Comments on the paper

"Structural Interactions and Long Run Growth: An Application of Experimental Design to Agent-Based Models" by T. Ciarli

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The wealth of nations depends on a great number of factors. Classical economists emphasized the role of accumulation of physical capital, as well as the constraints of natural resources. Solow also shared the view of classical economists, except that he pointed to the importance of technological change. Romer (1986) however noticed that the emphasis on capital accumulation would lead to a conclusion of accelerating growth in the earlier phases of development, and at a dismal growth in more advanced stages of development. Such a conclusion, he argued, is patently against any historical records. If Romer pushed the line of the market mechanism that favors the appearance of new technologies, as a way to explain the modern acceleration of growth, Lucas (1988) hypothesized that human capital formation has an even more fundamental role. Arrow (1966), in an article so much ahead of his time, thought that the accumulation of capital and the adoption of a new technology are indeed just two faces of the same coin, for usually investments carry also new technologies. Contrary to many neoclassical economists, he preferred a fixed coefficient production function, underplaying the role of substitution of labor and capital as a key mechanism in the process of growth. Ciarli (2012) follows somehow Arrow's approach, in the production of goods, by giving an explicit vintage structure to the production process, but enriches it with further elements to account for institutional aspects of the labor market, where there are three types of individuals – managers, engineers, and production workers –, and to incorporate modern developments of the innovation literature. Indeed not only both horizontal and vertical innovations are modeled, but also the introduction of a new product proceeds in two separate phases – invention and development of a prototype.

Since the literature has emphasized, investments, innovation, structure of the labor market, composition of consumption, inequality, initial endowments, as the key elements of the long run fortune of advanced countries, Ciarli sets up an exercise that delivers us a ranking of these factors. This is indeed what policy makers ask for whey they turn to economists, only to get frustrated when they discover that every economist has a strong prior of what matter most for long run growth.

Ciarli goes some way towards remedying this defect of the profession, by proposing a model that encompasses a great number of elements found in different literatures of macro and growth. Since the research question he sets up is a quantitative exercise of evaluating which features matter more in the explanation of modern growth acceleration, inevitably he has to face the problem of assigning sensible parameters values to technological, institutional, and preferences parameters. Once such set of parameters are found, he runs the numerous difference equations of the model several times, and uses the statistical properties of the calculated patterns to infer the likely behavior of the economy. If the values of some parameters are drawn from an extensive empirical literature, such as the capital depreciation rate or the wage premium for engineers, others are kept on the side in order to earn degrees of freedom in running the simulations. The list of free parameters include the arrival rate of new goods, the rate of improvement of capital goods, the ratio between supervisors and supervisees, and the wage premia. It also includes preference parameters for basic as opposed to sophisticated consumption goods, and of low-quality as opposed to high-quality goods.

To introduce some discipline into the experiment, Ciarli wisely picks up a lower and a higher bound of the free parameters in light of values estimated in the literature – or in absence of such estimates according to values suggested by the structure of the model itself.

A second discipline device he uses is the fact that the productivity series and output series generated by the model are to be verified against the historical numerical data. Ciarli chooses not to commit to any particular country as far as data are concerned, for, presumably, all developed countries followed at a similar path, at least at low frequency, in the last two thousand years – the length of the experiment.

Ciarli studies the importance of a given parameter, by running simulations under each of the extreme values of the parameters and verifying the extent to which each parameter affects the patterns of

the simulated time series, for all possible combinations of the remaining nine parameters, and for a given set of the fixed parameters. ANOVA techniques are used to assess the statistical significance of each factor.

The main outcome of the analysis is that technological change and the conditions of production are relatively more important than the organization of the labor market in explaining differences in growth rate. Ciarli also found little evidence that the preferences on different types of goods are important for long run growth. Interestingly, the ranking of the factors essential for growth seems to reflect the priority the literature has set into it. Indeed, as I said at the beginning, modern growth theory developed mostly around the right incentives to introduce innovation. What is perhaps not in line with the emphasis given by scholars of growth is the high significance of income distribution. This is a welcome suggestion for current and future research.

I should note, however, that the model does not allow to important forces to play any role. In particular, there is no human capital, no trade, and there are no financial constraints. Furthermore, it is not clear whether the size of the market or of the population could be tested. These elements have been widely cited as a possible source or a barrier to progress. A policy maker would probably like to know at least the importance of education and the role of financial institutions.

I also have a reservation about the amount of thrust we can have on the ranking of the factors essential for progress, even conditional on having some of them excluded. A scholar of the field would be tempted to have a lot of thrust in it, for it echoes the emphasis of the theoretical and empirical literature on the subject. But the dynamics are brought into light only through simulations, depriving the reader of the power of judging the main mechanisms of the model.

As for the simulations themselves, I would have liked to read a more elaborated explanation of why simulating the economy under extreme and unlikely parameters generates good information for producing realistic time series.

Reply to Comments

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First, I would like to thank Maurizio for a very positive and open comment on the paper, which is the outcome of a few years of intermittent collaborative work with a number of friends and colleagues: André Lorentz, currently at the Université de Technologie de Belfort-Montbéliard, Maria Savona, at SPRU, University of Sussex, and Marco Valente, based at the University of L'Aquila. Over the years we have combined our common interest in (long run) economic change as an outcome of technological change, to investigate different dimensions of structural change. We have inclined towards interpreting structural change as an intrinsic aspect of economic evolution and the steady—albeit cyclical—economic growth experienced by many world areas in different epochs. Each of us had a different research background (within the evolutionary/Schumpeterian tradition), covering Keynesian-inspired approaches to growth theory, the sectoral and organisational transformations that lie behind the service industry, consumption behavior, and the structuralist school of economic development. All these ingredients are reflected in various aspects of the modeling strategy in the paper. An additional aim of the paper written for this special issue, as clearly discussed by Maurizio, was identifying which of these approaches to economic thinking points to aspects with the greatest fit to explain long term economic development when we include a number of causes of structural change in the model.

My reading of the comments implies that the paper does not put sufficient stress on some important aspects and motivations of this paper, particularly with reference to the method used and the centrality of (different aspects of) structural change. I briefly comment on those before moving to Maurizio's reservations. On methods, we adopted simulation modeling (essentially agent-based) for two main reasons. The first is related to the complexity of the subject studied. This Special Issue more than adequately shows how much we can learn by constructing macro economic models of agent properties and their interactions. This is particularly true to investigate the changing

structure of these interactions in the economy. Structural change implies that the relations between the agents in an economy vary through time (e.g. due to an increase in income, satiation in consumption, change in preferences, change in the composition of goods or in the working relations). As it is summarised in a quote already used in the paper, "What does it mean for a system to be in equilibrium when its composition keeps changing due to the emergence of qualitatively different entities?" (Saviotti and Gaffard, 2008, p. 116). Simulation modeling (agent-based) allows to model these changes as emerging properties of the model, *i.e.* occurring only under given conditions—that can be endogenous or exogenous, depending on the degree of complexity introduced in the model.

On the second aspect I would like to stress, while the paper assesses a number of classical and evolutionary forces of economic growth and (structural) change highlighted in the literature—as commented on brilliantly by Maurizio—there is more to this paper: which is the interaction between different aspects of structural change. For example, the model combines the relevance of physical capital (and its vintage structure), of technological change in the production of new vintages, of their relation with the labour structure, of how this in turn affects the level and composition of demand, and on the effects of product innovation leading to the emergence of new sectors supplying goods to consumers with different characteristics. In other words, this is not only a comparative dynamics exercise to assess the relative importance of each parameter proxying a factor of growth; it is first of all an analysis of how different aspects of structural change interact with one another.

In this respect I then would like to put more emphasis on the results showing how the effect of single determinants of structural change is significantly modified when other aspects of structural change vary. For instance, it is one thing to say that capital accumulation is relevant, especially when capital brings technological change, but quite another to stress under which conditions capital accumulation is more or less relevant. With respect to the pace of embedded technological change, for example, the model shows that a fast pace has a negative effect on output in the presence of a strongly unequal organisation of labour. This is explained by lower total demand: very large productivity gains reduce the price of goods, but also the number of vacancies. Also, large wage differences concentrate demand in the high income classes with preferences insensitive to prices, not inducing firm selection based on price differences. As I briefly mention in

the paper, firms' heterogeneity and concentration of production—both linked to demand—are fundamental sources of growth in this model.

This brings me to the second reason for our adopting simulation modeling in this long term project: we think that this method allows us to capture the mechanisms behind aggregate behavior. Unfortunately, as rightly noted by Maurizio, for space and time reasons I was unable to include a description of the mechanisms behind each individual result in this paper, something that, as suggested, would have improved the credibility of my results. The paper describes only the main mechanism driving the transition from linear to exponential growth (beginning of section 4). This mechanism turns out to explain many of the results in this paper: given that we run the model for a limited number of periods, the main differences in output level and average growth lie in the timing of take-off. In essence, under most of the thousand combinations of conditions examined in this paper economies reach take-off within the first 2000 periods. However, the sooner an economy makes the transition from linear to exponential growth, the larger are the output levels and average growth rates. To return to the main point of the explanation of mechanisms and economic phenomena, the advantage of simulation modeling is that it allows long study of the reasons behind each result, and of the reaction of agents to changes in other agents and in the system. Clearly, there is the need for another paper or, better, a separate paper devoted to each parameter analysed here.

When building complex models there is always a trade off between maintaining a simple structure leading to intuitive results, and adding more sources known to affect the studied phenomenon. As Maurizio suggests there are many other factors that are known to affect growth, at least in the medium term ?, (e.g. Durlauf *et al.*, 2008). Education and institutions are definitely factors with a strong effect on long run growth, as illustrated by numerous modern theories of economic growth—respectively, e.g., Acemoglu *et al.* (2005), Adam and Dercon (2009), Rodrik (2007) and Galor (2010). But stochastic effects and 'initial' conditions also have an influence (Diamond, 1997). Access to finance and trade technologies have been major structural changes in the organisation of the economy. The latter is the focus in, for example, Hausmann and Hidalgo (2011) and Galor and Mountford (2006). The first of these papers links the diversification of production (and exports) with initial endowment and further development of skills, showing that only high capability goods sustain high income

growth. The second paper assumes that the returns from trade in manufacturing are invested in human and physical capital while returns from agricultural exports are used to sustain population growth. Both provide very useful insights into one possible determinant of long run growth. Compared to our model these models assume a relation observed in the data, and show one mechanism at work. Rarely are more than two mechanisms (trade and skills, or rule of law and investment) considered together and their interaction analysed rather than assumed from the outset. Finally, in our model the size of the market is a crucial determinant of growth (Ciarli *et al.*, 2010).

I agree that it would be extremely interesting to study how introducing access to finance, education, and trade, would change the model results. For those willing to pick up from this project, I would also suggest focussing on the organisation of production, introducing explicit outsourcing and vertical integration. However, as mentioned, there is a trade off between the ability to explain each result and the number of experiments required to analyse all combinations of the parameters. The number of simulations needed to study five aspects of structural change (5 determinants of growth) is already extremely large; adding more factors increases the number of combinations exponentially. But there is one further aspect that is important to note here. All the determinants studied in this paper, and those suggested by Maurizio, are studied as proximate causes of growth—in the sense of Abramovitz (1986). What would be more useful for policy makers would be to know which type of education—with which incentives, disciplines, quality, methods, and so on—which type of finance, and especially which types of institutions—from rules of law to individual beliefs. But these are elements that, for the time being, cannot be modeled as deep sources of growth.

I then come to the final reservation in the discussion, on the use of limit values of the parameters. Choosing a 2^k full factorial design to assess the relative effect of all unknown parameters determining structural change required the selection of two extreme values. The choice of values above or below those observed is due to the choice to consider the whole parameter space. It might be rare for a firm to employ one manager at each tier $n-1$ to supervise three employees working in the tier , or for a firm to invest all of its profits in R&D. But it is not impossible. The idea behind this paper is that one first explores what are the most relevant parameters in looking at the extremes in the distribution, that is, possible although very unlikely,

and then focusses on those most relevant parameters to analyse non-monotonic effects between the two extreme values.

I want to end by commenting on whether this exercise is really useful for policy makers. Qualitatively, I would say, it suggests aspects of societal transformation that are more relevant for explaining long run growth than others. These aspects are probably worth exploring in more detail, moving from what are still proximate causes to the causes underlying the economic mechanisms. Quantitatively, I would not suggest that policy makers should believe in these numbers. What should be of use to policy makers is the availability of more powerful tools and methods to analyse economic change than standard equilibrium models.

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