DEM Discussion Papers

Department of Economics and Management

2013/13

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ISSN 2282-2801 DEM discussion papers [online]

UNIVERSITÀ DEGLI STUDI DI TRENTO

DEM DISCUSSION PAPER

ISSN 2282-2801 DEM Discussion Papers [online]
Università degli Studi di Trento

Department of Economics and Management, University of Trento, Italy.

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Scope and Flaws of the New Neoclassical Synthesis*

Ronny Mazzocchi †

This version: November 2013

Abstract

The current consensus in macroeconomics represented by the New Neoclassical Synthesis (NNS) is based on dynamically stochastic general equilibrium (DSGE) modeling with Real Business Cycle (RBC) core to which nominal rigidities are added by way of imperfect competition. The claim is that the NNS model is capable of rigorously reproducing observable phenomena and is able to provide a microeconomically well-founded basis for the design of optimal policy rules, since it is amenable to welfare analysis. Nevertheless these results come at the price of many ad-hocery and other shortcomings which are indispensable for intertemporal equilibrium modelling of the current kind. Moreover the NNS did not let us think about the financial crisis and the macroeconomic imbalances that were forming in the years of the Great Moderation.

JEL Classification: B22, D50, E21, E22.

*I wish to thank Roberto Tamborini, Hans-Michael Trautwein, Axel Leijonhufvud, Giorgio Fodor, Dirk H. Ehnts, Massimo Molinari, Emiliano Santoro, Francesco Saraceno and Andrea Fracasso for helpful discussions and comments. I wish also thank the Institut für Volkswirtschaftlehre und Statistik of the University of Oldenburg for the long and valuable period of study and research I spent there.

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1 Introduction

Over the last 30 years the global financial markets have become increasingly volatile, with bubbles and crises alternating in ever larger waves at shorter intervals. It was perhaps all the more surprising that macroeconomics, during the same period, essentially began to redevelop around the core of the *efficient market hypothesis* of finance theory (Fama, 1970). Rational expectations, efficient processing of informations in the markets, perfect coordination through price mechanisms were the main ingredients of the macroeconomic debate between the 1980s and 1990s. Surely there were still, for a while, a lot of controversies between the so called Real Business Cycles theory (RBC), the New Keynesian Economics (NKE) and the diverging approaches that look at the consequences of information asymmetries and other market imperfections that may cause financial crises, mass unemployment and other macroeconomic pathologies.

In the Nineties the combined assault of the time inconsistency problem and the RBC literatures (Kydland and Prescott, 1977; 1982) eventually led to the formation of consensus models called *New Neoclassical Synthesis* (Goodfriend and King, 1998; Blanchard, 2000). Like the Old Neoclassical Synthesis of Hicks, Samuelson and Patinkin, the New Neoclassical Synthesis (NNS) tries to link micro- and macroeconomics, using a general equilibrium framework to model some typically Keynesian features. The main idea of this literature is to furnish a common vision of neoclassical and Keynesian theories entrusting to them separate roles in the construction of the model: the RBC part of the model explains the evolution of the potential output embodying *Dynamic Stochastic General Equilibrium models* (DSGE), while the transitory deviations from this trend are explained using the slow adjustment of prices and wages which were developed in the 1980s by the NKE. Like RBC models, the NNS assigns a very important role to real shocks in the explanation of short run fluctuations; numerous recent studies have shown how monetary policy is able to explain only a part of economic fluctuations, and therefore real shocks play an essential role in the study of business cycle[1]. Differently from the RBC models, however, the NNS does not consider these fluctuations efficient and desirable, and does not think that monetary policy is totally ineffective. In fact, because of the delays in the adjustment of prices and wages, the consequences of real shocks are undesirable. An active economic policy can therefore intervene to reduce these distortions.

The NNS became the consensus view not only because of the elegant

[1]This has also an important theoretical implication: the impact of the Neoclassical Counterrevolution of the 1970s has not established a new vision of the macroeconomic phenomena (which was the explicit aim of the Real Business Cycle authors), but it has instead forced the old mainstream to adopt new and more sophisticated methodological techniques.

theoretical formulation, but also because it seemed to be successful. The reduction in the volatility of business cycle fluctuations starting in the mid-1980s, the low inflation and the predictable policy were long seen as the new theoretical framework was correct (Clarida, 2010). However the so-called *Great Moderation* (Stock and Watson, 2002; Bernanke, 2004) is now also interpreted as missing inflation that followed from a combination of global financialization and balance of payment imbalances (Borio and Lowe, 2002). Moreover the conventional wisdom on the links between monetary and financial stability[2] has been seriously questioned. While the empirical evidence is broadly consistent with the idea that monetary instability can cause financial instability, the interpretation of this evidence - and the policy conclusions that follow - could be criticized under different point of view. In particular, the evidence does not mean that either unexpected changes in the inflation rate are by themselves the major source of instability or that financial imbalances will not develop in a low and stable inflation environment. The coexistence of an unsustainable boom in credit and asset markets on one side, and low and declining inflation on the other can be explained by a large number of factors. The main reason[3] is the positive association between favorable supply-side developments (which push down the prices) and asset price booms (easier access to external finance and optimistic assessment of risk)[4]. The combination of rising asset prices, strong economic growth and low inflation can lead to overly optimistic expectations about the future which could generate increases in asset and credit markets significantly beyond those justified by the original improvement in productivity[5]. On this line we can mention the contribution of Mandelbrot (2005) who argued that it was the abuse of the efficient market hypothesis - and the underlying assumptions of white noise and Gaussian normal distribution - that prevented economists and analysts to contemplate both increasingly

[2]This link is nicely summarized by Bordo et al. (2000) who write that "*a monetary regime that produces aggregate price stability will, as a by-product, tend to promote stability of the financial system*".

[3]Other relevant factors could be the successful implementation of the stabilization programs after the 1970s, which anchors price expectations and lead to a significant reduction in inflation. These situation create a general optimism about the future economic perspectives, which can underpin a consumption and lending boom, often financed by inflow of foreign capital. Another key role could have been played by the credibility of the central bank's commitment to price stability, by anchoring expectations and hence inducing greater stickiness in prices and wages, alleviating the inflationary pressures normally associated with the unsustainable expansion of the aggregate demand.

[4]In the United States the faster productivity growth and the shifts in the structure of the labour market were partly responsible for the low inflation of the late 1990s and the strength of many equity markets.

[5]Yet, a self-reinforcing boom can emerge, with increases in asset prices supported by stronger demand and sustained, at least for a while, by optimistic expectations. While the stronger demand can put upward pressure on inflation, this pressure can be masked by the improvement to the supply side of the economy.

risky behavior on behalf of financial intermediaries and their clients. This fault - together with a benign neglect of asset price inflation and systemic risks on behalf of the central banks and supervisory authorities (Bernanke and Gertler, 1999; 2001) - has undoubtedly contributed to destabilize the economic system (Leijonhufvud, 2007).

It is not necessary to go as far as fractal geometry or other more complex theories of turbulences to explain the basic macroeconomic problem underlying the great credit crisis and many of the developments prior to it: *investment-saving imbalances* and their consequences for the formation of budget constraints and expectations. The coordination of saving and investment decisions was analyzed by earlier macroeconomics, especially in the works of Wicksell (1898), Keynes (1930, 1936, 1937b), and their respective followers (Lindahl, 1930; Lundberg, 1937), but in the last forty years it was drifted so far out of focus as to be virtually forgotten. The intertemporal coordination failure problem is especially important because, without it, we are left with theories of unemployment that look only at the imperfections in the labour/goods markets and do not seem able to explain the real phenomena.

At the beginning of the last decade Michael Woodford gave the impression to have brought back to center stage pre-Keynesian macroeconomics. In his authoritative contribution *Interest and Prices* (2003) he furnished an excellent representation of the dynamic interaction between interest rates, price level and output[6]. The book self-consciously borrows its title from Knut Wicksell's (1898) masterpiece on monetary economics and indeed the main aspect of Woodford's contribution is the rediscovery of the Wicksellian nominal interest rate, *vis-á-vis* the "natural" interest rate prevailing at full-employment general equilibrium, as the pivot of rule-based monetary policy. Unfortunately in the book most of the pre-Keynesian features are notably absent. In particular, Woodford does not consider the presence of frictions in the capital market which generates the first pillar of Wicksells view, i.e. the bank intermediation among savers and investors. Moreover there is no room for information problems and the intertemporal disequilibrium which could produce the well-known dynamics of money creation, of prices and of nominal income, i.e. the so-called *cumulative process* (Boianovsky and Trautwein, 2006). These weaknesses not only prevent the discussion of the effects and the relations between financial market and the real economy, which were the core of old macroeconomics, but it seems to have led economic theory far away from the understanding of the behavior of the global economy in the last decades. Coordination failures in the market system that have their origin in the capital markets and cannot independently be

[6]Many economists have noted the contrast between the title of Patinkin's treatise (1965), *Money, Interest and Prices*, and Woodford's *Interest and Prices* as making it very clear the diminished role of the quantity of money in modern macroeconomic theory.

corrected in the goods or in the labour markets: if there is a discrepancy between saving and investment at the full employment rate of real income, the flexible adjustment of money wages will not restore the economy at its potential level but rather can make things worse.

The chapter is organized as follow. Section [2] offers a historical reconstruction and clarifies some basic theoretical issues underlying the NNS. Section [3] explores the alleged "Wicksell connection" of the NNS put forward by Woodford. Section [4] presents a model with endogenous determination of the capital stock whereby it is possible to assess some basic issues concerning the current consensus in macroeconomics. Section [5] shows the main weaknesses of NNS framework with particular emphasis on coordination and information problems. Section [6] concludes.

2 From the Old to the New Neoclassical Synthesis

In the last twenty years we have seen the development of a new macroeconomic framework usually defined as an IS-LM model of second generation, designed to replace the traditional one in the academic research and in the teaching activities. The Hicksian interpretation of Keynes' work (Hicks, 1937) was the origin of the first consensus view that came to be dubbed "*Neoclassical Synthesis*" by Samuelson (1951, p. 336). Its basic tenets were that market systems would be hypothetically self-stabilizing around full-employment equilibrium, but that, in reality, they would frequently tend to settle at inefficient states of underemployment equilibria. Such constellations could occur in cases of extreme liquidity preference in financial markets (liquidity trap), strong pessimism of business firms in the goods markets (investment trap), or nominal wage stickiness in the labour market (nominal rigidities).

Even though IS-LM modeling was confined to comparative-static analysis of equilibria in goods and asset markets, underemployment was conceived as a disequilibrium phenomenon. A part of the labour force would be involuntarily unemployed as market forces fail to push the economy back to full employment equilibrium starting from an intersection of IS - goods market equilibrium - and LM - asset market equilibrium - at which the labour market is out of equilibrium. It was argued that the state ought to play the role of a benevolent social engineer who minimizes the negative welfare effects of macroeconomic malfunctionings by way of fiscal and/or monetary measures to stabilize aggregate demand.

This first consensus view essentially combined at least some neoclassical modes of thinking with Keynesian prescriptions for economic policies to reduce or even to dissolve underemployment in the short run. Full-employment IS-LM was taken to correspond with the long-run perspective of the standard Solow model of steady-state growth (Solow, 1956), even though the two frameworks were not well connected. Since liquidity and investment traps came to be increasingly considered as empirically irrelevant or episodes of market psychology confined at best to the very short run, the Keynesian explanation of underemployment slowly boiled down to wage rigidities. In this respect, the consensus view embodied in the old synthesis did no longer differ much from the approaches of pre-Keynesian neoclassics, such as Cassel (1918) or Pigou (1933). Since nominal rigidities and pessimistic profit expectations were seen as a short-run phenomena that would be eliminated sooner or later by market forces, it was considered plausible that thinking about economic growth could be based on entirely different analytical frameworks, where differences between the neoclassical concept of marginal productivity and the Keynesian concept of the marginal efficiency of capital would not matter.

Up to the 1950s this model was very successfully. This was possible for some important circumstances: first, the presence of a certain monetary stability and of rather peaceful industrial relationships that justified - at least in the short run - the basic hypothesis of fixed prices and wages. Second, the slow shifts of the aggregated supply curve observed in the empirical data allowed economists to consider it as fixed, at least in the medium run. Finally, the substantial stability of the two curves allowed economists to use the IS-LM model for designing possible macroeconomic policies. Starting from the 1960s, and particularly toward the end of the decade, it was however clear that the IS-LM model could not represent a general vision of the economy, and that the supply side could not be neglected, even in the short period. The need to develop an *ad hoc* price-wage equation was solved with the introduction of the Phillips curve. Nevertheless, the lack of coherent expectations[7] and of structural relationships derived from a maximization process of rational agents constituted meaningful objections that conducted to the collapse of the old Neoclassical Synthesis.

The pendulum of high-brow opinion swung back to the view that market systems are inherently efficient and stable. The Neoclassical Synthesis came under heavy fire by the Monetarist and New Classical "counter-revolutions". The emphasis put on the need to incorporate the rational expectations in the model has led to a first reformulation of the IS-LM model: using Lucas' AS curve (Lucas, 1972) in place of the traditional Phillips curve, it showed the irrelevance of macroeconomic policies and the impossibility of inefficient equilibria according to the conclusions obtained by Sargent and Wallace (1975). Starting from the 1980s the DSGE methodology - in particular its more popular version, the RBC model - has become the major paradigm in macroeconomics. Its essential features are the assumptions

[7]The importance of the expectations was underlined already by Keynes which in his works were exogeneous one, i.e. not connected with the evolution of the state and control variables.

of intertemporal optimizing behavior of an economic representative agent[8], competitive markets and price-mediated market clearing through flexible wages and prices. It therefore assumes that all markets - including product, capital and labour markets - are cleared in all periods, regardless of whether the model refers to the short run or the long run. The continuous market clearing hypothesis requires that prices are set at an equilibrium level, which can be proved under certain assumption. But little has been said about how the general equilibrium can be achieved. In an economy in which both firms and households are price takers, an auctioneer who adjusts the price toward the general equilibrium is implicitly presumed to exist. Therefore, how an equilibrium is brought about is essentially a Walrasian *tâtonnement* process. Since output fluctuations are basically considered to be optimal response, the RBC theorists reject the old Keynesian view that the state ought to stabilize aggregate demand. On the contrary, they argue that problems of dynamic inconsistency would make discretionary action to stabilize output or price level ineffective, if not inefficient (Barro and Gordon, 1983).

Working with such a framework of competitive general equilibrium is elegant and perhaps convenient. Nevertheless, this model was totally unsatisfactory from different points of view. It neglects many restrictions on the behavior of agents: the trading process, the market-clearing process, the implementation of new technology, the market structure and many others. Moreover the RBC model fails to replicate essential product, labour and capital market characteristics. All these theoretical contributions were criticized especially regarding the impulse mechanism. In the standard DSGE model, technology shocks are the driving force of the business cycles and are assumed to be measured by the Solow residual. However, there are several reasons to distrust it as a measure of technology changes. First, the Solow residual is computed on the basis of observed output, capital and employment and it is presumed that all factors are fully utilized. Second, Mankiw (1989) and Summers (1986) have argued that such a measure often leads to excessive volatility in productivity and even to the possibility of technological regress, both of which seems to be empirically implausible (Calomiris and Hanes, 1995). Third, it has been shown that the Solow residual can be expressed by some exogenous variables that are unlikely to be related to the factor productivity[9]. Fourth, the Solow residual can be contaminated

[8]While Ramsey (1928) constructed his famous model to provide the basis for the normative analysis of a central planner's problem of maximizing society's consumption over time, writers in the RBC tradition have reinterpreted it as a positive description of a decentralized economy.

[9]Jorgenson and Griliches (1967) show that the Solow residual, rather than changes in technology, highlights changes in the use of capital and the labour-hoarding phenomena. Hall (1986, 1990) shows that the distribution between labor and capital occurs according to the exponents of the Cobb-Douglas only in the case of perfect competition environment. Therefore in imperfect competition the Solow residual includes also changes in markup over the business cycle. Moreover if we admit increasing returns to scale the Solow

if the cyclical variations in factor utilization are significant. Another main weakness of the RBC models - that is rather consistent with the transmission mechanism - is that technology shocks are strongly pro-cyclical: these models predicts a significantly high positive correlation between technology and employment (Stadler, 1994), whereas empirical research demonstrates a negative or almost zero correlation (Galí, 1999; Francis and Ramey, 2005, 2003).

The dissatisfaction with the RBC models stimulated research to move towards a post-Walrasian microeconomics in order to derive the commonly observed macroeconomic phenomena from correct microeconomic principles (Stiglitz, 1991). Over the last decades a shift has begun away from a concentration on the Walrasian price-taker models towards a world where firms may be strategic agents. This new approach uses the standard tools of New Classical Macroeconomics (NCM): consumers, workers and firms are rational, agents always maximize and markets clear. But the output of these new models follows Keynesian lines: the aggregate economy has multipliers, economic fluctuations are not Pareto optimal, and finally government interventions can be effective to control business cycles.

Imperfect competition is a key assumption of this approach (Blanchard and Kiyotaki, 1987; Dixit and Stiglitz, 1977): it opens new channels of influence of monetary policy but also creates the possibility that an increase in output may be welfare improving (Cooper, 2004). To ensure that aggregate demand is always sufficient to match aggregate supply - other than simply assuming it - further conditions need to be fulfilled. Thus it must be assumed that households own firms, that they receive firm's profits as part of their income in each period, and that there are no distribution effects of output and inflation gaps that could feed back onto the latter. All these elements are taken care of by the conventional assumption of the representative household. Finally, the assumption that both households and firms have rational expectations of future output and inflation gaps makes the optimal plans self-fulfilling, at least in the absence of shocks. In this setting, output and inflation gaps have no influence on the speed and extent to which information is incurred, processed and used for predictions.

Imperfect competition by itself does not create monetary non-neutrality[10], but its combination with some other distortions can generate potential real effects (Fischer, 1977; Taylor, 1979; Taylor, 1980; Ball et al., 1988). The existence of nominal rigidities in the goods markets is, in fact, crucial for

residual is almost entirely determined by components other than pure technological shocks. Empirical evidence on this point is provided by Hartley (1994).

[10]Woodford (2003) actually uses the strong assumption of a monopolistically competitive system with *flexible* prices, in which output growth would not substantially differ from that of a perfectly competitive system, to define the so-called natural rate of output. This rate, and hence the fiction of imperfect competition with fully flexible prices, serves as benchmark for assessing the welfare losses that accrue from sticky prices.

generating suboptimal equilibria in this new framework. Sluggish price adjustments are introduced in order to make profit-maximizing firms choose between price and output adjustments in response to disturbances that affect marginal costs (Woodford, 2003, ch.3). These menu costs and other rigidity components are exogenously given[11].

In the last fifteen years many attempts have been made to introduce all these "Keynesian" features into DSGE model. In those types of models, producers set the price optimally, according to their expected market demand curve. If one follows a Calvo price-setting scheme (Calvo, 1983), there will be a gap between the optimal price and the existing price. However, it is presumed that the market is still cleared, since the producer is assumed to supply the output according to what the market demands at the existing price. Yet, by stressing nominal rigidities in the model, in case of unexpected shock not all markets may be cleared even with dynamically optimizing agents. Therefore sticky prices can explain suboptimal output fluctuations and provide a substantial role for monetary policy to reduce welfare losses. This last element was introduced in the model when Taylor (1993) described the observed behavior of central banks in terms of a simple feedback mechanism. This gave rise to a large literature about the so-called Taylor rule (Orphanides, 2007) that consists of reaction function by which central banks adjust their key interest rates to take account of deviations of inflation and output from their target values.

3 NNS in a Neo-Wicksellian Framework

Along the lines described in the previous section, a new consensus developed in the late 1990s. Blanchard (1997) observed that almost all macroeconomists now work within a framework that combines three ingredients: intertemporal optimization, imperfect competition and nominal rigidities. This combination characterizes what is generally labelled the *New Neoclassical Synthesis* (Goodfriend and King, 1998) or the *NNS triangle* (Tamborini et al., 2014). In analogy with the *IS-LM-AS* of the illustrious ancestor, the canonical NNS model can be characterized as *IS-AS-MP*, a three-equations system through which output gaps, inflation gaps and interest rates gaps are jointly determined. An intertemporal IS curve, derived from RBC theory and formulated in DSGE terms, is combined with an aggregated supply function in terms of a Phillips curve with expectations (AS) and a reaction function for monetary policy (MP), usually represented in a Taylor rule form (Boianovsky and Trautwein, 2006; Trautwein, 2006).

On this framework is based most of the current macroeconomic literature

[11] Another approach to the study of nominal rigidities is that proposed by Akerlof and Yellen (1985a, 1985b), which justify the barriers to the adjustment of prices with the presence of "*quasi rationality*".

(Clarida et al., 1999; Romer, 2000), and its most authoritative statement is found in Michael Woodford's *Interest and Prices*, which provides both a comprehensive summary and numerous extensions of the NNS. The main objective is to develop a framework for monetary policy analysis that is based on dynamic, optimizing, general equilibrium analysis in a stochastic context, while departing from RBC assumptions by replacing the latter's presumption of full price flexibility with an optimizing form of nominal price stickiness. All the models contained in the book are usable for analysis of alternative policy, with much concern given to the design of an optimal policy rule, with optimality evaluated in terms of the utility of a typical household. Woodford shows that non-policy forces affecting output behaviour can be summarized in terms of a natural rate of interest, i.e. the time varying equilibrium real rate of return that one would obtain if prices were fully flexible. Woodford (2003, ch. 4) describes his models as a "neo-Wicksellian framework" just because the output and inflation dynamics are generated by gaps between the natural rate and the market rate of interest. This is clearly reminiscent of Knut Wicksell's *Interest and Prices* (1898) and of his proposal to eliminate inflation by adjusting nominal interest rates to changes in the price level (an idea that has much in common with modern policy rules *á la Taylor*). In particular, Woodford motivates his advocacy of rules to fight inflation on the potential non-neutrality of monetary policy: *[...] It is because instability of the general level of prices causes substantial real distortions leading to inefficient variation both in aggregate employment and output and in the sectoral composition of economic activity that price stability is important* (2003, p.5). Woodford's theory of monetary policy is based on the assumption that central banks can control short-term market rates of interest and, hence, affect inflation without taking any recourse to monetary aggregates. He argues that the current practice of monetary policy is determined by the implementation of a "channel system" of lending and deposit rates that keeps overnight interest rates in line with the target fixed by the central bank. Since the achievement of this target does not require any quantity adjustment through open market operations, the monetary base does not play any strategic role in the process of controlling inflation.

Despite the numerous praises for the work of Knut Wicksell, Woodford doubts that the original "*Wicksellian theory can provide a basis for the kind of quantitative analysis in which a modern central bank must engage* (2003, p. 5-6). Bridging the gap between the old-style approach and modern econometrics may have its problems, but Woodford brings in intertemporal general equilibrium theory as the main prerequisite for a proper theory of monetary policy. He argues that old-style Wicksellian theory does not conform to "*modern standards of conceptual rigour*", because it lacks explicit microfoundations. Even though business cycles and growth are analyzed within a single framework that is based on Walrasian principles, "*this does not mean that the Keynesian goal of structural modeling of short-run aggre-*

gate dynamics has been abandoned. Instead, it is now understood how one can construct and analyze dynamic general-equilibrium models that incorporate realistic representations of both short-run and longer-run responses to economic disturbances" (Woodford, 2009). The pivotal role that Woodford's book has played - at least until the beginning of the Great Crisis - in academic and political debate about modern monetary policy demonstrates the power of the NNS consensus.

Most of the attention of commentators and analysts focused on the basic version of the model. One of the key assumption underlying the benchmark model is that the aggregated demand just consists of consumption. As Woodford (2003, p. 243) points out, the model "*abstracts from the effects of variations in private spending (including those classified as investment expenditure in the national accounts) upon the economy's productive capacity*", therefore the model should be interpreted "*as if all forms of private expenditure were like nondurable consumer purchase*"[12]. Woodford (2003, p.352) comments on these modeling choices saying that "*while this has kept the analysis of the effects of interest rates on aggregate demand quite simple, one may doubt the accuracy of the conclusions obtained, given the obvious importance of variation investment spending both in business fluctuations generally and in the transmission mechanism for monetary policy in particular*". Indeed, this approach eliminates one of the main benefits of the DSGE approach begun by Kydland and Prescott (1982), namely that it is inherently intertemporal in nature and incorporates the supply side of the economy. Moreover, the *inter*temporal coordination problem between future consumption (saving) and future production (investment), which is the key problem to be solved by the interest rate in general equilibrium theory, vanishes. There remains the sole *intra*temporal coordination problem between current aggregate demand and supply at each date that is dealt with by the spot price system. Lastly, as King and Rebelo (2000) argue, "*the process of investment and capital accumulation can be very important for how the economy responds to shock*".

Despite these critical elements, the preference for models without endogeneous capital stock depends on different reasons. As rightly pointed out by Laidler (2009), the lack of investment by the NNS models is a remarkable feature of monetarism which abstracted entirely from it in the explanation of fluctuations in nominal income. Moreover, sticky price models with endogenous investment imply unrealistically high volatility in the endogenous variables. In other words, changes in nominal interest rates translate one for one into changes in real rates therefore leading to the excessively high volatility of investment. These theoretical shortcomings have been partially overcome assuming staggered price setting *á la Calvo* com-

[12]The same approach is used by Jeanne (1998), Rotemberg and Woodford (1997) and McCallum and Nelson (1997).

bined with firm-specific investment by firms[13]. Woodford (2003, ch.5; 2004; 2005), Sveen and Weinke (2003; 2004) and Casares and McCallum (2000) extend the basic framework including capital investment explicitly in the optimizing analysis. The purpose of this extension is not to offer a fully realistic quantitative model of the monetary transmission mechanism but rather to provide insights regarding several modeling techniques that are used in a number of recent examples of estimated models with optimizing foundations.

4 The NNS model

The model I present in this section is a simple DSGE with monopolistic competition and nominal price rigidities (Woodford, 2003, 2004; Casares, 2002). It includes the endogenous determination of the capital stock. It considers three types of agent: household, firms and a central bank. Households hold real money balances, choose labor supply and consumption demand. Firms produce differentiated goods and act under monopolistic competition. They face restrictions on both price adjustment and capital accumulation. Finally the central bank sets a target of inflation and fixes the nominal interest rate. The whole model is fully developed in the Appendix at the end of the paper. Let me show here the most important building blocks of this framework. I restrict my attention to a log-linear approximation of the equilibrium dynamics around a steady-state with zero inflation. Thus the percentage deviation of a variable with respect to its steady-state is denoted by a hat.

The real sector of the economy is derived analyzing the optimal behavior of the households and of the firms and the respective equilibrium conditions. Unlike the basic model, the result is not a single equation, but a system of four equations (Woodford, 2003; ch. 4). The first relation is the household's labour supply equation:

$$\hat{\omega} = \phi \hat{n}_t + \sigma \hat{c}_t \tag{4.1}$$

where $\hat{\omega} = \hat{w}_t - \hat{p}_t$ is the real wage, $\hat{n}_t$ is the labour supply[14] and σ denotes household's relative risk aversion.

The second equation is obtained by log-linearizing the first order condition of optimal intertemporal consumption $\hat{c}_t$:

$$\hat{c}_t = E_t \hat{c}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - \rho) \tag{4.2}$$

[13]There are other model with endogenous capital accumulation which assume a rental market (Yun, 1996; Smets and Wouters, 2003; Schmitt-Grohé and Uribe, 2004). However Sveen and Weinke (2004) show that the rental market assumption is not innocuous in a model with staggered price setting.

[14]More precisely n_t is the logarithm of the number of hours worked in each period.

where i_t denotes the nominal interest rate, π_t is the rate of inflation and ρ is the time discount rate or the so-called "natural rate of interest" or "Non-Accelerating Inflation Rate of Interest" (NAIRI).

The law of motion of the aggregate capital stock is the following:

$$\hat{k}_{t+1} = \frac{1}{1+\beta}\hat{k}_t + \frac{\beta}{1+\beta}E_t\hat{k}_{t+2} + \frac{1-\beta(1-\delta)}{\epsilon_\psi(1+\beta)}E_t\hat{\chi}_{t+1} - \frac{1}{\epsilon_\psi(1+\beta)}(i_t - E_t\pi_{t+1} - \rho) \tag{4.3}$$

where χ_t denotes the average real marginal savings in labour costs, β is the rate of time preferences and ϵ_ψ are the adjustment costs of capital.

Finally, the level of aggregate spending is given by the following relation:

$$\hat{y}_t = \zeta\hat{c}_t + (1-\zeta)\frac{1}{\delta}\left[\hat{k}_{t+1} - (1-\delta)\hat{k}_t\right] \tag{4.4}$$

where ζ denotes the steady-state consumption to output ratio while the steady-state capital to output ratio is thus given by $(1-\zeta)\frac{1}{\delta}$. Moreover δ represents the rate of depreciation of the capital stock.

The system of the previous equations (4.1)(4.2)(4.3) and (4.4) then comprises the IS block of the model which suffices to determine the paths of the variables $\hat{y}_t$, $\hat{c}_t$, $\hat{k}_{t+1}$, $\hat{\omega}t$ given the initial capital stock $\hat{k}_t$ and the evolution of the short term interest rate $\hat{i}_t - E_t\pi_{t+1}$.

The second part of the model is composed by an AS-block of two equations which investigate the implication of the endogenous capital stock for the price setting decisions of firms. We have to consider that a) the capital stock affects the marginal costs of firms (and therefore the output) and b) how the capital stock will evolve over time so that its price remains fixed. Indeed we assume that firms set prices *à la Calvo*, i.e. in each period only for a randomly selected fraction $1-\theta$ of enterprises (where $0 < 1-\theta < 1$) it is possible adjust the price in a period, while the remaining θ firms post their last period's price. With probability θ^k a price that was chosen at time t will still be posted at time $t+k$. When setting a new price $P_t^*(i)$ in period t firm i maximizes the current value of its dividend stream over the expected lifetime of the chosen price.

The first problem is solved with a simple manipulation of the marginal costs expression. The second problem takes into account the fact the the price setting decision - in addition to the usual inflation and average marginal cost terms - depends also on the current and expected capital gaps over the random lifetime of the chosen price. Woodford (2004) shows that the associated inflation takes the following form:

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \kappa\hat{s}_t \tag{4.5}$$

where κ is a parameter computed numerically and $\hat{s}_t$ is the real marginal cost.

Finally, the following aggregate production function holds up to a first-order approximation:

$$\hat{y}_t = \alpha \hat{k}_t + (1 - \alpha)\hat{n}_t \tag{4.6}$$

where α is the capital share. Therefore the AS block is composed by equations (4.5) and (4.6) and it provides the characterization of the inflation dynamic $\hat{\pi}_t$ and the labour hours $\hat{n}_t$, given the evolution of $\hat{y}_t$, $\hat{k}_t$ and ω_t from the IS block. It takes into account the effect of changes in the capital stock on the real marginal costs and hence on the short-run trade-off between inflation and output.

The monetary policy block is composed by a single feedback equation in a Taylor fashion. It gives us the evolution of $\hat{i}_t = i_t - i^{SS}$, given $\hat{y}_t = y_t - y^{SS}$ and $\hat{\pi}_t = \pi_t - \pi^*$ from the IS and AS block, respectively.

$$i_t = i^{SS} + \gamma_\pi(\pi_t - \pi^*) + \gamma_y(y_t - y^{SS}) \tag{4.7}$$

where the two weight factors γ_π and γ_y are policy coefficients that describe the relative intensity of the interest-rate reactions to deviations of actual inflation and output gap from their respective target values. The target value for the output gap is defined as the steady-state value of the output gap consistent with the inflation target. This closes the model in two ways. First, it makes the Taylor rule internally consistent, as the definition of y^{SS} ensures that i_t equals i^{SS} whenever the inflation target π^* is achieved. Second, the reaction function for monetary policy permits the determination of the endogenous variables $\hat{i}_t$, $\hat{\pi}_t$ and $\hat{y}_t$ in the previous equations. Woodford argues that the Taylor rule is optimal if the inflation target is set near zero inflation. In this case, the welfare losses that arise from price stickiness and the fluctuations and persistence of output gaps will be minimized.

The model thus is composed by seven equations - namely (4.1)(4.2)(4.3)(4.4) (4.5)(4.6) (4.7) - with seven unknowns - i.e. $\hat{i}_t$, $\hat{y}_t$, $\hat{n}_t$, $\hat{c}_t$, $\hat{\omega}_t$, $\hat{k}_{t+1}$ and $\hat{\pi}_t$, with one predetermined variable $\hat{k}_t$.

5 Strengths and weaknesses of the NNS framework

5.1 Monetary foundation, nominal rigidities and problem of aggregation

Despite all self-praise in the literature (Blanchard, 2000, Woodford, 2009), it is not easy to say whether the NNS framework is good or not. Logical consistency and empirical relevance are the standard criteria for analytical power as well as for empirical capabilities. The specific norms in the application of these criteria to various disciplines and sub-disciplines vary. In the case of NNS macroeconomics the dividing lines between consistency and relevance are not always clear, neither in praise nor in rejection of its apparatus. Its proponents argue that the NNS is highly consistent, because it is rigorously modeled in terms of the DSGE methodology. The strategy of the NNS is based on two main pillars: on one side the aim is to minimize the frictions that are required to reproduce Keynesian results - in terms of persistent real effects of monetary policy - and Wicksellian results - in terms of interaction of interest and prices - in a rigorous framework with intertemporal optimization, forward-looking behavior and continuously clearing markets. On the other side, it is considered essential to build structural - rather then purely statistical models - whose parameters do not change substantially when policy changes (Lucas, 1976). The claim is that the DSGE framework is capable of rigorously reproducing observable phenomena and to provide a microeconomically well-founded base for the design of optimal policy rules, since it is amenable to welfare analysis. Another claim is that NNS research is empirically highly relevant because these models do seem to have done fairly well in empirical applications, at least for some time. If standard NNS models are not directly capable of replicating the behavior of the relevant time series, further frictions and complication can easily be added (Mankiw and Reis, 2003; Blanchard and Galí, 2005).

Critics, on the other hand, point out loose ends in the basic NNS structures that imply serious logical flaws, which naturally also get in the way of serious empirical work. Indeed, the current limbo of the NNS comes at the price of some *ad-hocery* and other shortcomings that have been criticized by way of many papers (Boianovsky and Trautwein, 2006; Laidler, 2006; Mazzocchi et al., 2009; Tamborini et al., 2014). Some of these ad-hocery and weaknesses might be refined or made redundant in some version of the NNS, but some of it are indispensable for intertemporal equilibrium modeling of the current kind. Let us briefly analyze the main issues that characterize the NNS.

First, there are no proper theoretical foundations of monetary control in a cashless economy with "perfect financial markets". Most of the general money supply literature is not explicit about the reasons for the existence of a positive quantity of money in a general equilibrium framework. While the old Neoclassical Synthesis used the assumption of an exogenous money supply, the NNS works without any liquidity preference theory of interest rate. Despite the simplicity of Woodford's conclusions, there are doubts about the fact that the central bank can really take control of interest rates and determine the development of prices in a cashless economy. As Boianovsky and Trautwein (2006) pointed out, in an perfect competition environment with complete financial markets like in Woodford's fashion, other riskless nominal assets are perfect substitutes for money, so the law of one price holds. Therefore the central bank is not price-setter, as Woodford claims, but price-taker. The only way to support Woodford's conclusion[15] is to as-

[15]The whole of Woodford's argument is based on the idea that the the central bank is in

sume that there are frictions that make all other assets imperfect substitutes of the base money and gives the central bank the power to vary its price and quantity at will. But with this implicit assumption the model is not free of monetary frictions as Woodford wanted. And if we want to maintain the frictionless hypothesis, we have to admit that central bank is not able to control interest rate.

Second, there have been many criticisms also on the mechanisms that have been chosen to introduce nominal rigidities in NNS models. The first models developed in the early nineties (Mankiw and Romer, 1991) used a price-setting mechanism based on the so-called *small menu costs* theory (Mankiw, 1985). Yet, with this trick the real effect of monetary policy would be eligible only if the shock was of modest size. In fact, if the shock were large, firms would prefer to adjust prices instead of quantities, which would imply an increase in the capital stock. Moreover, the justification given by the small menu costs theory does not seem fairly strong: printing a new catalog requires only a good database in the computer. Nevertheless, if these restrictive conditions hold, they are not enough. In fact it is not clear why this procedure has not be applied to all the firm's decisions, and only to the price setting. Finally, empirical evidence shows that small nominal frictions determine price rigidity only with non plausible parametric values (Ball et al., 1988; Ball and Romer, 1990; Jeanne, 1998)[16]. For these reasons, in almost all the models developed in the last fifteen years it has been decided to adopt Calvo-pricing. Although this price-setting mechanism is totally unrealistic and not well microfounded, it is very popular in the NNS view of monetary theory. But it should be noted that it is plausible only in a low inflation environment, thus it is totally useless in the analysis of accelerating or persistently high inflation. Moreover the drawbacks of the Calvo pricing mechanism are related also to the empirical relevancy: as Eichenbaum and Fisher (2004) pointed out, the postwar U.S. time series show a strong evidence against the standard Calvo model. Only if they allow for a lag between the time that firms re-optimize and the time that they implement their new plans, the model is no longer rejected (Christiano et al., 2001)[17].

Third, the NNS is built on the assumption of forward-looking behavior of the private sector. As Caballero (2010) and De Grauwe (2010) pointed out,

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a special situation: indeed it is an issuer of liabilities that promise to pay only additional units of its own liabilities. This allows the central bank to fix both the nominal interest yield on its liability and the quantity of them in existence. Nevertheless this argument is not believable: in Woodford's model the liabilities of the central bank play only the role of unit of account, not the role of a means of payment.

[16]Because of this weakness, usually economists combine nominal and real rigidity, especially on the labour market (Kiley, 1997; Blanchard and Galí, 2005; Bratsiotis and Martin, 2003).

[17]Another possibility is to assume that prices are set optimally one period in advance by a fraction of sellers (with the other flexible).

the NNS approach confuses the precision it achieved within its own narrowly defined framework with the precision it achieved about the real world. Presuming intertemporal optimization as aggregate behavior is not uncontroversial: in particular, it becomes problematic when a single agent's dynamic optimization behavior is posited - as in the representative agent NNS model - also to hold for the aggregate behavior[18]. Aggregate relationships will not be the same form as those for an individual agent and will typically involve other features of the distribution of the micro variables than just averages. As Keynes (1936, ch. 24) warns us, individual optimal choices do not necessary result in socially preferred outcomes. Social aggregate choice may be needed to complement individual behaviour. General equilibrium involves the interaction of many heterogenous individual agents, subject to correlated shocks: even if microeconomic parameters were structural, their aggregation may make their macro analogues non-structural (Fernandez-Villaverde and Rubio-Ramirez, 2007)[19]. The usual shorthand is to assume that random errors of the individuals cancel out across agents. This requires that individual errors to be cross-sectionally independent or at least only weakly correlated. This assumption is contradicted by numerous empirical studies that show that the dynamic times-series properties of the aggregate variables can be fundamentally different from those of the underlying micro units (Pesaran and Chudik, 2011).

Even if we ignore this shortcoming, we have to consider that the main problem with all the models that assume forward-looking behaviour is that they attribute extraordinary cognitive capabilities to individual agents. Intertemporal optimization calculations typically require expectations far into the future and survey measures of distant expectations are rarely available. The shorthand typically used by NNS is to assume that agents have rational expectations. According to this assumption the subjective characterization of uncertainty as conditional probability distributions will coincide with the associated objective probability outcomes. Of course, the rational expectation hypothesis is mathematically elegant and allows model consistent solutions (Blanchard and Kahn, 1980), but it requires private agents to know or learn the true conditional probability distributions (Fuster et al., 2010). This assumption is problematic when agents need to form expectations about the expectations of others, as in Keynes's beauty contest. More in general, many economic and financial processes are not stationary and ergodic as the rational expectation hypothesis required, but are continu-

[18]A further problem that arises when intertemporal decision framework is applied to macroeconomics is of course due to the accuracy of the solution methods used when moving toward empirical application of large-scale models. However, this issue is beyond the scope of this chapter.

[19]Another key point is to understand whether any instability is a response of policy interventions. There is little evidence that structural breaks can be attributed solely to macroeconomic policies.

ally affected by technological, political and institutional changes which are largely unpredictable. Thus the rational expectations hypothesis should be used with great caution (Hansen and Sargent, 2008).

5.2 Information problems and coordination among economic agents

Closely related to cognitive limitations in the definition of individual plans, there is the problem of information of private agents and policy-makers, especially the central bank. These weaknesses also arise due to poor theoretical accuracy with which the NNS has been built. As pointend out by Boianovsky and Trautwein (2006) the definition of Non-Accelerating Inflation Rate of Interest (NAIRI) and of Non-Accerelating Inflation Rate of Output (NAIRO) seems to be very confused. The problem arises especially with the introduction of the monopolistic competition and sticky prices in DSGE models. In this type of models, we can identify at least three definitions of the level of output (and thus of interest rate). There is a level of output that is compatible with a regime of perfect competition and flexible prices, y_t^{PC}. There is another level that is compatible with a regime of monopolistic competition and perfect flexible prices, y_t^N. Finally there is the actual output, i.e. the level of output compatible with monopolistic competition and staggered-prices, y_t. In particular it is unclear whether nominal rigidities - and the underlying pricing mechanisms - are part of the definition of natural rate or not[20]. The definition of the benchmark is critical to determine the type of economic policy to be applied. More specifically, the problem to be solved is to understand what should be the measure of the output gap (and the interest rate gap) relevant for the implementation of monetary policy. With reference to what I wrote above, it is unclear whether the measure of the output gap should be $\hat{y}_t = y_t - y_t^{PC}$ or $\hat{y}_t = y_t - y_t^N$. It is a problem that occurs even when we pass to analyze models with endogenous determination of the capital stock like that presented in the previous section. In that framework the capital stock is no longer anchored to its steady state level, but it is a function of past monetary policy when prices were sticky (Trautwein and Zouache, 2009). The nominal rigidity generated

[20] A good representation of the confusion on this point can be noticed in Woodford's book (2003). Indeed he defines first the natural rate of output and interest as the equilibrium of real output and real rate of return in the case of perfectly flexible prices. But he said also that the "*[the nominal rigidities] are taken to be an institutional fact, just like the available production technology*" (Woodford, 2003, p. 7). In other words, in some part of the book Woodford seems to support the traditional RBC view, according to which the natural rate of output and of interest are given by consumer's preferences and producer's technologies and therefore represent the optimal and efficient dynamic paths of real output and interest that we could obtain with perfectly flexible prices. On the contrary, in another part of his work Woodford suggests that the rigidities can be considered as part of the natural rate definition.

by the Calvo-pricing does not only influence the actual output but also the potential output. We can distinguish now an equilibrium rate compatible with the capital stock that would exist if prices had always been flexible in the past[21] and an equilibrium rate with a state-contingent capital stock dynamics. Using the latter definition, the natural rate of interest is not an attractor for the market rate of interest, but it is determined by other factors influenced by monetary policies. Moreover, by using this new benchmark it is not clear why policy-induced changes in the capital stock could not be considered Pareto-superior ex-post[22].

Even if we neglect these problems of the definition of the NAIRI and the NAIRO, there is the undue neglect of central banks' problems with information about these two key variables. Skepticism about the use of the natural rates for monetary policy was largely prevailing in the past. Wicksell himself (1898) thought that the natural rate is inherently unobservable and would be difficult to measure in practice[23]. Keynes was even more radical, casting doubts on the existence itself of a single general equilibrium rate of interest and output (1937a; 1937b). Friedman still made the point when he linked the natural rate of unemployment to the natural rate of interest in his Presidential Adress (1968, p.8), but he also warned that attempts at conducing monetary policy with reference to natural rates might be fallacious. More recently Blinder (1998) states that the natural rate of interest is "*difficult to estimate and impossible to know with precision. It is therefore most usefully thought of as a concept rather than as a number, as a way of thinking about monetary policy rather than a basis of mechanical rule*". A growing literature shows that wrong information may seriously destabilize the system (Orphanides and Williams, 2002a, 2006; Primiceri, 2006; Tamborini, 2010). The common view of these models is that poor stabilization performance may be due not to the lack of the "right" rule but to the lack of the "right" information about that rule. Moreover, the risk of this information deficiency is not only the worsening of the stabilization performance, but the driving of the economy on an altogether non-convergent path. From an empirical point of view, both the NAIRI and the NAIRO are thus unobservable. Their estimations are not straightforward and are associated

[21] Woodford (2003, ch.5) defines this measure "constant-capital natural rate of output", i.e. the real output and interest that would be if prices were flexible and the capital stock did not vary from its steady-state level.

[22] For example, an expansionary monetary policy, which is not optimal *ex-ante*, could help to enlarge the output of consumption goods, and therefore could be considered optimal *ex-post* (Trautwein and Zouache, 2009).

[23] Wicksell argued that the central bank should aim to maintain price stability, which in theory could be achieved if the interest rate were always equal to the economy's natural rate of interest. However, recognizing that the latter is merely an abstract, unobservable concept, he noted: "*This does not mean that the bank ought actually to ascertain the natural rate before fixing their own rates of interest. That would, of course, be impracticable, and would also be quite unnecessary*" (Wicksell, 1898, pp. 82-84).

with a very high degree of uncertainty. That is why it is still difficult to understand what the NAIRI and NAIRO really are (Laidler, 2011). In any case economists have increasingly devoted attention to developing estimation strategies for both variables. Nevertheless there is no consensus on the estimation technique and on the determinant of these two rates.

As for the interest rate, the simplest approach is to assume that the NAIRI is equivalent to the trend real rate of interest. The papers consistent with this view (Basdevant et al., 2004; Gnan and Ritzberger-Gruenwald (2005); Cuaresma et al., 2004; Cour-Thimann et al, 2004; Larsen and McKeown, 2004) typically make use of the Kalman filter or other filtering techniques to split the actual real rate into a trend (the natural rate of interest) and a cyclical component (the real rate gap). However, these models do not necessarily contain judgements about the determinants of the NAIRI. Rather, this approach is closer to a pure statistical measure and may be reasonable over periods when inflation and output growth are stable, but leads to substantial biases when output or inflation varies significantly. Therefore, the interpretation of the natural real interest rate in this context is likely to be more relevant in a "shorter" time perspective and consider more the effect of monetary policy on the determination of the natural rate path[24].

A more robust approach is to combine statistical tools with structural macroeconomic modeling techniques. A group of economists which includes Giammarioli and Valla (2003), Mésonnier and Renne (2004), Neiss and Nelson (2001) and Sevillano and Simon (2004) associate the fluctuation in the NAIRI with the evolution of real fundamentals such as determinants of trend GDP growth and preferences. These variables are typically stable in the short/medium run, but may display some variation in the longer run. Therefore the natural interest rate should also be relatively stable in the short run, and it should be considered in a long-run perspective. However also the econometric results obtained with these specifications are not very precise and there is very high uncertainty around the estimate of the level of the natural rate of interest. Clark and Kozicki (2005) analyze the difficulties in estimating today's NAIRI based on the contemporaneous data initially released historically (the so called *real-time* estimates) and conclude that such estimates "*will be difficult to use reliably in practical policy applications*". A third method extracts the natural rate of interest from the financial market indicators (ECB, 2004) or from a money demand function which depends on the expected natural rate of interest (Andres et al., 2009). Comparing the methods, Caresma et al. (2005) conclude that the differences in levels and volatility are big enough to take the results with caution.

More generally, all the techniques show at least three major kinds of diffi-

[24]For instance, inflation was rising during most of the 1970s, suggesting that the trend of the interest rate was, in fact, well below the natural level. Likewise, inflation fell rapidly in the early 1980s, suggesting that the average interest rate was much higher than the natural level.

culties that discourage the use of such estimates for the conduct of monetary policy. First, we can observe the data only up to today. Thus the estimate of the NAIRI based on data that are available today will be different from the estimate we will make when we have data beyond today because the latter will take into account future data over next periods. The discrepancy between the two estimates could be as large as one to two percentage points. Moreover, macroeconomic data are often revised, and sometimes the revision can be quite substantial. As pointed out by Clark and Kozicki (2005) these mistakes could be as high as one to two percentage points, depending on the size of the data revisions. Lastly, the estimates of the NAIRI are particularly sensitive to model specification: these differences can be as large as two percentage points. The previous President of the Deutsche Bundesbank Axel Weber was even more pessimistic when he quoted Parker's: "*Estimation error becomes policy error, and stabilization policy becomes destabilizing*". His own conclusion was: "*one cannot judge the usefulness of the natural rate of interest for monetary policy purposes without taking into account the serious problems that accompany its measurement and estimation. As has been pointed out, these problems are severe and comprise a considerable degree of data as well as model uncertainty*" (Weber, 2006, p. 9)

These and other more important problems may also be noted with regard to the estimate of the NAIRO. It is doubtful whether some of the fundamentally retrospective empirical procedures often used to determine potential - such as univariate filter-based methods - can be appropriately applied in the context of a genuinely forward-looking concept (i.e. the future growth perspectives of an economy measured in terms of potential output). It is also doubtful whether labour input in production function-based methods can be reliably projected into the future given that such volumes are influenced in their turn by changes in labour market structures, technological trends or macroeconomic developments (Hauptmeier et al., 2009).

Another important weakness is that most of the NNS models are focused on the analysis of the functioning of a closed economy, though there have been some extensions to two block structures and small open economy versions (Benigno, 2002; Galí and Monacelli, 2002). Moreover the NNS theory naturally extends to financial variables, since the consumption Euler equation - which is the centre of the DSGE framework - is also the basis for most of the finance theories. However, the NNS models have typically been restricted not to cover financial variables such as long term interest rates, equity prices and exchange rates. These models do not allow to discuss the effects and the relations between financial market and the real economy. As recognized by Robert Lucas "*[...] the problem is that the new theories, the theories embedded in general equilibrium dynamics [...] do not let us think about the US experience in the 1930s or about financial crises and their consequences [...]. We may be disillusioned with the Keynesian apparatus for thinking about these things, but it does not mean that this replacement* *apparatus can do it either*" (Lucas, 2004). For this reason in recent years new models have been designed to take stock of pre-crisis debates and to overcome various limitations that emerged from theoretical weaknesses as well as from empirical reconstructions and stylized facts of boom-bust cycles (Christiano et al., 2010).

Despite these efforts in strengthening the NNS models, it still leaves us the need of explanations for the recent *dot.com* boom and bust, for the subprime mortgage crisis, for the stock market crash of 1929 which ushered in the subsequent Great Depression, for the collapse of the Japanese "bubble economy" and for many others similar episodes. None of these crises was precipitated by any obvious exogenous shock, neither by attempts to maintain an unsustainable exchange rate, nor, crucially, were they heralded by a significant burst of broadly-based price inflation (Laidler, 2009). A possible way out is to be found in those elements of the inter-war literature whose often disparate components are linked by what Leijonhufvud called "the Wicksell connection" (Leijonhufvud, 1981). Even if Keynes and many others saw that the coordination of saving and investment decisions as the core problem of macroeconomic theory, in the NNS the problem of intertemporal coordination drifted so far out of the focus as to be virtually forgotten. Indeed the NNS framework is set in continuous intertemporal equilibrium and cannot deal with imbalances of planned saving and investment, nor can it deal with financial intermediation and its effects on budget constraints in the long run. Since it assumes financial markets to be perfect, the model finds its equilibrium at the natural rate of interest as determined by the forces of productivity and thrift that equate saving and investment at full-employment of resources. Deviations from the optimal growth path of the economy are essentially explained in terms of sticky-prices, sticky-wages or other imperfections in the goods or labour markets.

As soon as the banking system comes into play all these arguments no longer necessarily hold. One important reason is that intermediaries act with limited information about the natural rate, which is a reason why deviations of the market real interest rate from the natural rate may ever arise. In the NNS, whenever the market real interest rate deviates from the natural rate, households reallocate resources towards present/future consumption along a new intertemporal equilibrium path with an equivalent impact on aggregate demand. This is a consistent transmission mechanism as long as there are no capital goods, but where there are capital goods to be purchased by means of money and there is a market for loanable funds made by independent borrowers and lenders, the consequence of the market real interest rate on loans being higher/lower than the natural rate is that households wish to save more/less whereas firms wish to invest less/more: neither side of the market can achieve intertemporal equilibrium of plans. Thus the problem is that the banking system as a whole might both expand/reduce the total nominal purchasing power in the economy and allocate it at terms that differ from those dictated by full-employment saving-investment equilibrium. Over-investment or over-saving allowed for by imperfect bank intermediation are therefore the main explanations of price changes and of the business cycles. As Borio and Disyatat (2011) pointed out the lack of discussions of these elements in the NNS models not only has led to a failure to consider the distinguishing characteristics of a monetary economy, but also has been the main contributing factor to the recent financial crisis. Yet ruling saving-investment imbalances out of the theory constitutes a major theoretical weakness of the NNS (Van der Ploeg, 2005).

6 Conclusion

The NNS can be regarded as the newly established macroeconomic consensus. Blanchard (1997, p.290) correctly observed that almost all economists now work within a framework that combines intertemporal optimization, imperfect competition and nominal rigidities. The NNS is based on a system of three building blocks that determines the short-run dynamics of output, inflation, interest rates and other variables. Most attention is confined to the study of small fluctuations around a deterministic steady state, thus the model is presented as a log-linear approximation of the conditions for intertemporal general equilibrium. Despite the problems and weaknesses that we have highlighted in this chapter, the NNS has undoubtedly provided a strong enough structure that can be easily compared with the RBC models developed during the eighties. After a period in which we observed the rise of separate field of murky ad-hocery, macroeconomics seems to return back to a proper extension of a standard general equilibrium theory. The latter can be modified in many ways to cater to the different sub-disciplines, such as labour economics, industrial organization. In this way it becomes easier to connect macroeconomics with all the other disciplines, modeling specific frictions into a standard framework that help to explain the usual macroeconomic pathologies and identify the political instruments and time consistent strategies to deal with them. Thus the NNS started investigating a new class of models in which agents optimize intertemporally in economies with some non-Walrasian features.

While the NNS has proved quite permeable with regard to the explanation of the nominal and real rigidities in product and labour markets, the same can not be said for the financial market, which remains perfectly Walrasian. This lack makes inadmissible the claim of many economists to be a kind of successor of the great founders of modern macroeconomic thought, not only Keynes but also Wicksell. In fact, the existence of intermediaries between savers and investors, which was the main feature of the Wicksellian literature, can only be due to some departure from the Walrasian paradigm. Moreover, all three actors on the capital market act with limited information, which is the reason why deviations of the market interest rate from the natural rate may arise. In other words, the main contention of the old macroeconomics was saving-investment imbalances - i.e. capital market failures and intertemporal disequilibrium in modern parlance - that are notably absent from the NNS[25].

The most serious consequence of this deficiency is that the NNS did not let us think about the financial crisis and the macroeconomic imbalances that were forming in the years of the Great Moderation. Analyses in a Wicksellian vein of recent episodes of over-investment, such as the U.S. "New Economy" bubble in the late 1990s and the housing and mortgages boom in the last few years, point out the *missing inflation puzzle* as a critical element in the picture that has probably played a role in driving monetary policy onto a wrong track (Borio and Lowe, 2002). The lack of attention to exchange rates, to the stock market, to the financial intermediaries and to the real estate market led to the progressive loss of control of the entire system. In this situation even a Taylor rule - whether optimal or adaptive - may break down: the central bank discovers whether its market rate is too low or too high by the price level starting to rise or fall, and it can then adjust the rate accordingly. The problem is that this crucial feedback loop can be short circuited by the rise of a saving-investment imbalances. The trouble with inflation targeting in present circumstances is that a constant inflation rate gives no information about whether monetary policy is right or not. And a wrong monetary policy allows the financial imbalances to grow without end.

The failure of the NNS framework leaves open the question of what can be done with models that exclude in advance the possibility of any pathology in the working of the market system, and certainly of any collapse in the trading system to the extent that we have recently encountered. NNS models convey a Panglossian view of the working of the economy as they rule out the possibility that markets can fail and that agents may find themselves in a state where they are unable to achieve their optimizing plan (De Vroey and Malgrange, 2011). When the economy is in a state of plain sailing, this neglect is admissible, but it is no longer justifiable when the economy shows signs of collapse. Laidler (2006) has rightly summarized this by saying that NNS framework can be applied only to "fair weather conditions".

Exit routes, however, are not easy to find. The claim of the critics of the NNS have prompted further developments in two main direction. The first - although consider the DSGE framework a "too big to fail" industry that will survive the present crisis due to vested interest (Leijonhufvud, 2009) - thinks that is futile to try reinterpret Keynes and other earlier macroeconomists

[25] In comparison with the *NNS triangle* of imperfect competition, sticky prices and intertemporal optimization, Mazzocchi et al. (2009) propose a *Wicksell-Keynes triangle* that can thus be described by the key words "imperfect capital market", "interest-rate misalignments" and "intertemporal coordination".

in terms of models that share a number of features with current DSGE modeling[26]. The second instead investigates whether and to what extent a reconsideration of those original ideas may improve our understanding and policy of business cycles sticking as closely as possible to the object of criticism, namely the NNS (Boianovsky and Trautwein, 2006; Tamborini, 2010; Tamborini et al., 2014; Mazzocchi, 2013). As long as there is not a plausible alternative in terms of a unified analytical model, it should still be a fruitful exercise to criticize the current consensus by their own standard and thus help them to become skeptical enough to try to make progress along different lines of thinking.

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[26]During a recent presentation at the London School of Economics, Paul Krugman pointed out that "*most work in macroeconomics in the past 30 years has been useless at best and harmful at worst*".

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A Appendix: the NNS model

In this section we fully derive the NNS model with endogenous capital stock.

The Households A representative household maximizes expected discounted utility (Mas-Colell et al., 1995; Kreps, 1990)[27]:

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \frac{1}{1-\gamma} \left(\frac{M_t}{P_t} \right)^{1-\gamma} - \frac{N_t^{1+\phi}}{1+\phi} \right) \tag{A.1}$$

where β is the discount factor, $\sigma < 1$ denotes household's relative risk aversion, $\phi > 0$ can be interpreted as the inverse of the aggregate labour supply elasticity, $\gamma < 1$ is the inverse of the semi-elasticity of the household's demand for real balances with respect to the nominal interest rate, N_t is the number of hours worked in period t, $\frac{M_t}{P_t}$ are the real money balance and C_t denotes the time t consumption aggregator (Dixit and Stiglitz, 1977). The latter has the following expression:

$$C_t = \left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{A.2}$$

The price level P_t has the following expression:

$$P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}} \tag{A.3}$$

Cost minimization by households implies that:

$$\max C_t = \left[\int_0^1 C_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{A.4}$$

subject to:

$$\int_0^1 P_t(z) C_t(z) dz = Z_t \tag{A.5}$$

where Z is the income. By setting the Lagrangian and after some manipulations we get:

$$C_t(i) = \frac{P_t(i)}{P_t}^{-\varepsilon} C_t \tag{A.6}$$

which is the demand for good i. From this allocation it follows that:

$$\int_0^1 P_t(i) C_t(i) di = P_t C_t \tag{A.7}$$

[27]This type of utility function - the so called CRRA - has important characteristics. In particular the marginal utility of consumption $\frac{\partial U}{\partial C_t} = C_t^{-\sigma}$, the intertemporal marginal rate of substitution IMRS=$\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}$.

The maximization problem will be thus the following:

$$\max E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \frac{1}{1-\gamma} \left(\frac{M_t}{P_t} \right)^{1-\gamma} - \frac{N_t^{1+\phi}}{1+\phi} \right) \tag{A.8}$$

subject to a sequence of budget constraints:

$$C_t \leq \frac{W_t}{P_t} N_t + \Pi_t + \frac{M_t - M_{t-1}}{P_t} - \frac{\frac{1}{R_t^n} B_t - B_{t-1}}{P_t} \tag{A.9}$$

where B_t denote the nominal payoffs associated with the portfolio held at the end of period $t-1$. Moreover P_t gives the price index, W_t is the nominal wage as of period t, and Π_t denotes profits resulting from ownership of firms.

Let me define the Bellman equation as follows:

$$\upsilon \left(\frac{M_{t-1}}{P_t}, \frac{B_{t-1}}{P_t} \right) = \max \left[U_t + E_t \beta \upsilon \left(\frac{M_t}{P_{t+1}}, \frac{B_t}{P_{t+1}} \right) \right] \tag{A.10}$$

subject to (A.9). The FOCs of the household's maximization problem are as follows:

$$C_t^{\sigma} N_t^{\phi} = \frac{W_t}{P_t} \tag{A.11}$$

$$C_t^{-\sigma} = E_t \left\{ \frac{P_t}{P_{t+1}} \beta C_{t+1}^{-\sigma} \right\} + \left(\frac{M_t}{P_t} \right)^{-\gamma} \tag{A.12}$$

$$\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = R_t \tag{A.13}$$

The first and the second equations are the optimality condition for labour supply and the demand for real balances. The third equation is the standard Euler equation for consumption. Finally, let us note that the nominal interest rate can be expressed also in real term as $R_t = R_t^n \frac{P_t}{P_{t+1}}$. Substituting (A.13) into the (A.12) we get:

$$C_t^{\sigma} N_t^{\phi} = \frac{W_t}{P_t} \tag{A.14}$$

$$\frac{M_t}{P_t} = \left(1 - \frac{1}{R_t^n} \right)^{-\frac{1}{\gamma}} C_t^{\frac{\sigma}{\gamma}} \tag{A.15}$$

$$\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = R_t \tag{A.16}$$

The Firms Each firm uses both labour N_t and capital K_t to produce output Y_t according to the following constant return to scale production function:

$$Y_t(i) = K_t(i)^{\alpha} N_t(i)^{1-\alpha} \tag{A.17}$$

where parameter α is the capital share. Each firm i makes an investment decision at any point in time with the resulting additional capital becoming productive one period after the investment decision is made. Therefore the law of motion of capital at the firm level is given by the following equation:

$$K_{t+1}(i) = (1-\delta)K_t(i) + I_t(i) \tag{A.18}$$

where $I_t(i)$ denotes the amount of composite good purchased in period t by firm i and δ is the depreciation rate. It is natural to consider how aggregate demand is determined since it affects each firm's demand and therefore the price setting decisions of price setters. Let us assume that the investment good is an aggregate of all the goods in the economy with the same constant elasticity of substitution as in the aggregate consumption[28]:

$$Y_t^d = \left[\int_0^1 Y_t^d(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{A.19}$$

Cost minimizing by firms and households implies that demand for each individual good i in period t can be written as follows[29]:

$$Y_t^d(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} Y_t^d \tag{A.20}$$

Knowing the law of motion of the capital (A.18), the aggregate investment demand $I_t = \int_0^1 I_t^d(i)$ and the aggregate capital stock $K_t = \int_0^1 K_t^d(i)$, the total demand is given by:

$$Y_t^d = C_t + I_t \tag{A.21}$$

Finally, let us assume that firms face a convex adjustment cost of changing their capital holdings[30]. Given $K_t(i)$, the amount of composite good $I_t(i)$ that has to be purchased by that firm at this point in time in oder to have a capital stock $K_{t+1}(i)$ in place in the subsequent period is given by:

$$I_t(i) = I\left(\frac{K_{t+1}(i)}{K_t(i)} \right) K_t(i) \tag{A.22}$$

[28]This implies that firms buy the different capital goods in the same proportion as in the consumer aggregate.

[29]Proof is omitted by is available upon request

[30]Example of such costs are the costs of installing the new capital and training workers to operate the new machines (Eisner and Strotz, 1963; Lucas, 1967).

where $I(1) = \delta$, $I'(1) = 1$ and $I''(1) = \epsilon_\psi$. Parameter δ denotes the depreciation rate, whereas parameter ϵ_ψ measures the capital adjustment cost in a log-linear approximation to th equilibrium dynamics[31].

Firms set prices *à la Calvo*, i.e. in each period only for a fraction $1-\theta$ of enterprises (where $0 < 1-\theta < 1$), randomly selected, it is possible adjust the price in a period, while the remaining θ firms post their last period's price. With probability θ^k a price that was chosen at time t will still be posted at time $t+k$. When setting a new price $P_t^*(i)$ in period t firm i maximizes the current value of its dividend stream over the expected lifetime of the chosen price. Formally, given $K_t(i)$, price setters chooses contingent plans for $\left\{P_{t+k}^*, K_{t+k+1}(i); N_{t+k}(i)\right\}_{k=0}^{\infty}$ in order to solve the following problem:

$$\max_{P_t^*(i);I_t(i)} E_t \sum_{k=0}^{\infty} \left\{ \frac{1}{R_{t+k}} \left[Y_{t+k}^d(i) P_{t+k}(i) - W_{t+k} N_{t+k}(i) - P_{t+k} I_{t+k}(i) \right] \right\} \tag{A.23}$$

subject to:

$$Y_{t+k}^d(i) = \left(\frac{P_{t+k}(i)}{P_{t+k}} \right)^{-\varepsilon} Y_{t+k}^d \tag{A.24}$$

$$Y_{t+k}(i) = K_{t+k}(i)^\alpha N_{t+k}(i)^{1-\alpha} \tag{A.25}$$

$$I_{t+k}(i) = I\left(\frac{K_{t+k+1}(i)}{K_{t+k}(i)} \right) K_{t+k}(i) \tag{A.26}$$

$$P_{t+k}(i) = \begin{cases} P_{t+k+1}^*(i) & \text{with probability } 1-\theta \\ P_{t+k}(i) & \text{with probability } \theta \end{cases} \tag{A.27}$$

The implied FOC for capital accumulation is the following:

$$\frac{dI_t(i)}{dK_{t+1}(i)} P_t = \frac{1}{R_t^n} E_t \left[\Lambda_{t+1}(i) - \frac{dI_t(i)}{dK_{t+1}(i)} P_{t+1} \right] \tag{A.28}$$

where $\Lambda_{t+1}(i)$ denotes the nominal marginal savings in firm i's labour cost associated with having one additional unit of capital in place in period $t+1$. The intuition behind this equation is that the marginal cost of installing an additional unit of capital at time t (including adjustment costs) is equalized to the expected discounted marginal contribution to the firm's value associated with having that additional unit of capital in place at time $t+1$. The latter is given by the marginal return from using it for production[32] - $\Lambda_{t+1}(i)$ - and selling the remaining capital after depreciation.

[31] Eichenbaum and Fisher (2004) interpret parameter ϵ_ψ as the elasticity of the investment to capital ration with respect to Tobin's q.

[32] As Woodford (2003) pointed out, the relevant measure of the marginal return to capital is the marginal savings in a firm's labour cost: firms are demand constrained and hence the return from having an additional unit of capital in place results from the fact that this allows to produce the quantity that happens to be demanded using less labour.

The FOC for the price setting is given by:

$$\sum_{k=0}^{\infty} \theta^k \frac{1}{R_t^n} E_t \left\{ Y_{t+k}^d(i) \left[P_t^*(i) - \mu S_{t+k}(i) \right] \right\} = 0 \tag{A.29}$$

where $\mu \equiv \frac{\varepsilon}{\varepsilon - 1}$ is the frictionless mark-up over marginal costs and $S_t(i)$ denotes the nominal marginal cost. Equation (A.29) is the familiar FOC implied by the Calvo model: optimizing price setters behave in a forward-looking manner, i.e. they take into account not only current but also future expected marginal costs in those states of the world where the chosen price is still posted. The only non-standard feature is that capital affects labour productivity and hence firm's marginal cost.

Central bank Monetary policy determines M_t. Let me consider a simple Taylor rule like the following:

$$R_{t+1}^n = R^n \left(\frac{\frac{P_t}{P_{t-1}}}{P_t^*} \right)^{\gamma_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\gamma_y} \tag{A.30}$$

where R^{n*} is the steady state real interest rate (natural rate), Y_t^* is the NAIRO and ε_t^r. Note that the (A.30) indirectly determines M_t (see eq. (A.15)).

Equilibrium Clearing of the market requires the following conditions:

$$N_t = \int_0^1 N_t(i) di \tag{A.31}$$

$$Y_t(i) = Y_t^d(i) \tag{A.32}$$

$$Y_t = C_t + I_t \tag{A.33}$$

where $I_t = \int_0^1 I_t(i)di$, $K_t = \int_0^1 K_t(i)di$ and auxiliary variable $\widetilde{Y}_t \equiv K_t^a N_t^{1-a}$[33]

Log-linear version We restrict our attention to a log-linear approximation to the equilibrium dynamics around a steady-state with zero inflation. Lowercase letters represent the logarithm of each variable. The percentage deviation of a variable with respect to its steady state is denoted by a hat, i.e. $\hat{x} = x - \bar{x}$. Thus $\hat{x}$ is the logarithmic deviation from the steady-state.

[33]The difference between $\widetilde{Y}_t$ and the aggregate output in the economy $Y_t = \left(\int_0^1 Y_t^{\frac{\varepsilon-1}{\varepsilon}} d(i) \right)^{\frac{\varepsilon}{\varepsilon-1}}$ is of second order. We can safely ignore it for the purpose of log-linear approximation to the equilibrium dynamics.

IS block Let us start with the household's labour supply equation (A.14):

$$\hat{\omega} = \phi \hat{n}_t + \sigma \hat{c}_t \tag{A.34}$$

where $\hat{\omega} = \hat{w}_t - \hat{p}_t$ is the real wage. This is equation (4.4) in the main text. Log-linearizing and rearranging equation (A.16) we get:

$$\hat{c}_t = E_t \hat{c}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - \rho) \tag{A.35}$$

where i_t denotes the nominal interest rate and $\pi_t \equiv \log\left(\frac{p_t}{p_{t-1}}\right)$ is the rate of inflation. Finally, the dime discount rate is given by $\rho \equiv -\log \beta$. This is equation (4.2) in the main text.

We log-linearize the FOC for capital accumulation (A.30) and average it over all firms in the economy. Combining the resulting relationship with the (A.35) we obtain the law of motion of the aggregate capital stock (equation (4.3) in the main text):

$$\hat{k}_{t+1} = \frac{1}{1+\beta}\hat{k}_t + \frac{\beta}{1+\beta}E_t\hat{k}_{t+2} + \frac{1-\beta(1-\delta)}{\epsilon_\psi(1+\beta)}E_t\hat{\chi}_{t+1} - \frac{1}{\epsilon_\psi(1+\beta)}(i_t - E_t\pi_{t+1} - \rho) \tag{A.36}$$

where $\chi_t \equiv \frac{\lambda_t(i)}{p_t}$ denotes the average real marginal savings in labour costs. Assuming capital adjustment cost implies that capital is a forward-looking variable.

Finally, let me consider equation (A.35). After invoking equations (A.17), (A.20) and (A.22) we log-linearize the resulting relationship and obtain:

$$\hat{y}_t = \zeta \hat{c}_t + (1-\zeta)\frac{1}{\delta}\left[\hat{k}_{t+1} - (1-\delta)\hat{k}_t\right] \tag{A.37}$$

where $\zeta \equiv \frac{\rho+\delta(1-\alpha)}{\rho+\delta}$ denotes the steady-state consumption to output ratio while the steady-state capital to output ratio is given by $(1-\zeta)\frac{1}{\delta}$. This is equation (4.4) in the main text.

AS block The inflation equation is derived from averaging optimal price setting decisions and aggregating prices via price index. Following Galí et al. (2001) and Sbordone (2002) we start from the log-linearized real marginal cost S_t at the firm level:

$$\hat{s}_t(i) = \hat{s}_t - \frac{\varepsilon\alpha}{1-\alpha}\hat{p}_t(i) - \frac{\alpha}{1-\alpha}\hat{\widetilde{k}}_t(i) \tag{A.38}$$

where $\widetilde{k}_t(i) \equiv \frac{K_t(i)}{K_t}$ and $s_t = \int_0^1 \frac{S_t(i)}{P_t}$ The intuition behind this equation is the following: for a zero capital gap a firm that posts a higher than average price faces a lower than average marginal cost due to the decreasing marginal product of labour (second term). With capital accumulation there is an extra effect coming from the firm's capital stock (last term). Conditional on posting the average price in the economy a firm that has a higher than average capital stock in place faces a lower than average marginal cost. The reason is that the marginal product of labour increases with the capital stock used by the firm.

Invoking equations (A.31) and (A.38), the optimal price of firm i defined as $\widetilde{p_t^*(i)} \equiv \frac{P_t^*(i)}{P_t}$ can be log-linearized as:

$$\widetilde{\hat{p}_t^*(i)} = \sum_{k=1}^{\infty}(\beta\theta)^k E_t \hat{\pi}_{t+k} + \xi \sum_{k=0}^{\infty}(\beta\theta)^k E_t \hat{s}_{t+k} - \psi \sum_{k=0}^{\infty}(\beta\theta)^k E_t \widetilde{\hat{k}_{t+k}(i)} \quad \text{(A.39)}$$

where $\xi \equiv \frac{(1-\beta\theta)(1-\alpha)}{1-\alpha+\varepsilon\alpha}$ and $\psi \equiv \frac{(1-\beta\theta)\alpha}{1-\alpha+\varepsilon\alpha}$. In addition to the usual inflation and average marginal cost terms, the price setting decision depend also on the current and future expected capital gaps over the random lifetime of the chosen price. Woodford (2004) shows that the associated inflation takes the following form (equation (4.5) in the main text):

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{s}_t \quad \text{(A.40)}$$

where κ is a parameter computed numerically. Finally, we note that the following aggregate production function holds up to a first-order approximation (equation (4.6) in the main text):

$$\hat{y}_t = \alpha \hat{k}_t + (1-\alpha)\hat{n}_t \quad \text{(A.41)}$$

Monetary policy block Finally, we could close the model using the traditional Taylor rule (A.30) which guarantees the determinacy of the whole system. It gives us the evolution of $\hat{i}_t$, given $\hat{Y}_t$ and $\hat{\pi}_t$ from the IS and AS block, respectively.

$$\hat{i}_t = \gamma_\pi \hat{\pi}_t + \gamma_y \hat{y}_t \quad \text{(A.42)}$$

This is equation (4.7) in the main text.

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