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Bonaventura, Luigi and Caserta, Maurizio

2004

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April 3, 2007

Abstract

Investment activity produces effects on two different economic variables. On the one hand, it adds to the existing productive capacity, on the other, it represents a component of demand. What is required for demand may not be required for accumulation, and viceversa. As a consequence different adjustment mechanisms have been put forward in the economic literature to make the two aspects of investment compatible to each other. In all cases, a distinction has been made between the fundamentally macroeconomic nature of the demand aspect, and the fundamentally microeconomic nature of the capacity-augmenting aspect. This paper tries to discuss the foundations of a non-perverse adjustment mechanism based on the internalisation of the demand aspect of investment. The adjustment mechanism discussed earlier is based on investment reacting to positive or negative excess aggregate demand. Once it is shown that a collectively efficient equilibrium can be reached even on an entirely arbitrary basis, one may set out to show that a behaviour which gets selected in a small population can be easily extended to a large one.

JEL Classification - E12; E22; B52; C73

Key words - Investment; demand; capacity-aumenting; coordination-rule; evolutionary analysis.

1 Introduction

Macroeconomics is about the behaviour of aggregates. Such aggregates are usually modelled according to some *ad hoc* rule or are reduced to the agency of some representative individual. Alternatively, the behaviour of aggregates can be modelled as resulting from some repeated interaction among different populations of individual agents, which ends up with the establishment of a successful

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rule of behaviour. This kind of evolutionary explanation of macroeconomic regularities is followed in this paper.

The macroeconomic regularity studied is investment in the transition from a given warranted growth path to a differently scaled warranted growth path. The question is not of little importance in the theory of demand-led growth as it is an instance of the more general problem of the ability of autonomous demand to determine the path of growth. Starting with Harrod, the problem has engaged the mind of many economists who have tried to develop models of equilibrium growth where aggregate demand plays a prominent role. Unlike the line followed in the existing literature, which has fundamentally used *ad hoc* assumptions to accommodate demand in a model of equilibrium growth, the line followed in this paper suggests an alternative way to accommodate demand.

One of the main problems encountered in modelling demand-led equilibrium growth is the dual role of investment, as a component of demand as an act of accumulation. It is not at all obvious that what is required for investment in one of its role is also required for investment playing the other role. To model successfully the role of aggregate (investment) demand in the process of growth that conflict must be resolved. It is suggested here that the conflict might be resolved through the emergence of a rule of behaviour which becomes established as the outcome of an evolutionary process. This process illustrates the evolution of a set of populations by the evolution of their aggregate behaviour: through time the aggregate behaviour of each population changes, as more successful strategies replace the less fit ones. This process comes to an end when each individual member of the population is following the most successful strategy within the population. Since the proposed dynamics leads to a polarization of behaviour and since the rule necessary to resolve the conflict between the two role of investment is a rule of containment, where one population behaves differently from the other, it is argued here that such a containment can be seen as resulting from an evolutionary process.

The structure of the paper is as follows. Section 2 will identify the possible role of demand in the explanation of growth. Section 3 will illustrate the conflict between the two roles of investment and the solutions which have been provided in the literature. Section 4 will pave the way for a different resolution of the conflict. Section 5 will show the need for an evolutionary dynamics in the explanation of the studied macroeconomic behaviour. Section 6 will illustrate the working of the evolutionary dynamics. Section 7 will argue that such a dynamics can provide a way to model the transition from a given warranted growth path to another one.

2 Demand-led growth

Textbook growth theory suggests that growth depends primarily on the availability of productive resources without paying any attention to demand factors. It is through the accumulation of produced resources that labour can grow more and more productive with the result that the main limit to growth comes from insufficient accumulation. Economies are thus engaged into the problem of allocating their income through time but never fail to fulfil their intertemporal plans. Problems may arise form market imperfections, externalities and the like but no interference originates from insufficient demand, i.e. no interference originates from the very simple fact that output must be sold before it is turned into income. Growth therefore is presented as an unambiguously supply-side process.

Once such an interference is allowed for, two main consequences follow. At any given time, output may be lower than its potential level. As a result, accumulation may be different, with an obvious consequence on the path of labour productivity. The growth path the economy is going to follow is necessarily different from that it would follow if no demand problem existed. Thus, at any given time, output is influenced by present and past demand failures. Economies will be more or less prosperous according to whether demand is not or is capable of holding output and accumulation in check. In the introduction to a symposium on demand-led growth, Setterfield (2003) points precisely to this double impact of demand on economic growth. He recalls that, at any given time, demand affects the degree of utilisation of productive resources, questioning the usual assumption that in the long run the actual degree tends to the normal degree of utilisation. He also recalls that a variable aggregate demand implies a variable investment demand. Hence, the future availability of productive resources is affected by the current degree of utilisation of productive resources. According to Setterfield a variable aggregate demand may also affect the type of investment planned and even the availability of financial resources. Thus the principle of effective demand operates both in the traditional Keynesian fashion, as the main determinant of the level of output relative to existing resources, and as the main determinant of existing productive resources, which are always created with the purpose of meeting demand[1].

Once the role of demand in the process of growth is recognised a model of demand-led growth must be put forward. This requires modelling demand and a mechanism through which demand determines a particular pattern of growth. In most cases it is equilibrium growth which has been searched for, that is a pattern of growth where demand and output grow at a constant rate through time. The literature on growth is full of models which yield an equilibrium rate of growth as a result of the operation of an independent demand. The component of demand which has been given a prominent role is clearly investment demand.

The reason why investment demand is accorded a prominent role in the theory of demand-led growth is because Say's Law cannot be proved in the case of investment demand. When investment is a component of demand, it is no longer true that demand is always equal to supply, as not all supply turns automatically into demand. Investment demand is not necessarily associated

[1] The extended operation of the principle of effective demand is advocated in the work of Garegnani (1978, 1992) and set within the tradition of Sraffian Economics. The general idea is that the growth of autonomous demand is the main factor behind the growth of productive capacity. This is made possible by a flexible degree of utilisation of the existing productive resources.

to the supply of output, but is independent by its very nature. Once this is made clear the road is open to modelling investment demand and to studying its relevance to the process of growth.

Giving prominence to investment demand in modelling demand-led growth carries with it an important implication. Since investment is both a component of demand and an act of accumulation, it ends up capturing the full impact of demand on economic growth. Investment demand failures, therefore, affect current output but also future output through the effects on the accumulation of productive resources. Thus investment plays an active dual role in the process of growth: on the one hand, as a component of demand it must bear a desired relation to some variable, on the other, as new capacity it must bear a desired relation to some other variable. It is clear that the reconciliation between the two roles of investment is the key to a successful development of a model of demand-led equilibrium growth.

3 Demand-led equilibrium growth

The reconciliation between the two roles of investment has engaged the mind of many economists, from Keynes to Harrod and Kalecki, from Kaldor to Solow. What is required for investment as a component of demand may not be required for investment as new capacity, and *viceversa*. As a consequence different adjustment mechanisms have been put forward in the economic literature to make the two aspects of investment compatible to each other. In all cases, a distinction has been made between the fundamentally macroeconomic nature of the demand aspect, and the fundamentally microeconomic nature of the capacity-augmenting aspect. Investment is driven by the prospect of profits, but investment demand in the aggregate is not necessarily compatible with full utilisation of productive capacity. When this is the case distribution (the rate of profit or the rate of interest) will change so as full utilisation of productive capacity is achieved. Adjustment is also possible by means of a variable degree of capacity utilisation.

The whole story starts with Keynes who, as a matter of fact, did not have to face any problem of reconciliation between the two roles of investment. Investment in Keynes is only a component of demand; no attempt is made to develop a model of equilibrium growth. According to Keynes the lapse of time between the purchase of new capital and its utilisation is usually too long for investment to be checked in the light of realised results. Once new capital is installed it is too late to ask whether it was the right thing to do. There is no point, therefore, in looking for an equilibrium condition for capital; even if it were realised it would have no relevance for future decisions[2].

The story continues with the work of Harrod who, unlike Keynes, tries to make the rate of growth of demand compatible with the rate of growth of capacity but cannot specify a mechanism through which this comes about. If the economy happens to be on the right track, the growth rate of investment demand

[2] Chick has consistently interpreted Keynes in this light. See for example Chick (1983).

will create no more nor less capacity than what is required to meet that very growth rate of demand. However, should the growth rate of investment demand change for whatever reason, no mechanism would make this new growth rate compatible with equilibrium growth. This problem is known as Harrod's knife-edge and arises from the assumption that investment demand reacts to overall variations in demand. Since investment is a component of demand the initial change in the growth rate of (investment) demand will be aggravated, with the result that a vicious circle is set in motion with no obvious mitigating device. Thus, in Harrod, the incompatibility between the two roles of investment is exposed, but not resolved.

Three routes were available to resolve the conflict. The first one was the extreme one: doing away altogether with investment demand. This route was taken by Solow who reduced investment to a mere realisation of saving decisions. Investment is just capital accumulation: equilibrium implies a particular capital-output ratio and a particular capital-labour ratio. No requirement is fixed for investment decisions other than that of being equal to savings. Thus Harrod's problem is solved through the elimination of the original source of the problem: no change in the rate of growth of aggregate demand is possible simply because there is no aggregate demand one can speak of.

The extreme route is not the only one, however. By making one of the two parameters of Harrod's model flexible, room is made for investment demand not to impinge on capital utilisation requirements. These are the routes taken by Kaldor, who made savings flexible by means of flexible income distribution, and Kalecki, who made the capital-output ratio flexible by allowing for different degrees of capital utilisation. The route taken by Kaldor starts from the assumption of differentiated saving propensities and is based upon the variability of the price level. If the growth rate of investment demand is increased more savings will be made available by the increase in the price level; if the growth rate of investment demand is reduced the price level will be reduced to let consumption compensate for the lack of aggregate demand. The autonomy of investment demand, therefore, ceases to be a problem as enough savings will be always available to make a given rate of growth of investment demand possible. Aggregate demand drives growth but its most typical manifestation, that is, a variable output, is suppressed.

A variable output, relative to capacity, is not suppressed in the route taken by Kalecki[3]. In this approach investment demand is allowed to play its effects on output but the requirements of capital utilisation are made less stringent. A change in the rate of growth of investment demand is accommodated through a change in the degree of capacity utilisation. It is assumed that within the limit of potential output capital need not be in a given relation to output. Thus investment demand affects current output and also future output through a variable rate of accumulation of productive capacity, but no particular requirement is imposed on the utilisation of capital.

[3] The so-called Kaleckian approach has generated a wide literature on growth. See, for example, one of the most quoted: Rowthorn (1981).

The conflict exposed by Harrod finds a resolution in the approaches followed by Kaldor and by Kalecki. In order to make investment demand play a prominent role in the process of growth, and produce at the same time a stable model of equilibrium growth, these approaches have had to devise adjustment mechanisms that weaken the requirements fixed in Harrod's approach[4]. The question faced in this paper is whether that conflict can be resolved without weakening any of those requirement, that is, without requiring other than normal degrees of capital utilisation and without requiring a variable saving rate.

4 A different route

If we dispense with the previous assumptions of a variable degree of capital utilisation and with a variable saving rate we are left with an adjustment mechanism which is rather perverse. An autonomous variation in the growth rate of investment demand (or an autonomous variation in the level of investment demand) will tend to aggravate the initial demand problem: positive excess demand induces an increase in investment; negative excess demand induces a reduction in investment. The system will move further and further away from equilibrium. There might be cases, however, when such perverse effects are mitigated or even cases when they are offset completely by opposing tendencies. It is precisely these cases that this paper intends to investigate further.

For investment to react to demand in a non-perverse way, positive excess demand should, at some point, cease to induce any more investment, and negative excess demand should, at some point, cease to induce any further reduction in investment. Later the foundations of a non-perverse adjustment mechanism will be discussed. The alternative mechanism should be based on the recognition that reducing investment with negative excess demand and increasing investment with positive excess demand is not a successful way of reconciling the two different roles of investment. In the aggregate such a mechanism aggravates the initial disequilibrium. In that case it becomes impossible to show how an autonomous variation in demand affects the growth path of the economy. The crucial question now is the following: is there a possibility that a non-perverse adjustment mechanism comes into effect, with the result that in the case of positive excess demand, the increase in investment meets with a superior limit and, in the case of negative excess demand, the reduction in investment meets with an inferior limit?

To show that such a mechanism can offer a reconciliation between the two roles of investment as a component of demand and as accumulated capacity a very simple story can be told. Let us assume that a Harrodian equilibrium is disturbed by an autonomous increase in the level of autonomous demand. What is required in this case is an increase in the scale of the economy without any change in its long-term rate of growth. If this transition were successful the role of demand would become apparent in the change in the scale of the economy. The path of growth could be said to be demand-led. The transition

[4] See as a recent example of this approach Erturk (2002).

starts with a positive reaction of investment to the positive excess demand. However, investment aggravates the initial demand problem. For the transition to be successfully completed the aggravation of the demand problem should not give rise to any further increase in investment. The economy should create the new capacity to meet the recent increase in the level of demand, but should not be affected by the induced increase in demand which has no autonomous justification. Similarly, in the case of a decrease in the level of autonomous demand, investment should be reduced to reduce the scale of the economy, but no further induced reduction should be allowed. What is necessary, in both cases, is a containment effect which leads investors to realise that further investment is not required, in the case of an increase in demand, or that no further reduction is needed, in the case of a decrease in demand.

In what follows an attempt will be made to provide foundations to such a containment effect. Unlike the Kaldorian or the Kaleckian ways out of the problem which are based on the relaxation of a constraint that is external to investment decisions, here a self-regulating mechanism will be suggested. Since what is required is that investors coordinate their plans so that not so much investment is generated in the case of an increase in aggregate demand, and not so little is generated in the case of a decrease in aggregate demand, a compensating mechanism will be suggested, primarily designed to differentiate investors plans.

5 A coordination rule

A collective rule of behaviour must be introduced, resulting from a spontaneous interaction among investors, requiring each of them to react differently to positive or negative excess demand. A process is also required designed to coordinate the different investors plans so that an equilibrium can be attained. In the case of a positive excess demand, for example, investors will increase investment, but through a process of differentiation of their behaviour overall investment will be forthcoming in the right amount. How do we explain the emergence of such a rule of behaviour? Is it possible to explain this rule by resorting to the theory of rational choice?

The question is not straightforward. It raises some problems especially with respect to the assumption of agent rationality within game theory. What is at issue is whether collective choices can be founded on rational individual action. It is widely acknowledged that it might be difficult to explain the effects of collective interaction by means of the theory of individual action. In some cases the assumptions of individual rationality and common knowledge limit the possibility of a plausible explanation of these interactions.

These types of interaction are commonly considered by game theory and usually grouped under the heading of *coordination* games. The main feature of these games is that of possessing multiple Nash equilibria with a not necessarily clear Pareto-ordering. In such circumstances and, also, when players cannot communicate, the assumptions of individual rationality and common knowledge do not necessarily allow any prediction of which equilibrium will be selected. Schelling (1960) uses the concept of *focal points* to identify the particular Nash equilibrium most likely to be selected. Focal equilibria are culturally determined, so they change according to the context in which the interaction takes place. If two individuals, not living in New York, are meant to meet somewhere in New York, but cannot communicate, they will probably take the Empire State Building as a focal point; unlike two new Yorkers who will probably choose Grand Central Station.

Which equilibrium becomes a focal point is determined by the social and cultural context of the interaction, i.e. by its past history. In this line focal points can be considered as stable social conventions resulting from a dynamic process which through time coordinates individual behaviour (Sugden, 1989). A convention, by its very nature, is not unique, but represents only one among many solutions of a game. It is the outcome of an evolutionary process which builds upon the interaction of many individuals in a long-term dynamics (Binmore and Samuelson, 2002). The main feature of these processes is an adaptive interaction, which means that agents are randomly paired in each period and they adapt their strategies by means an historic process. A convention is an equilibrium in which each agent is playing the strategy which she is expected to choose. But how are expectations formed in case of multiple equilibria?

The evolutionary approach offers a plausible explanation of the dynamics of the process through which expectations and strategies converge towards a specific equilibrium. Peyton Young (1998) has emphasized the merits of evolutionary analysis and the reasons why it should be preferred to classical analysis in the explanation of the emergence of equilibria. A distinguishing feature of evolutionary analysis is the notion of rationality assigned to individual agents. Agents look around, acquire information and adapt their behaviour according to a trial and error mechanism.

The purpose of this paper is to show how, by means of a process of coordination of the plans of individual investors, an equilibrium can be reached where investors play different strategies. If this equilibrium prevailed the above mentioned containment effect would be produced. To show all this a model where individual agents interact with one another is required. The particular game used, given the nature of the interaction, is a coordination game. Our model of coordination formation is based on Young's evolutionary model of bargaining (Young 1993). The model is bottom-up in the sense that the coordination behaviour emerge spontaneously from the decentralized interactions of self-interested agents. In each time period two randomly chosen firms interact, bargaining on the choice of investment. Their behavior, and their aspectations about others' behavior, evolve endogenously based on prior experiences.

It can be show that the coordination solution is an evolutionary stable lonrun behavior and starting from any arbitrary initial conditions, the system will converge into the two pure Nash equilibria.

The following game (fig. 1) is a pure coordination game, symmetrical in payoffs. The available pure strategies for each investor are I (invest) and N (not invest). The associated payoffs are the following: $a > 0$. The game has two strict Nash equilibria (I, N), (N, I) and one in mixed strategies (p^*, q^*), where each investor plays I with probability p and N with probability $1 - p$.

	I	N
I	0	a
N	a	0

fig. 1

How does a firm decide what strategy to follow in the previously game? Instead of assuming equilibrium, we wish to explore the process by which equilibrium emerges at the aggregate level, from the repeated, decentralized interactions of firms. We can think that the firms follow the history of how the other firms have played in the past, and choose a strategy for the future that is the best response to the past play of others. We call this *adaptive learning.*

6 Adaptive Learning

We begin by studying this question for a population of firms who are indistinguishable from one another, but who have different experiences that condition their beliefs.

Let the population consist of N firms. Each time period consists of $(N/2)$ "matches". In each match, one pair of firms is drawn at random from the population, and they play the game in fig.1. Every firm remembers the choices - I, N - played by each of her opponents in the last m periods, where m is the memory length. The concatenation of all firm memory defines the current state of the society. Behaviorally, each firm forms its strategy on the opponet's prior choices, with the following matching rules; the best response to II is thus N, the best response to NN is I, and the best response to IN or NI is any combination of I and N. We take this combination to be: play I with probability 1/2 and N with probability 1/2. These rules for matching and behavior formation define a particular social dynamic as a function of the population size N and memory length m. Notice that it is a Markov process, because there is a well-defined probability of moving from any given state s to any other state s' in the next period.

If S is the finite set of available strategies to firms, and N is the finite population of firms, then there will be S^{Nm} "states of game". In the simplest example with $N = 2$ and $m = 2$, there are sixteen distinct "states" of the game, which we label *abcd*, where each of the letters can be I or N, b is the last move by firm 1, a is firm 1's move previous to this, d is the last move by firm 2, and c is firm 2's previous to this. For instance, $IINI$ means firm 1 moved I on the previous two rounds, while firm 2 moved first N and then I.

Ordering the "states of game"; *IINN, IIII, IIIN, IINI, INNN, INII, ININ, INNI, NINN, NIII, NIIN, NINI, NNNN, NNIN, NNNI, NNII*, we can now compute the probability of a transition to any other state on the next play of the game. *IINN* (and similarly *NNII*) is an attractor state in the sense that, once it is entered, it stays there forever. The state *IIIN* goes to the states *IINN* and *INNN*, each with probability 1/2. The state *ININ* goes to *NNNN, NINN, NNNI, NINI* each with probability 1/4. And so on.

We can summarize the transitions from state to state in a 16×16 matrix (generally $|Z| = S^{Nm} \times S^{Nm}$), call Z the *probability transition matrix*, and the dynamic process of moving from state to state is a *Markov chain.* In our example, we will assign for any row and column a relative "state", as follows: *IINN* =1, *IIII* =2, *IIIN*= 3,..., *NNII* =16.

Also, if we represent the S^{Nm} states by the S^{Nm} row vectors $\{v_1, v_2, ..., v_s\}$, where $v_1 = (1, 0, 0, ..., 0)$, $v_2 = (0.1, 0, ..., 0)$, and so on, then it is easy to see that if we are in the state v_i in one period, the probability distribution of states in the next period is just $v_i = Z$.

If the system starts in state i at $t = 0$, $v_i Z$ is the probability distribution of the state it's in at $t = 1$.

$$v_i Z = p_1 v_1 + ... + p_s v_s$$

Then, with probability $p_j$the system has probability distribution $v_j Z$ in the second period, so the probability distribution of states in $t = 2$ is

$$v_i Z^2 = p_1 v_1 Z + ... + p_s v_s Z$$

Similar reasoning shows that the probability distribution of states after k periods is simply $v_i Z^k$. Thus, just as Z is the probability transition matrix for one period, so is Z^k the probability transition matrix for k periods. To find out the long-run behaviour of the system, we therefore want to calculate:

$$Z^* = \lim_{k \Rightarrow \propto} Z^k$$

I trust you understand that this cannot be calculated by hand! However, there are ways of computing Z^*; for instance, Mathematica the computer algebra software package calculate Z^k for larger and larger k , high values of N (number of firms) and many periods of recall m.

We are interested in the long-run behavior of an ergodic Markov chains. In particular, we are interested in the behavior of a system that we espect will attain a long-run equilibrium independent from its initial conditions. Young (1993) pointed out that for a special class of n-person games adaptive play converge to a Nash equilibrium. These games have the property that, from any initial choice of strategies, there exists a sequence of best replies that leads to a strict, pure strategy Nash equilibrium. In other words, no matter where you start, you end up in one of the *attractors* (*IINN*), (*NNII*), which is a strict Nash equilibrium in the coordination game. We conclude that the *adaptive learning leads with probability 1 to a Nash equilibrium in which the firms coordinate themselves differencing their strategies.*

7 The knife edge mitigated

The previous model shows that whatever situation we move from, the adaptive evolutionary process will lead to an attractor state in a k periods. The population of firms will select itself into two strategies will do one thing and the other will do the other thing. This final outcome is reached through a process of trial and error whereby each member of a population adapts her behaviour to the history of the opponents. The essential idea is to show how an equilibrium based on coordination behavior can emerge spontaneously from the interactions of many firms. Due to the self-reinforcing nature of the process, these behaviors tend to perpetuate themselves for long period of time, even thought they may have arisen from purely random events and have no a priori justification.

This kind of dynamics can be used to provide the containment effect that is required in a model of equilibrium growth when the traditional assisting devices are no longer available, i.e. when neither a variable degree of capital utilisation nor a flexible distribution are in operation. For that containment effect to be produced the following conditions are required: *(i)* when an autonomous increase in aggregate demand disturbs the warranted growth path, a contained increase in investment; *(ii)* when an autonomous reduction in aggregate demand disturbs the warranted growth path, a contained decrease in investment. This means that all the populations of firms should not react to the disturbance in an homogeneous fashion. If all the populations managed to contain their reaction, the transition to the new growth path would be successful. The idea put forward here is that such a containment is achieved by a polarization of behaviour: if one population invests the other should not invest.

The evolutionary dynamics illustrated earlier can give a plausible account of the process leading to the establishment of a rule of behaviour in the case of aggregate demand disturbances. By means of a process of trials and errors, firms establish themselves as belonging to the reacting or to the non-reacting type. Once the disturbance occurs the polarization of their behaviour is precisely what is required to ensure a successful transition to the new steady growth path.

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