Technological Shocks and the Conduct of Monetary Policy

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This paper analyses the impact of alternative monetary policies on the performances of an economy facing technological changes. It shows that the restructuring of productive capacity necessary to embed the new technologies usually implies initial drops in employment and productivity, that are reabsorbed only if the transition is successful. Furthermore, it shows that the process disrupts the financial structure of firms (the coordination over time of costs and revenues), and makes external financing crucial for a successful restructuring. An "optimal" monetary policy, in this framework, should then be expansionary during the transition, and tighten once the technological advance is embedded in the system. Thus, we reach conclusions that are in sharp contrast with the policy prescriptions of the New Keynesian approach.

CHOCS TECHNOLOGIQUES
ET CONDUITE DE LA POLITIQUE MONÉTAIRE

L'article analyse l'impact de politiques monétaires alternatives sur les performances d'une économie soumise à des changements technologiques. Il montre que la structuration de la capacité productive nécessaire pour incorporer les nouvelles technologies implique une diminution initiale de l'emploi et de la productivité, seulement réabsorbée si la transition est réussie. Au-delà, il montre que le processus introduit une rupture dans la structure financière des firmes (dans la coordination intertemporelle des coûts et des revenus), et rend crucial le financement externe dans le succès de la restructuration. Une politique monétaire "optimale", dans ce contexte analytique, devrait, alors, être expansionniste pendant la transition et restrictive une fois que le changement technologique a été incorporé dans le système. Ainsi, l'on obtient des conclusions qui sont en opposition stricte avec les prescriptions de politique économique de l'approche de la Nouvelle Économie Keynesienne.

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INTRODUCTION

In the past few years, there has been a resurgence of interest in the issue of how to conduct monetary policy in an economy facing strong and recurrent technological changes. This resurgence was motivated by the need to explain the extraordinary performance of the US economy over the nineties characterized by high productivity growth and low rates of inflation and unemployment. The new developments in the theory of monetary policy that go under the label of New Keynesian[1] (NK) have the merit of highlighting the real effects of monetary policy. Nevertheless, they have not challenged, but rather reinforced, the common belief according to which optimal policy is the one that fully stabilizes prices. A change of perspective that consists in focusing on the co-ordination problems arising with the restructuring of productive capacity through which innovation necessarily takes place, leads to a different conclusion. Optimal policies (in particular monetary ones) have to accommodate the processes of change that characterise dynamic economies, and as such they may have to tolerate, at least temporarily, inflation pressures. This is true in particular for technological shocks, the main source of economic growth, and thus the main topic of investigation for these analyses.

The paper is structured as follows. Section 2 will contrast two different approaches: the New Keynesian approach that belongs to the class of dynamic general equilibrium models and the neo-Austrian (NA) one, that focuses on out-of equilibrium processes. Section 3 will describe the sequential analytical framework which allows to bring into light co-ordination issues that are typical of the NA approach. Then section 4 will show, by means of numerical simulations, why technical advances cause a transition during which productivity may actually drop and how monetary policy influences the evolution of macroeconomic variables. Section 5 will summarize and conclude.

NEW KEYNESIAN VERSUS NEO-AUSTRIAN ANALYSIS

According to the standard macroeconomic analysis, technological change is the main source of a long-term steady growth, while co-ordination failures are the short-term forces that explain business cycles. In contrast with this view, the RBC approach sees the erratic nature of technological change as the major cause of short term fluctuations in real variables. The latter approach opens the door for a new interpretation of the natural output and hence of the output gap. The evolution of real variables under full wages and prices flexibility remains the benchmark. But this benchmark, no longer a static long run equilibrium à la Solow, is the dynamic path generated by the optimal response of rational agents to stochastic productivity shocks. The level of output that prevails at each moment of time along this equilibrium path with flexible wages and prices is the

1. The recent book by Woodford (2003) is the more complete reference on the subject. Other contributions in this stream of research include Clarida, Gali and Gertler (1999), Gali (2002), and Gali, Lopez-Salido and Valles (2003).

natural rate of output. In this context, price stickiness will result in an output gap defined as the deviation of the actual output from the fluctuating natural one. In the New Keynesian models (Gali, 2000, 2002; Woodford, 2003), optimizing policy makers seek to eliminate these distortions that arise as a consequence of firms' inability to adjust their prices to changing costs conditions. This optimal monetary policy consists in setting a rate of interest allowing to obtain the natural values of real variables. Following technological improvements, prices should change so that the real interest rate increase will induce consumers to reallocate intertemporally their consumption (*via* a standard Euler relation). If price stickiness prevents this adjustment from taking place, then the monetary authority has room for intervention; appropriate changes of the nominal interest rate will yield the same level of the real rate that in the flexible-price case was assured by the change in prices. In other words, in presence of an output gap induced by price distortions, optimal policy would have to play the role of price variations in inducing the consumers to reallocate intertemporally their consumption via real interest rate variations. Under the optimal policy, "the interest rate –both nominal and real– inherits the random walk property assumed for productivity growth, with an acceleration (deceleration) in the latter bringing about a permanent increase (decrease) in interest rates" (Gali, 2000, p. 11). In other words, the optimal reaction to technological improvements should be a tightening of monetary conditions, and *vice-versa*. Gali further shows that the Taylor rule, with appropriately defined weights, approximates the optimal rule. This broad property of optimal policy is at the basis of an assessment of the Fed performance by Gali, Lopez-Salido and Valles (2003); they claim to have found evidence in favour of a regime change occurred with the Volcker chairmanship; before that, the Fed policy was too biased in favour of income stabilization, whereas in the Volcker-Greenspan era it has behaved in substantial accordance with the optimal rule.

An important consequence of this setup is the absence of a trade-off between the objective of price stability and the growth objective. In fact, optimal policy fully stabilizes the output at the (fluctuating) natural level.

The proponents of this view claim it to be a revival of the Wicksellian one making use of the instruments of modern intertemporal optimisation models. As in Wicksell, it is the gap between a natural and a money rate of interest that determines the economic dynamics. However, there is a crucial methodological difference: while Wicksell focused on cumulative processes, that is, on the working of the economy during a disequilibrium period,[1] NK models assume that the economy is always in equilibrium, proceeding by means of comparative statics (or dynamics) analysis. Indeed, more than 20 years ago, Hicks had already warned against the risks of such an attempt: "It is not wise to run on, in the manner of Wicksell's successors,[2] converting the Wicksell model into a sophisticated model of equilibrium over time, current investment depending on expectations and equilibrium a condition in which expectations are not disappointed". (Hicks,

1. In Wicksell's model as the market rate of interest is for example reduced below the natural rate, bank lending expands and prices start to rise. This results in market imbalances and windfall gains which are the characteristics of a disequilibrium process.

2. Here Hicks quotes Lindahl and Myrdal, as well as his own work in *Value and Capital* (1939) and in *Capital and Growth* (1965).

1977, p. 66.) In fact the properties of transition paths cannot be simply deduced from the comparison between two (intertemporal) equilibrium paths. And it may well be the case that "the establishment of a rate of interest which is appropriate to the new equilibrium will indeed be required, when the new equilibrium is reached; but it must not be established before that equilibrium is reached" (Hicks, 1977, p.72). In other word, dynamics are not meaningless transition trajectories between equilibria, as in the standard equilibrium analysis. Rather, they are the normal way of functioning of an economic system, and have to be studied as such. In particular, the outcome of these processes may not be determined from the outset, but is the result of a complex interaction between agents' behaviour, institutions, and policy choices. We believe that implementing an interest rate policy adapted to the transition phase requires to identify the nature of the disequilibrium to be corrected. As we shall see, adjustments of nominal (and real) interest rates to be carried out during the transition, far from being aimed at compensating price stickiness, have to deal with liquidity constraints.

The main effect of innovation is to stir a process of capacity restructuring. During the process of change productive capacity is distorted, as the balance between investment in new technologies and consumption of present production is lost. This is unavoidable, as it is the intrinsic characteristic of the qualitative change that defines technology improvements. Therefore, during the sequence of non equilibrium states caused by the restructuring, observed output and productivity levels do not represent deviations from a potential trend, for the simple reason that the latter is no longer there. Thus, the conceptual issue to be addressed does not revolve around the capacity of a new technology (e.g. information and communication technologies) to boost the rate at which productivity can grow in a sustainable fashion. The focus must move on to the identification of the conditions under which an economy can really take advantage of a new technology and on how they unfold over the time path; *i.e.*, we focus on the conditions under which the distortion is dealt with, and finally reabsorbed, during the process of change. We maintain, in other words, that an economy is unable to capture the gains associated with the implementation of a new technology, so to say, automatically by its own in-built mechanisms. The level of output and productivity that the economy is actually capable of realizing mainly depends on the way coordination problems are dealt with; and monetary policy, as we shall see, has a crucial role in the success of the transition. In this context, the concept of output gap does not play the crucial role that it plays in the NK models. The problem to be addressed by policy makers is less to reduce an output gap and target a maximum growth rate, which cannot be really defined *ex ante*, than to smooth fluctuations in real variables, which are intrinsic in out-of-equilibrium processes of change. In fact, it will be clear below that these fluctuations feed back into agents behaviours and may be amplified by technical irreversibilities. This may lead to cumulative processes that propel the economy into an unsustainable path. Thus, by smoothing as much as possible these fluctuations, economic policy maximizes the chances of a successful outcome of the transition. In particular, as we shall see, technological changes require an accommodating monetary policy that by relaxing liquidity constraints allows full employment to be re-established and productivity gains to be effectively captured. As this may lead to temporary increases in the inflation rate, short term inflation targeting could prove to be too restrictive, and thus hamper the success of the transition.

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Another important consequence of neo-Austrian framework is that stickiness in the adjustment of prices and wages, instead of being the source of distortions, may under certain conditions appear as a means of avoiding cumulative processes and global instability. Thus, the NA and the NK approach appear to be radically different both in the analysis and in the role for policy action. True, in both approaches the room for policy action originates from distortions in the working of the economy; but while in the NK approach this is an institutional distortion (price stickiness) that has to be compensated by policy action, the NA model sees the distortions as an intrinsic characteristic of any process of qualitative change; the role of policy is then not so much to try to replicate an "ideal" state, but to manage the disequilibrium processes in order to ultimately guarantee the viability of the system. An important consequence of this difference is the way we look at the relation between monetary policy and structural reforms. According to the NK approach, in the benchmark flexible-price case there is no role for policy; thus, were structural reforms implemented and price flexibility attained, markets would smoothly work by themselves. In the NA approach structural reforms could never be substitutes for policy action, because the distortions the latter deals with are unavoidable.

As it is well known, technological possibilities change very slowly. This makes really implausible the assumption of technology shocks offering an explanation of business cycles. This is a critique that NK models share with the more general class of RBC models, so that it may seem at first sight odd to use them as a reference. But in fact what really matters is less the shock –its nature and its amplitude– than the way it will be absorbed by the economy. So rapid technological changes do not automatically result in fluctuations in real variables while minor changes may induce strong fluctuations: all depends on the way co-ordination issues are dealt with. And in this respect, an assessment of the role of policy variables is crucial, in the NK as in the NA approach.

Contrary to the traditional literature on vintage capital,[1] NK models focus on the role of policy in shaping the (equilibrium) path of the economy following a technology shock. As such, they are the natural term of comparison for the NA approach.

The next section will present a general aggregative model based on technical and behavioural irreversibilities. These characteristics allow to give a meaningful meaning to concepts such as "process" and "transition" and make the model fit to embed the features of technical change emphasized above.

1. This stream of literature was initiated in the early 1960s (e.g. Salter, 1960; Solow, 1960), and it has been recently revived (Greenwood and Jovanovic, 2001; Boucekkine, del Rio and Licandro, 2003) as a candidate for explaining the productivity slowdown of the 1970s.

Besides their lack of interest in policy issues, vintage capital models do not appear to have delivered the expected insight on the issue of technological progress. It can be shown (Phelps, 1962) that in spite of their analytical complexity, they still make productivity changes depend on technology parameters (with the addition, in the newer versions of the theory, of the rate of time preference) as in the standard disembodied progress models.

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A SEQUENTIAL ANALYTICAL FRAMEWORK

The immediate effect of any shock affecting the regular behaviour that defines an equilibrium state of the economy, is to throw the economy itself out of equilibrium. This depends on modifications in the structure and the functioning of the underlying productive capacity which actually determines this behaviour. The focus must therefore be put in the first place on the production process, and, in particular, on its time dimension.

For the purpose of building a sequential economy to track disequilibrium adjustment paths it is convenient to develop a model that crucially builds on two features: the first is a production process in Neo-Austrian terms (Hicks, 1973; Amendola and Gaffard, 1988, 1998, 2003). The second is a sequential order of events, which means a sequential articulation not only of the production process but also of the decision process. In particular, we have no longer instantaneous price adjustments (prices are fixed within the period). This allows disequilibria to come to the surface and take the form of undesired stocks of final output or of financial assets.

Consider then an economy where a single homogeneous commodity is produced by means of a primary input –labour– with a fully vertically integrated process of production taking place through a sequence of periods 1, 2, ..., n^c, $n^c + 1$, ..., $n^c + n^u$ These periods stand for the different operations (from the first project to the appearance of the final output) through which the production process takes place over time. Following Hicks these periods are grouped into two essential phases: a phase of construction *c* and, following it, a phase of utilization *u* of productive capacity. The time profile of an elementary process of production at each time *t*, is described by the labour input vector

$$\mathbf{a} = [a_i]; \qquad i = 1, \ldots, n^c + n^u \tag{1}$$

where a_i are dated labour input coefficients; and by the vector of final output

$$\mathbf{b} = [0, \ldots 0, b_{n^c+1}, \ldots, b_{n^c+n^u}] \tag{2}$$

where b_i are final output coefficients.

Thus, while labour is applied through the whole process of production, final output only accrues during the phase of utilisation, that is, after the phase of construction required to bring about productive capacity.

The intensity of productive activity at time (t) is given by

$$\mathbf{x}^c(t) = [x_1(t), x_2(t), \ldots, x_{n^c}(t)] \tag{3}$$

$$\mathbf{x}^u(t) = [x_{n^c+1}(t), x_{n^c+2}(t), \ldots, x_{n^c+n^u}(t)]$$

$\boldsymbol{x}^c(t)$ and $\boldsymbol{x}^u(t)$ are the vectors of the production processes in the phase of construction and the phase of utilization, respectively, where each element $x_i(t)$, $(i = 1, 2, \ldots, n^c + n^u)$, represents the number of elementary production processes of age i in existence at time *t* and figures out a degree of intensity of the productive activity. In other words, the productive capacity of the economy is described as a population of production processes the demography of which is changing over time.

In a neo-Austrian model production costs are reckoned in terms of the only primary input, labour, and hence the wage fund represents the resources which sustain the process of capital accumulation. The resources required to carry out production and to sustain consumption are financial resources, not physical output (all exchanges are intermediated by a financial asset : "money"). There are "external" and "internal" financial resources: $f(t)$ are the external financial resources (in short, the money supply); the money proceeds from sales (internal financial resources) are

$$m(t) = \min[p(t)s(t), p(t)d(t)] \tag{4}$$

where s and d are the supply and demand of final output and p the price. As we shall see below, on the one hand, $p(t)$ depends on excess demand $(d(t-1) - s(t-1))$ in the previous periods, and, on the other hand, *real* supply and demand, $s(t)$ and $d(t)$, depend on the current price level $p(t)$ determined, at the beginning of the period, by firms which are price makers.

The wage fund may include all the financial resources available for financing production processes, $\mathrm{F}(t)$, or, in case of a limited supply of labour, the part of these resources actually absorbed by the existing labour supply $\mathrm{L}^s(t)$ at the prevailing wage rate $w(t)$, that is:

$$\omega(t) = \min[\mathrm{F}(t), w(t)\mathrm{L}^s(t)] \tag{5}$$

with

$$\mathrm{F}(t) = m(t-1) + h^f(t-1) + f(t) - c(t) \tag{6}$$

where $\mathrm{L}^s(t) = \mathrm{L}^s(0)[1+\bar{g}]^t$ is labour supply ($\bar{g}$ is the natural growth rate), $w(t)$ is the wage rate, $c(t)$ is the "take out" (the fraction of resources withheld from financing production processes and used for consumption) and $h^f(t)$ the monetary idle balances which pile up when the human resource constraint is more stringent than the financial constraint, so that the financial resources available for investment in production processes cannot be fully used up:

$$h^f(t) = \mathrm{F}(t) - w(t)\mathrm{L}^s(t)\,. \tag{7}$$

The sequential articulation of the production process in the neo-Austrian representation makes it possible to bring into light the problems of intertemporal complementarity which result from the breaking of an equilibrium state. For the associated co-ordination problems to emerge we must count on a sequential articulation not only of the production process but also of the decision process. We consider therefore a sequence of decision periods and we let all decisions concerning price changes happen only at the junction of one period to the next, not within each given period. This implies a lag in response which makes the market disequilibria originated in the production side come to the surface rather than be immediately re-absorbed, as would be the case if we assumed instantaneous responses.

PRODUCTION DECISIONS. The money value of current desired supply is determined on the basis of expected money proceeds, which reflect expectations about the value of final demand determined on past experience:

$$s(t) = \frac{[1+g_m^*(t)]m(t-1)}{p(t)} \tag{8}$$

where $g_m^*(t) = (1-\lambda)\sum_{i=1}^{\tau}\lambda^{i-1}g_m(t-i)$. Current desired production $q(t)$ is then the difference between the current supply $s(t)$ and the stocks actually put back on the market $o(t-1)$:

$$q(t) = s(t) - o(t-1) \tag{9}$$

where $o(t-1) = p(t-1)\ \max[s(t-1) - d(t-1), 0]$. Produced quantity is subject to a (inherited) productive capacity constraint:

$$q(t) \leqslant \mathbf{b}\,\mathbf{x}(t-1)' \tag{10}$$

In case of excess capacity the vector of processes in utilization $\boldsymbol{x}^u(t)$ is scaled down by scrapping.

CONSUMPTION DECISIONS. Households are resumed to spend all their revenues (both wages and social revenues) unless they are rationed on the final good market. This corresponds to a behaviourist rather than optimizing view of the decision process. Accordingly, the money value of current households' final demand is determined by their financial constraint:

$$y(t) = p(t)d(t) = \omega(t) + c(t) + h^h(t-1) \tag{11}$$

where $h^h(t-1) = p(t-1)\ \max[(d(t-1) - s(t-1)), 0]$ are the monetary idle balances of households which pile up when the value of final demand exceeds the value of current supply.

INVESTMENT DECISIONS. Desired investment is aimed at preventing the distortions in the structure of productive capacity that represent a threat to the viability of the process of change undertaken. This implies that the desired rate of starts of new production processes at each period t is

$$x_1(t) = x_{n^c}(t)[1+\bar{g}]^{n^c} \tag{12}$$

By investing in new processes at the steady state rate $\bar{g}$, firms prevent distortions in the age structure of productive capacity. The total of resources needed for investment is then obtained by adding the new investment to the amount needed to pursue construction that is already undergoing:

$$\omega^c(t) = w(t)\left[a_1x_1(t) + \sum_{i=2}^{n^c}a_ix_i(t)\right] = w(t)\mathbf{a}^c\mathbf{x}^c(t)' \tag{13}$$

However, the investment which can be actually carried out is constrained by the availability of productive resources: in general, the actual evolution of the economy will diverge from that desired. The investment actually realized will be determined as the minimum between the investment desired by firms and the whole of available financial resources not required to carry out current production

$$i(t) = \min[\omega(t) - w^u(t), \omega^c(t)] \tag{14}$$

where $\omega^u(t) = w(t)\boldsymbol{a}^u\boldsymbol{x}^u(t)'$.

In this perspective, the rate of interest does not play an essential role– and, accordingly, is not explicitly considered in the model. As a matter of fact, a punctual variation in the rate of interest does not appear as a sufficient reason for the firms to change their investment decisions and hence does not appear as an effective co-ordination instrument. This is so because each investment belongs to a bundle of complementary investments over time and it would not be rational for a firm to drop it only because the interest rate increases at a given moment of time (Hicks, 1989, p. 119). On the other hand, a permanent increase in real interest rates will result in a stronger liquidity constraint. Total employment will be given by:

$$\mathrm{E} = \mathbf{a}^c \mathbf{x}^c(t') + \mathbf{a}^u \mathbf{x}^u(t') \tag{15}$$

EQUILIBRIUM. Consider now an economy in the equilibrium state associated with a given technique. This state is supported by a productive capacity characterized by a given equilibrium structure:

$$x_i(t) = x_{i-1}(t-1) = x_{i+1}(t)[1+\bar{g}] \tag{16}$$

In equilibrium, there is a given relation between processes in the (different periods of the) phase of construction and processes in the (different periods of the) phase of utilization; that is, an age structure of productive capacity which is constant over time: only the scale of the processes increases.

This equilibrium productive structure has a horizontal dimension –expressed at time t by the vectors $\mathbf{x}^c(t)$ and $\mathbf{x}^u(t)$ associated with the age structure required to sustain a certain equilibrium state or path– which also implies a corresponding vertical dimension (the time pattern of production associated with this age structure of productive capacity). These must be consistent with each other: a given equilibrium growth rate –that is, a given increase in the number of production processes arriving to the phase of utilisation in each period– necessarily implies a given (equilibrium) relation among the ages of the different production processes at each given moment of time. Then, together with construction and utilization, also investment and consumption (associated with construction and utilisation) and supply and demand of final output are harmonized, at each given moment of time and over time.

A shock of whatever kind, and in particular a technological shock, results in a modification of the age structure of production processes (*i.e.* a modification of the time profile of the $\mathbf{x}'s$). This is so because the shock both affects the rate of starts of new processes, $x_1(t)$, and involves some scrapping of existing processes, so that

$$x_i(t) = x_{i-1}(t-1) - u_i(t) \text{ for } (i=2), \ldots, n^c + n^u \tag{17}$$

where $u_i(t)$ are the processes scrapped (different scrapping rules can be assumed: we shall consider them in particular when commenting the different simulations carried out by making use of this model). This results in a distortion of productive capacity with respect to its previous equilibrium configuration,[1] a distortion that, even in the absence of specific interventions, propagates over

1. That is, a change in the ratio of construction to utilization production processes with respect to the equilibrium ratio.

time without needing any further shock. The co-ordination problems resulting from the original distortion imply that the age structure of productive capacity cannot be re-equilibrated. This is due to the existence of constraints on the rate of starts, and to the scrapping of production processes both in the construction and in the utilization phase.

The breaking of the intertemporal complementarity of the production process, that is a change in the age structure of productive capacity which does no longer sustain a steady state, is associated with the arising of problems of co-ordination over time of economic activity, that is, with the appearance of market disequilibria. As we have just seen, when construction and utilization are no longer consistent over time, the same is true for investment and consumption and for supply and demand. Thus co-ordination problems originate in the production side of the economy, namely, from distortions in its productive structure, and take the form of market disequilibria.

Reaction to these disequilibria, and the adjustments of productive capacity aimed at re-establishing the consistency over time of construction and utilization disturbed by the original shock, stimulate an out-of-equilibrium process that, through sequentially interacting disequilibria, propagates the initial distortion over time in a way that depends on how the adjustment takes place step-by-step. The sequential order of events –which means a sequential articulation not only of the production process but also of the decision process– has a crucial role in this context. In particular, we have no longer instantaneous price adjustments which allow markets to clear systematically. Markets are "fix-price", not in the sense that prices do not change, but in that it takes time to change.[1] This allows disequilibria to come to the surface and take the form of undesired stocks of final output or of financial assets.

Price and wage adjustment. The price of final output and the wage of labour adjust step by step to oncoming disequilibria in the respective markets. The price reacts to net excesses of demand observed in previous periods:

$$g_p(t) = \kappa\Phi(t-1) \tag{18}$$

where $g_p(t)$ is the rate of change of the price, and $\Phi(t-1)$ the rate of excess demand for final output. An alternative price adjustment rule that we shall use in the simulations below states that the price of final output can be adjusted in reaction to changes in the unit cost:

$$g_p(t) = \gamma\Upsilon(t-1) \tag{19}$$

where $\Upsilon(t-1)$ is the rate of change of the unit cost.

The labour market works in much the same way. Wages are changing from one period to the next either in relation to labour market disequilibria (whose

1. "While classical, new or old, viewed markets as generating real prices and wages, Keynes stressed that we live in a monetary economy, in which the wages and prices determined in markets, both in equilibrium and during disequilibrium adjustments, are wages and prices expressed in the monetary unit of account. Because these adjustments take real time, real wages and prices will deviate from their equilibrium values for finite periods of time, perhaps even for extended periods of time." (Tobin, 1995, p. 34).

effects are more or less mediated, according to the value of the parameter ν) or as a result of some indexation rule:

$$g_w(t) = \nu\Psi(t-1) \tag{20}$$

where $g_w(t)$ is the rate of wage change and $\Psi(t-1)$ the rate of excess demand for labour. The demand for labour, on the other hand, reflects not only past disequilibria on the labour market but also production decisions.

As a matter of fact, instead of having a simultaneous market determination of prices and quantities, prices (and wages) are determined in reaction to market disequilibria of the previous period, while output, and hence labour demand, are determined by reference to expectations that also reflect what happened during the previous periods. In other words, all the variables are determined within an analytical framework which exhibits both general and sequential interdependence. In this context "perfect flexibility", meaning by this that prices are at every instant at the values that equate supply and demand at the same instant, does not exist. Price flexibility is conceived as strong price variability within the context of markets which do not clear rather than prices that are at every instant at the values that equate supply and demand. In a sequential context there is always a certain degree of price rigidity.

The evolution path of the economy out of equilibrium is actually determined by the behaviour of control variables, namely, the supply of money and the take out.

External money demand is matched with money supply f^s, exogenously determined by the monetary authority. We did not directly model the interest rate because, as we said, we have made investment decisions depend on expected demand, and on the availability of funds (a similar viewpoint can be found in Stiglitz, and Greenwald, 2003). As a consequence, we are not concerned, in this paper, with the transmission mechanism of monetary policy through the interest rate. Coherently with these premises, we model monetary policy as a money supply function:

$$f^s(t) = f^s(t-1)\{(1-\zeta)(1+\bar{g}^*) + \zeta[1+\xi g_{f^d}(t) - (1-\xi)g_p(t-1)]\} \tag{21}$$

where $\bar{g}^*$ is the steady state growth rate of the economy, g_{f^d} is the growth rate of money demand which may be higher than $\bar{g}^*$ (when restructuring requires additional investing and financial means), and g_p is the expected growth rate of the price level. With $\zeta = 0$ a sort of Friedman (money growth target) rule is applied; With $\zeta = 1$ instead, monetary policy reacts to output and the inflation rate. In the latter case ξ and $(1-\xi)$ are the weights of growth and inflation objectives respectively[1]. This simple formulation, "helicopter" money, is enough in our framework to show the effects of monetary policy on liquidity constraints and on investment decisions.

1. This second case resembles to a sort of "Taylor rule". The underlying idea of adapting monetary policy to growth and inflation is in fact the same. But in our formulation as we explained, monetary policy acts through net credit supply and not through the rate of interest. Furthermore, it does not target the deviations from steady state values, but rather the growth rates of prices and income. This choice is consistent with our view that what matters is the out-of-equilibrium path of the economy, in which reference to a steady state would lose much of its sense.

The take out is determined on the basis of the current growth rate

$$c(t) = c(t-1)[1 + g_m(t-1)] \tag{22}$$

that is in such a way to maintain a constant ratio of public spending to the global revenue.

These mechanisms contribute to determine to what extent resources will be devoted to the utilization of the existing productive capacity and to the construction of a new one, respectively: thus also determining the age structure of productive capacity and its evolution over time.

In this context real wages, productivity and employment become all endogenous variables. What happens to productivity and employment is the result of feed-back mechanisms which depend on how the economy actually evolves and that can therefore change along the way. Thus the impact of changes in technology on productivity and employment cannot be reduced to technological or institutional factors only, but reflects rather the complexity of the interaction between decisions (as to current production, investment, prices, wages,...) and existing constraints in a sequential process.

SIMULATION OF ALTERNATIVE MONETARY POLICIES

In the simulations carried out we consider an economy in a steady-state with full employment to begin with, hit by a shock represented by the introduction of a superior technology characterized by an increase in construction costs more than compensated by the reduction of costs in the following phase of utilization of the new productive capacity, that is, by a strong forward biased technical progress.[1]

Our benchmark will be the case in which problems of co-ordination do not arise, notwithstanding the distortion of productive capacity resulting from the shock just mentioned (Amendola and Gaffard, 2003). This case requires in fact extreme assumptions. Firms are supposed to have a perfect knowledge of the model and, hence, they try to maintain the coherence of production processes over time so as to prevent distortions of productive capacity. This means, as regards investment decisions, to tune the dynamics of the rate of starts of production processes to the equilibrium growth rate of the economy, and, as regards current production decisions, never to scrap production processes in the utilization phase for a lack of demand, as if firms expected in each period a final demand such as to absorb all output from inherited productive capacity.[2] Moreover they do not bear any financial constraints: we assume that money supply is endogenously determined on the basis of the financial needs of firms, which means that monetary authorities have themselves perfect knowledge of these

1. The Fortran code used for the simulations is available from the authors upon request.

2. In other words, in this benchmark case firms do not react to current market disequilibria, which are considered as purely random phenomena, and do not revise their production plans in response to these disequilibria; current production is not given by equation 8, but by $s(t) = \mathbf{b}\ \mathbf{x}(t)' + o(t-1)$.

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needs and determine the amount of credit so as to satisfy them. The economy cannot jump to the new steady state, because the new technology has to be embedded into productive capacity, and this takes some time. An initial fluctuation brings about a temporary increase of unemployment as well as a temporary fall in productivity. However, in this benchmark case, the fluctuation very soon dampens down and the economy converges to a new steady-state corresponding to the superior technology, with a higher level of productivity –which allows lower prices and higher real wages– and full employment (figure 1). The full intertemporal co-ordination of the decision process, maintained notwithstanding the shock, owing to the assumed firms' behaviour, assures the re-absorption of the initial negative effects on employment[1] and productivity. These initial effects, on the other hand, depend on a distortion of productive capacity due to the appearance of a temporary human constraint even in the absence of a financial constraint. Thus the decision of firms to maintain a productive capacity in equilibrium over time notwithstanding the increase in construction labour costs of the new technique, which implies an increase in investment, cannot be implemented because of an insufficient labour supply. In any case it is worth mentioning that the temporary negative effects on employment and productivity do not depend on the specific features of the new technology but on a temporary breaking of the complementarity of productive resources. In particular, there is a fall in the rate of starts of production processes due to the fact that the existing labour supply cannot immediately match the increasing labour requirements of the new technology.[2] Finally, increasing price and wage flexibility, in this benchmark case has positive effects, allowing a faster reabsorption of the shock.[3] This benchmark thus has the same qualitative features of a dynamic general equilibrium model, while it does not respect the so called first principles, that is, it does not refer to intertemporal optimizing behaviour.

We can now depart from this somehow extreme case. We put the co-ordination problems at the center of the stage by dropping in turn the assumptions that were aimed at preventing them. In the first place, assume that current production decisions are based on adaptive expectations on changes in final demand (that is, they take into account current disequilibria, as shown by equation 8). On the other hand, although we maintain the hypothesis of an investment behaviour aimed at preventing distortions of productive capacity, and therefore abstract from the consideration of current disequilibria, the fact that these disequilibria actually arise as the result of the appearance of co-ordination problems may set a constraint on investment itself, through the availability of financial and/or human resources.

Co-ordination concerns in the first place productive resources, that is, financial resources and human resources, which must be kept in a certain complementarity relation. This means to take into account the source and allocation of these resources. In particular, as regards the source of financial resources, it means to deal with monetary policy, represented in our model by the supply of money, and

1. Due to a sort of "machinery effect" of the Ricardian type, according to which the introduction of machinery –to which an increase in construction costs may be assimilated– has an adverse effect on employment in the short run.

2. As a matter of fact a more elastic labour supply, or a different allocation of time between leisure and work in favour of the latter, would have prevented these effects from appearing.

3. The simulations, not shown, are available upon request.

Figure 1. *The Benchmark economy*

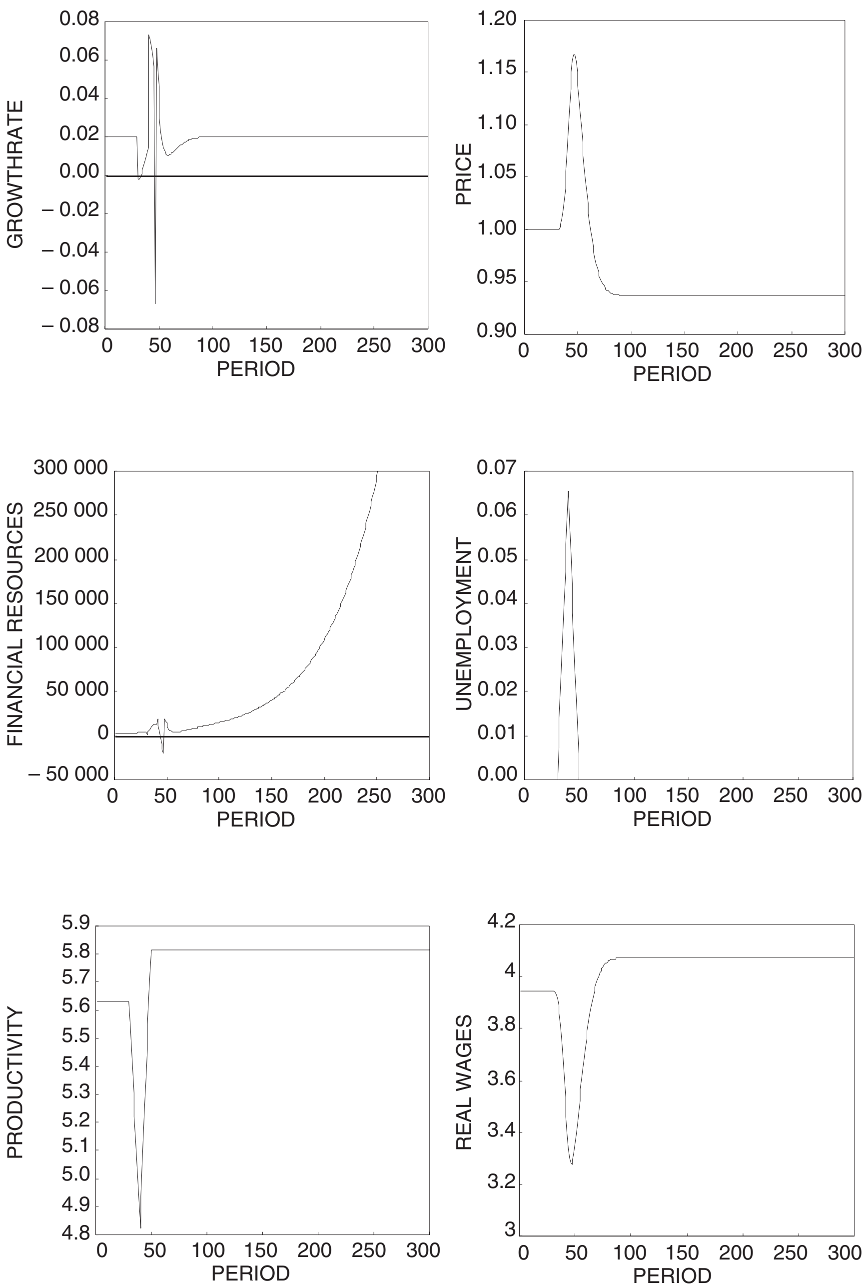
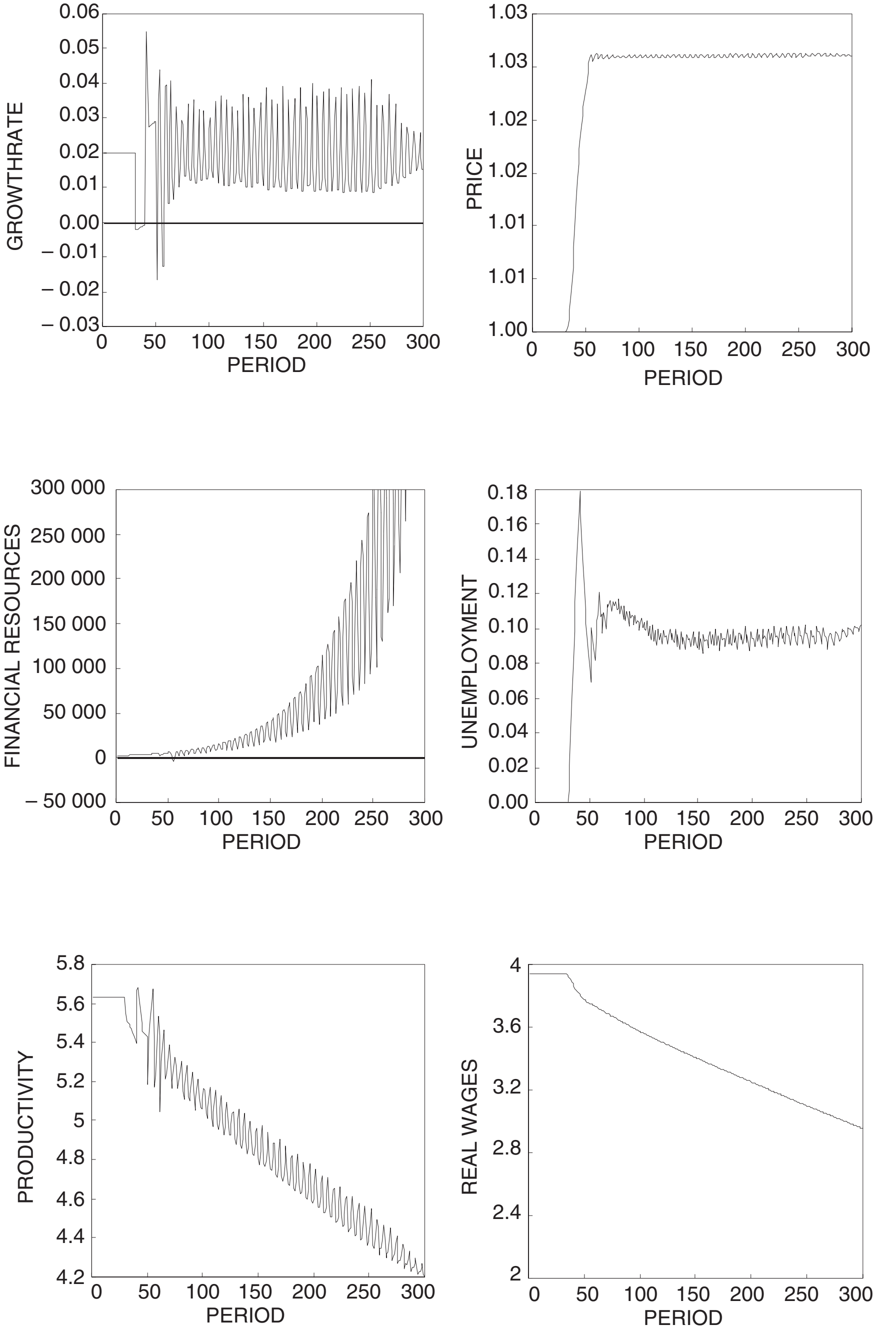


Figure 2. *A fixed money growth rule brings instability*



with social consumption, represented by changes in the "take-out". On the other hand, co-ordination also concerns the adjustment mechanisms, represented by price and wage changes, which determine the allocation of productive resources: namely, to what extent these resources are devoted either to the construction or to the utilization of productive capacity. Consider now a monetary policy that consists in letting the growth rate of the supply of money not to be affected by current shocks and be determined by the original steady-state growth rate of the economy (*i.e.* by a sort of Friedman rule, which implies $\zeta = 0$ in equation 21). With a growth rate of the "take out" which follows the current growth rate of the economy and a given degree of price and wage stickiness $\kappa = \nu = 0.01$, coordination problems, resulting in distortions of productive capacity, bring about permanent unemployment, and decreasing levels of productivity and real wages (figure 2). Although both nominal and real wages keep decrasing, unemployment is not re-absorbed and stabilizes to a positive value. Higher price and wage reaction coefficients do not help reabsorbing disequilibria. On the contrary they result in increasing unemployment that signals a global instability.

This phenomenon is a robust feature of our model, and is not limited to the particular parameter configuration corresponding to figure 2. To show it, we performed a Monte Carlo investigation on the price and wage reaction coefficients, *i.e.* of the (κ, ν) space. We made 900 random draws of $\kappa, \nu \in [0, 0.5]$, and recorded the difference between final and initial real wages and unemployment, with the corresponding frequencies. In most of the cases, unemployment increased as real wages decreased (figure 3). Let us now consider the effects of a tight monetary policy, that is, a policy aimed at maintaining stable prices ($\zeta = 1$, $\xi = 0$ in equation 21). With a given price and wage stickiness $(\kappa = \nu = 0.01)$ we have a reduction of the growth rate of output, a strong scrapping of production processes (reflecting strong fluctuations in final demand) and an asymptotic increase in unemployment notwithstanding the fall in real wages (figure 4). We also performed the same robustness check as before, by means of the Monte Carlo experiment. Figure 5 shows the results of 900 simulations corresponding to different values of the prices and wages reaction coefficients randomly chosen in the interval $\kappa, \nu \in [0, 0.5]$. In most cases, unemployment is persistent, and real wages decrease. Due to co-ordination failures, the producti-

Figure 3. *Monte Carlo simulations with a fixed money growth rule*

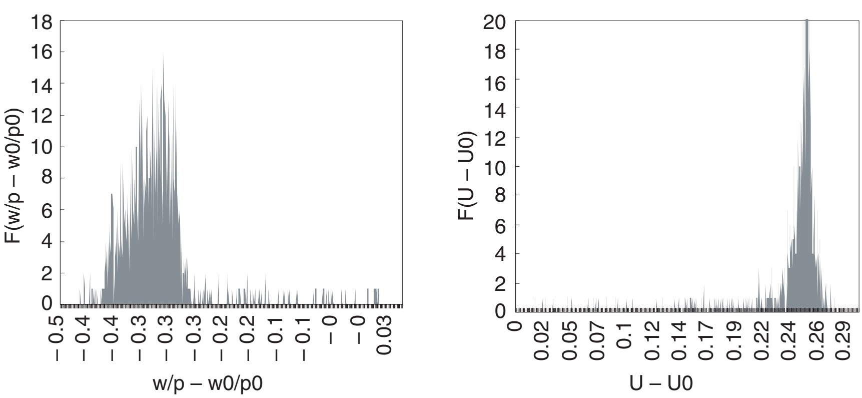


Figure 4. *Inflation targeting results in a continuous fall of productivity*

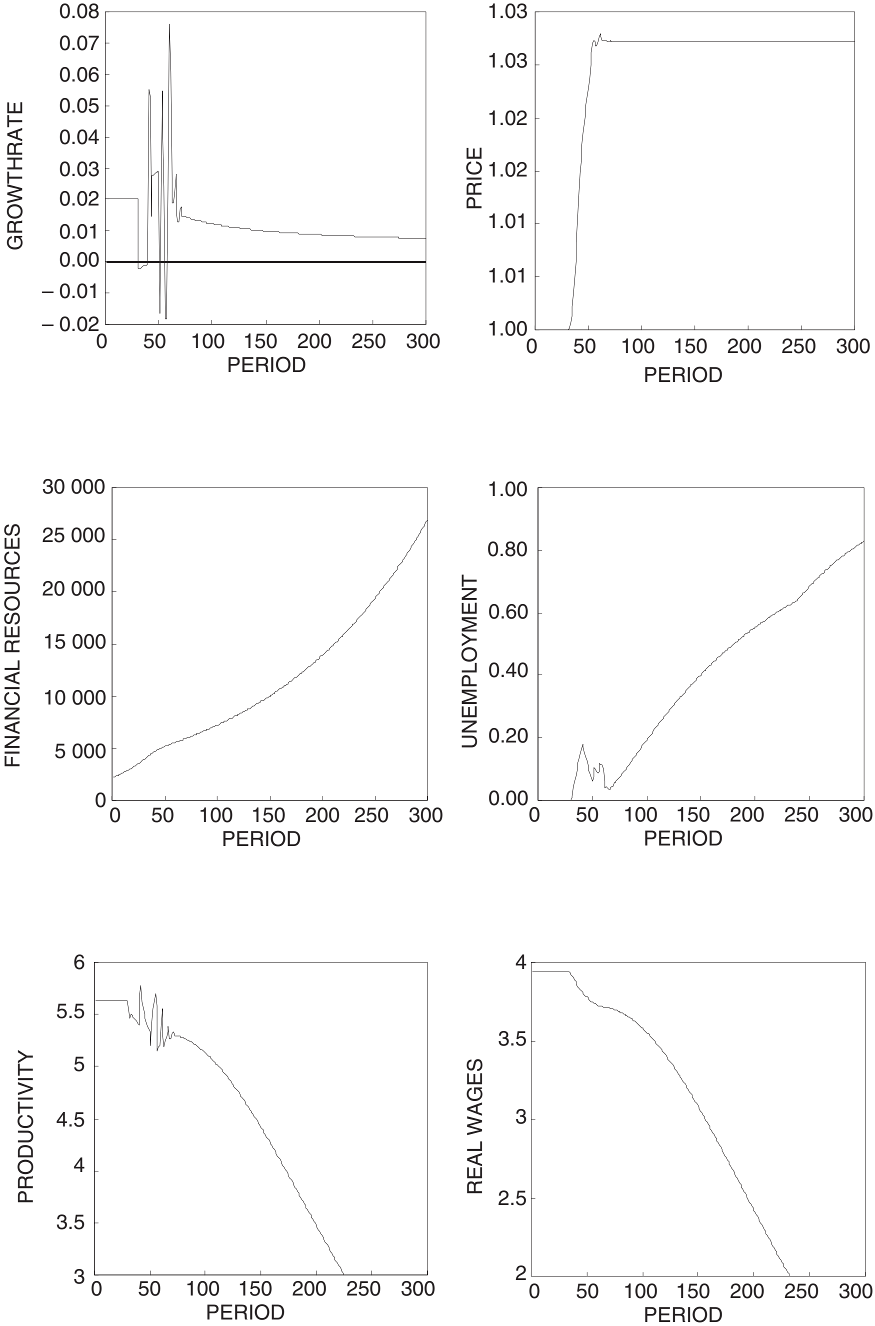
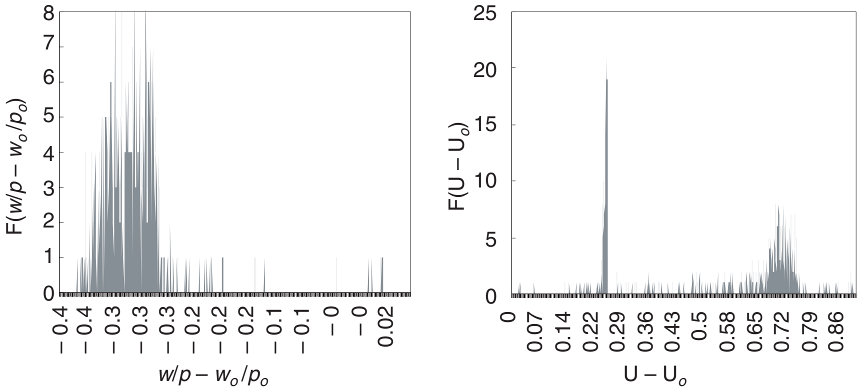


Figure 5. *The instability of inflation targeting is confirmed by the Monte Carlo experiment*



vity level of the economy decreases together with real wages, despite the fact that the new technique is more efficient than the old one.

An expansive monetary policy aimed at sustaining a transitory increase in the growth rate makes it possible to re-absorb unemployment, and to increase productivity and real wages, although at the cost of a limited inflation $((\zeta = 1)$, $(\xi = 1)$ in equation 21) As figure 6 shows it does, in other words, exactly what monetary policy should do: "to make sure that any productivity gains that occur spontaneously or as a result of supply-side policies are realized in jobs and output and do not go to waste in recessions and unemployment" (Tobin, 1996). The reason is that, thanks to the accommodating monetary (or banking) policy, there are not too strong distortions in the structure of productive capacity. The Monte Carlo method (figure 7) shows that once again this result is robust, as in most of the cases, unemployment is reabsorbed, and real wages increase. Due to a better co-ordination, the productivity level of the economy increases together with real wages in relation with the introduction of a superior technique. Price and wage flexibility does not matter. This is simply because financial constraints are removed, and hence coherent investment decisions can be carried out, which prevent too strong market disequilibria from appearing over time. Notice however, that in figure 6 the accommodating monetary policy yields increasing inflation and fluctuations in external financing. To avoid that, the supply of money should be brought back to its original growth rate after that the effects of the shock have been re-absorbed. Thus, after accommodating the transition, monetary authorities should go back to a steady state growth rate for external money $(\zeta = 0)$. In other words, monetary policy must be modelled following the evolution of the economy. Our simulations hence somehow yield a reappraisal of discretionary policy, tuned on the needs of the economy.

Finally, there is an alternative to an accommodating monetary policy that it is worth mentioning. When the price of final output is adjusted in reaction to changes in the unit cost and if the reaction coefficient is slightly superior to 1 (here 1.02), then, whatever the monetary policy carried out, the full employment equilibrium will be re-established, which is characterized by higher labour productivity and higher real wages. As a matter of fact, for a while, the increased mark-up results in additional liquidity and allows the desired investment to be

Figure 6. *A temporary increase in money supply provides liquidity and helps the reabsorption of the shock*

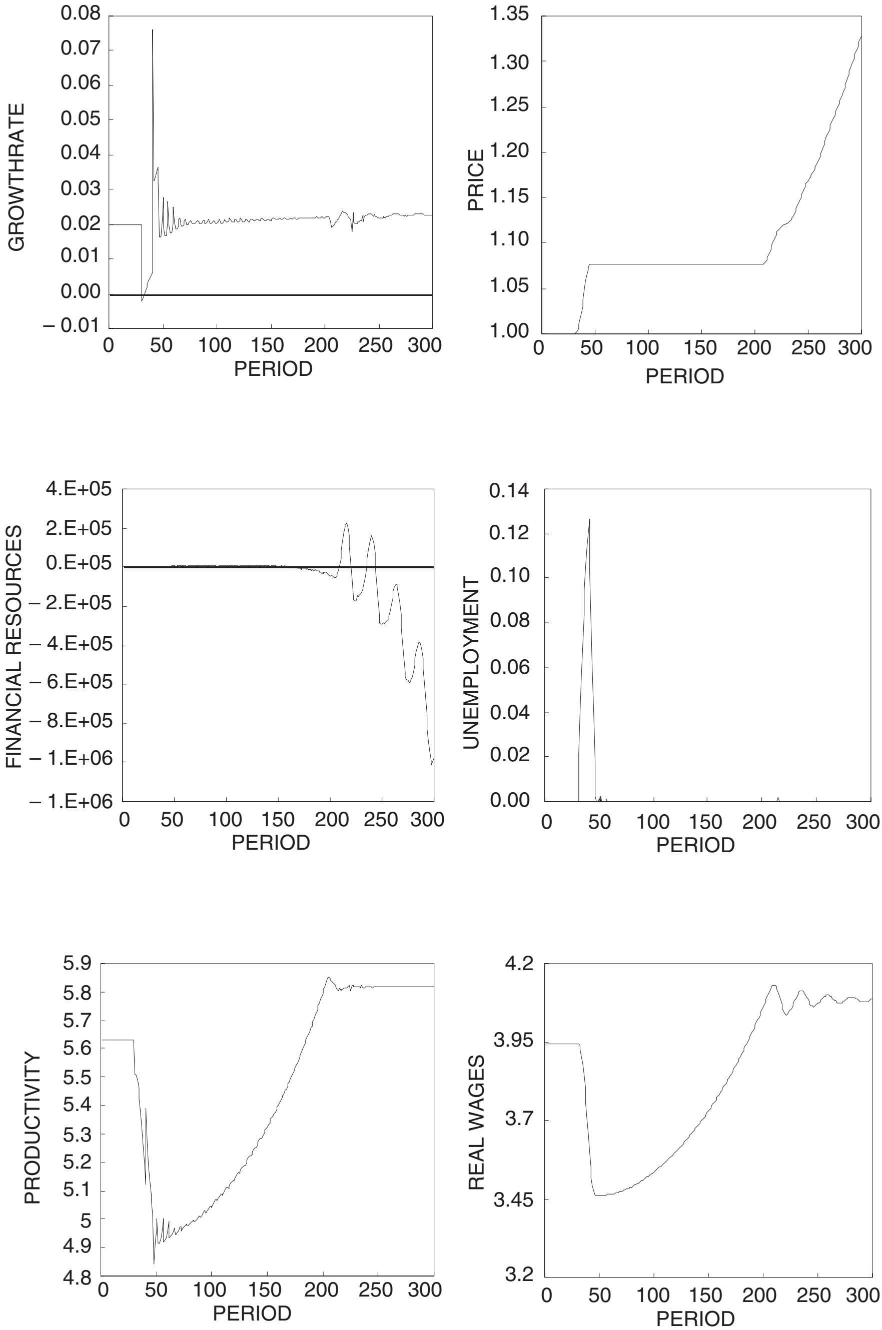
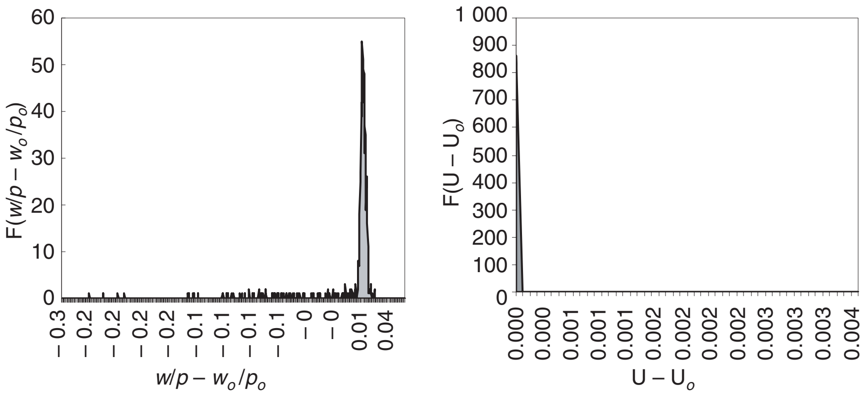


Figure 7. *Monte Carlo analysis with accommodating monetary policy: Shocks are completely reabsorbed*



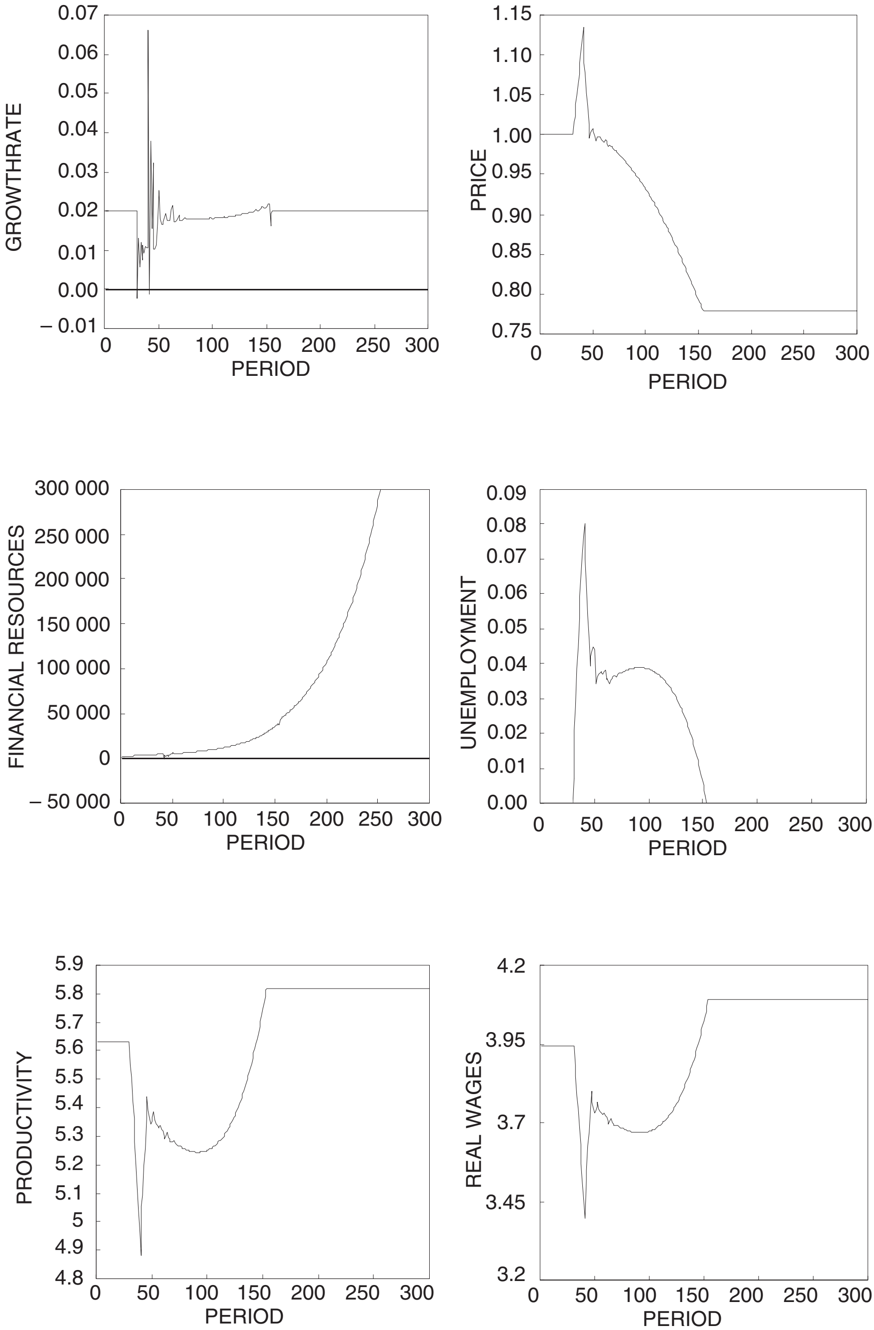
carried out (figure 8). In other words, monetary policy can be neutral or tight, but only in presence of monopoly power that allows firms to use extraprofits to finance investment. However, the new equilibrium will be reached for a value of the price reaction coefficient that falls down in a very narrow range. Any markup value outside this range will result in a cumulative process that hampers the viability of the economy, unless monetary policy is accommodating.

To sum up, similarly to NK models, an active monetary policy appears as an alternative to a full adjustment of prices to changes in the unit cost. But in our perspective the required policy in face of positive technological shocks is not tight but, at the opposite, an accommodating monetary policy. We saw that as a consequence the central bank faces a short run trade off between inflation and growth. This is due to the fact that investment plays a crucial role in the cyclical growth process in this model while the NK model focuses on the role of consumption behaviour within a dynamic general equilibrium framework.

CONCLUSION

Qualitative change, and paramount the creation of resources, is associated with structural modifications which imply a distortion of productive capacity such as to hamper the viability of the process of change undertaken. Dissociation of inputs from output and costs from proceeds is the real threat to viability, as it means the appearance of sunk costs which, by definition, cannot be dealt with by the proceeds of current productive activity or by means of the renewal of old credit contracts. "Additional" liquidity is then required to build the bridge through time at the heart of the production process destroyed by the distortion of productive capacity: and this can only be the outcome of an external intervention. The aim of this intervention is to re-establish consistency over time of construction and utilization, investment and consumption, supply and demand. It must therefore itself be articulated over time so as to properly interact with the modi-

Figure 8. *Mark up pricing and tight monetary policy: Monopoly power gives the firms the liquidity necessary for transition*



fication in the structure of productive capacity which is taking place sequentially; which means, in particular, being harmonized with the time profile of internally generated financial resources during this process. Although the natural rate of interest should increase in reference to the new and superior technology, during the transition the lack of financial resources makes it necessary to conduct a loose monetary policy. It will be carried out through a reduction in the monetary interest rate, which will respond to the temporary reduction in the productivity growth rate of the economy. This monetary policy allows minimizing both the output gap and the inflation rate over a given period of time, because it allows minimizing the distortions in the structure of productive capacity.

A policy dilemma exists, which is typical of economies that follow out-of-equilibrium paths. Innovation requires "to transmute the capital that was embodied in the late stages of old production processes into capital embodied in the early stages of new processes, that is a disruption of other activities which is 'bound to be a strain'" (Hicks, 1990, p. 535). Then inflationary pressures (and/or deficits in the trade balance in open economies) necessarily appear "because the goods in which the wages (...) will be spent (...) cannot be provided out of the product of the labour which is newly employed, for that is not yet ready" (*ibid.*).

Central banks can try to bring inflation back to the target level as soon as possible, with the consequence of exacerbating the initial negative impact of the shock on output and employment. They can, alternatively, decide an accommodating monetary policy bringing inflation back to the target more slowly with the consequence of simultaneously reducing inflation and unemployment. The latter policy consists in accepting transitory inflation in the perspective of reducing unemployment.

A recent empirical investigation reveals that the observed reduction in the volatility of the aggregate output in the US since the early 1980's emanated from the decline in the volatility within the durable goods sector alone (McConnell and Perez-Quiros, 2000). The latter change seems to support the view held in this paper, that is, can be interpreted as revealing less distortions in the structure of productive capacity over time, which is in our view the reason for a more regular growth path, and hence a higher level of employment. On the other hand the decline in the volatility just mentioned is closely correlated with changes in the conduct of US monetary policy, once again supporting the analysis carried out in the previous section.

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