volatility must not be negative. This would imply a trade-off between short-term stabilization and long-term growth. In both models besides the exogenous technology shock the economy is disturbed by a preference shock and a monetary growth shock. Stabilization policy takes the form of a counter-cyclical feedback rule for monetary growth responding to fluctuations in employment and inflation. Blackburn (1999) shows that it is essential if the additional learning during expansions is higher or lower then the loss of learning during recessions. Assuming increasing returns to labour in the knowledge accumulation process can - but must not - indicate a positive relationship of growth and volatility. This would generate a policy conflict between short-term stabilization and long-term growth.

Another model examining the relationship between growth and volatility is the set-up by Blackburn & Pelloni (2004). The authors show that in an economy which is exposed by demand disturbances the relationship between output growth and output variability depends on the source of the stochastic fluctuation. The relationship is positive if a real demand shock (preference shock) dominates and negative if a nominal demand shock (monetary growth shock) dominates. The intuition of this result is that the nominal uncertainty, which is introduced by both types of shocks and transmitted via the labour market to productivity, decreases long-run growth. On the other hand, the preference shock additionally affects the households consumption-investment decision. Using the convex property of the saving behavior and the effect of learning-by-doing, output increases and this leads to the positive relationship between volatility and mean of output. This may offset the negative impact through the employment channel.

Likewise in a similar model Blackburn & Pelloni (2005) argue that depending on the type of shock, monetary stabilization policy may either promote or disturb long-run economic growth. In the case of nominal shocks monetary policy acts both, stabilizing and enhancing long-run growth. On the other hand, in the case of a real shock (technology or preference shock) only one of these aims can be achieved. By conditioning monetary policy on the realization of a real shock, fluctuations in output can in fact be stabilized, but the greater nominal uncertainty leads to higher wages and a lower real activity. On the other hand, eliminating fluctuations from a nominal shock leads to a higher real activity and - via learning by doing - to a higher rate of the technological progress and growth.

The model of Blackburn & Galindev (2003) who introduce both, an internal and an external learning mechanism finds that the correlation between the mean and variance of output growth is more likely to be negative if technological change is driven predominantly by external learning. If the process of internal learning dominates, the correlation is positive.

b. *Credit Constraints*

Borrowing constraints of firms generate procyclical productivity growth. If firms are prevented from borrowing to finance investment in R&D and further human capital, they have to use their own profits to finance them. Thus, these kinds of procyclical expenditure emphasized also by Stiglitz (1993) are able to induce a positive impact of demand shocks on long-run productivity.

Aghion, Angeletos, Banerjee & Manova (2005) argue that the completeness of financial markets affects the correlation between volatility and growth. In order to come to this conclusion, the authors show that in the case of *tight financial markets* the share of long-term (productivity enhancing) investment behaves procyclically, whereas the share of short-term investment is countercyclical. Assuming *complete markets*, it is just the other way round. Short-term investment is defined as kind of investment taking relatively little time to build and generates output relatively fast. Long-term investment on the other hand, takes more time to complete but contributes more to productivity growth. Tighter constraints imply that long-term investment may be interrupted and face a liquidity risk[35]. As this is higher in recessions then in cyclical upswings, it makes the relative demand for this kind of investment procyclical.

Following the authors show, that the tighter the credit constraints are, the higher is the negative correlation of volatility and growth. Like in equation (23) aggregate productivity has two components, an endogenous shock and an exogenous shock. In an economy with incomplete markets the fraction of productivity enhancing investment is more procyclical and amplifies the cyclical behavior of output compared to a situation with complete markets. But simultaneously, the financial constraint leads to a lower productivity growth and hence to a lower output compared to complete markets (because long-term investment is lower and only short-term investment is higher). Consistent with the model, the authors find in their empirical analysis that the negative relationship between volatility and growth tends to be stronger in countries with lower financial development.

Likewise Aghion & Marinescu (2006) show that especially in countries with lower financial development, countercyclical budgetary policies are growth enhancing, in the way that they are reducing the costs that negative liquidity shocks impose on credit-constraint firms. Increasing the liquidity of firms in economic downturn phases, gives them the opportunity to continue their activity without shortening expenditures on R&D and other long-term growth-enhancing investments.

IV. Concluding Remarks

The paper reviews a selection of macroeconomic models which integrate (endogenous) growth and the business cycle in one framework. Our journey starts in the 1980s with the basic RBC model which represent a joint framework for growth and the business cycle.

[35] Short-term investment is not affected by this risk.

The model - and especially its New Keynesian extension - by now got widely used with the intention of analyzing business cycles fluctuations. But the determination of long-run economic growth is still exogenous by construction. Therefore neither the causality nor a correlation between growth and fluctuations can be investigated. Models using aspects of endogenous growth were able to shed light on the interrelation of growth and the business cycle. On the one hand any temporary disturbance can have an effect of long-run growth path of output, and on the other hand also the reverse causality from productivity to business cycles can be explained. This has important implications for macroeconomic policy, which is then able to effect aggregate output on both frequency domains. But so for, neither on theoretical nor on empirical grounds there has been found a clear conclusion on the sign of the relationship between economic growth and cyclical fluctuations. In order to draw conclusions for macroeconomic policy, this strand of research certainly demands a stronger attention in the future.

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