Residual Whiteness Principle for Automatic Parameter Selection in ℓ2 - ℓ2 Image Super-Resolution Problems

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# STRUCTURAL DYNAMICS AND EVOLUTIONARY CHANGE[1]

## *1. Introductory Remarks*

Evolutionary change and structural dynamics are important strands of current research into the transformation trajectories of economic systems. Two works that had a foundational role for the structural dynamics and the evolutionary dynamics research program respectively appeared almost simultaneously at the beginning of the 1980s: Luigi Pasinetti's *Structural Change and Economic Growth. A Theoretical Essay on the Dynamics of the Wealth of Nations* (Pasinetti, 1981) and Richard Nelson's and Sydney Winter's *An Evolutionary Theory of Economic Change* (Nelson and Winter, 1982).

The evolutionary and structural approaches to economic dynamics respond to the widely felt need of addressing processes of uneven, non-proportional economic dynamics by moving beyond the questions traditionally raised within equilibrium growth modelling. However, they do so in different ways. The evolutionary approaches emphasize the view of the economic system 'as an adaptive, evolving system, subject to probabilities of dynamics and nonlinear phenomena' (Arthur, Landesmann and Scazzieri, 1991, p. 2). In these approaches, 'new structures are considered as being continuously formed in the course of time, and complementarities over time do emerge as a result of historical (or «evolutionary ») linkages between events at different time periods' (Arthur, Landesmann and Scazzieri, *ibidem*). One fundamental implication of this point of view is that the economy is a system of highly interdependent components that tend to respond to their respective motions in a mutually reinforcing way (positive feedback mechanisms). Evolutionary approaches emphasize path dependencies rooted in these complementarities

[1] Comments presented at the 'Understanding Economic change' session of the Conference *Economic Change and Evolution*, Centro Linceo Interdisciplinare «Beniamino Segre», Accademia Nazionale dei Lincei, 10-11 November 2014.

and in boundedly rational (myopic) economic behaviour. Initial triggers of change are critical influences upon the evolutionary path followed by any given economic system in historical time. The structural dynamics approaches, on the other hand, also emphasize the complementarities between different components of any given economic system, but in this case the focus of analysis shifts to either : (i) the asymmetries across response patterns of different components due to a principle of relative structural invariance within a set of sequentially ordered speeds of motion (see Landesmann and Scazzieri, 1990, 1996), or (ii) the paths of structural change to be followed by evolving economic structures when macroeconomic or sectoral conditions for full adjustment have to be met (Pasinetti, 1981, 1993).

Evolutionary and structural analyses entail two different, yet complementary, ways of addressing what John Hicks called 'theory of economic history' (Hicks, 1969). The latter, in Hicks's view, may be described as 'a theoretical inquiry' by which the economist is led 'to classify states of society, economic states of society; we are to look for intelligible reasons for which one such state should give way to another. It will be a sequence not altogether unlike the « Feudalism, Capitalism, Socialism » of Marx, or the stages of economic development of the German Historical School' (Hicks, 1969, p. 6). However, the 'presuppositions' of this type of inquiry should be 'less determinist, less evolutionary than theirs' (Hicks, 1969, *ibidem*). For 'it is only a *normal* development for which we are looking, so it does not have to cover all the facts' (Hicks, 1969, *ibidem*). At the same time, the theory of economic history should 'admit exceptions, which nevertheless we should try to explain' (Hicks, 1969, *ibidem*). Hicks's formulation suggests viewing structural dynamics and evolutionary dynamics as alternative ways of addressing the relationship between normal *development* and *historical development*. Structural dynamics focuses on the structural conditions of economic systems subject to given complementarities and sources of change, and asks which types of structural change the economic system should undertake in order to meet certain systemic or sectoral conditions (such as full

employment or full utilization of productive capacity). In this case, the economic system is not seen as necessarily fulfilling those conditions, indeed it may generally be far from this state. However, identification of the normal structural change path to be followed may be seen as providing a heuristic into the causal mechanisms at work whenever 'exceptions' to that particular type of normal development are to be explained. Evolutionary dynamics follows a different route, for in this case emphasis shifts to historical development, so that complementarities are continuously unfolding over time rather than providing relatively persistent constraints and opportunities over significant periods. This suggests a focus on short-term (myopic) adaptations and 'compulsive' sequences of changes, and leads to causal heuristic centred on the time sequences of dynamic impulses (such as the building up of technological capabilities) and their relative intensities (relative growth rates) across different economic systems. The interaction between growth factors and historical processes is the key element of an explanatory framework focusing on 'connected stages of transformation' that reflect 'initial conditions, local characteristics and particular dynamics' (Scazzieri, 1994, p. 173).

The aim of these comments is to provide a comparative assessment of structural and evolutionary dynamics as alternative approaches to the analysis of economic systems going through processes of quantitative and qualitative transformation over time. Section 2 discusses the different intellectual origins of the two approaches and calls attention to the particular heuristics they provide. Sections 3 and 4 address the extent to which the specific domain of the evolutionary approach may be conducive to application of structural heuristics, and vice versa. Section 3 examines structural heuristics as tools for analyzing sequential processes of change (a characteristic field of investigation of the evolutionary approach). Section 4 focusses on evolutionary heuristic as tool for exploring long-term, irreversible transformations of economic structures (a characteristic field of investigation of the structural dynamics approach). Section 5 discusses ways in which integration of the two approaches may be a conducive to a comprehensive heuristic of historical processes of economic change.

*2. Evolutionary and structural dynamics: intellectual origins and analytical crossovers*

Evolutionary and structural dynamics approaches are characterized by a common origin followed by different research trajectories. The emergence of classical political economy in the eighteenth century provides the historical setting for identifying both commonalities and features of differentiation. A useful conceptual benchmark is Adam Smith's analysis of the 'natural progress of opulence' in Book III of the *Wealth of Nations* (Smith, 1976 [1776]). What is remarkable there is Smith's distinction between (i) the dynamic path that any given economic system *should* follow, for any given configuration of the productive system, under simplifying assumptions such as closed economy and full utilization of productive potential, and (ii) the actual (historical) path that the economy system finds itself following under its characterizing institutional and behavioural conditions. Smith's account provides an important cue into the distinction (and complementarities) between evolutionary and structural dynamics approaches, and it is worthwhile to examine it in full:

> According to the natural course of things […] the greater part of the capital of every growing society is, first, directed to agriculture, afterwards to manufactures, and last of all to foreign commerce. This order of things is so very natural, that in every society that had any territory, it has always, I believe, been in some degree observed. Some of their lands must have been cultivated before any considerable towns could be established, and some sort of coarse industry of the manufacturing kind must have been carried on in those towns, before they could well think of employing themselves in foreign commerce. But though this natural order of things must have taken place in some degree in every such society, it has, in all the modern states of Europe, been in many respects, entirely inverted. The foreign commerce of some of their cities has introduced all their finer manufactures, or such as were fit for distant trade; and manufactures and foreign commerce together, have given birth to the principal improvements of

agriculture. The manners and customs which the nature of their original government introduced, and which remained after that government was greatly altered, necessarily forced them into this unnatural and retrograde order (Smith, 1976 [1776], iii.i.8, p. 380).

Smith's distinction shows the interplay between two different concepts of 'economic structure'. On the one hand, the 'natural progress of opulence' goes back to the idea of economic structure as a set of interdependencies between magnitudes such as sectoral productions, population and technology that *may or may not* be mutually compatible in view of certain systemic requirements, such as the ability of the economic system to reproduce itself from one time period to another (see Baranzini and Scazzieri, 1990a, p.1), as well as to generate 'the greatest level of output for a given injection of capital' (Campbell and Skinner, 1976, p. 32). On the other hand, what we may call the actual progress of opulence goes back to the idea of economic structure as the 'economic fabric' of society. For it is to a mismatch between 'manners and customs' and system of government that Smith ascribes the 'unnatural and retrograde order' followed by the progress of opulence 'in all the modern states of Europe. In this case, attention is focused on social rules and personal or collective beliefs as providing 'the framework for the actions of economic agents ' (Baranzini and Scazzieri, 1990a, p. 1). Institutional lock in comes to the fore as a central explanatory factor for the type of path dependence that Smith considers a characterizing feature of the progress of wealth in modern Europe. Indeed, Smith's view is that the mismatch between institutions (Smith's 'government') and beliefs (Smith's 'manners and customs') is the central explanatory factor accounting for the particular type of path dependence characterizing the progress of wealth in modern Europe. Smith's analysis of institutions and beliefs provides an important instance of the way in which the institutional and cultural fabric of society may trigger evolutionary processes sharply divergent from the 'natural' dynamics that the productive potential of that society would suggest (see also Baranzini and Scazzieri, 1990b, pp. 257-8).

The intellectual origins of the distinction between the evolutionary and structural dynamics approaches go back to the duality expounded by Smith in the passage quoted above. For in the above passage we see both approaches at work, while the same passage suggests that neither approach would be able to provide a sufficient explanation of the actual course taken by the progress of wealth under specific historical conditions. The structural approach starts with identification of a system of interdependencies between different sectors of the economic system. It then makes use of the causal structure embedded in those interdependencies in order to investigate which sequence of structural changes would allow the economic system to make full use of its productive capacities. This approach focuses on what may be called 'the natural order of investment' (Negishi, 1985, p. 30), which specifies 'how the capital accumulation leads to improvement in productivity due to the division of labor', thereby emphasizing that 'investment must start in a most unspecialized, self-sufficing industry and gradually proceed so that industries are more and more subdivided and specialized' (Negishi, 1985, p. 30). The evolutionary approach, as already instanced by Smith, takes a different route. For in this case, the emphasis shifts to starting points (Smith's 'original government'), mismatches between institutions and cultural beliefs, path dependencies that those mismatches may trigger. The outcome is a type of analysis accounting for historical dynamics primarily in terms of 'exceptions' due to the context-dependence of the way in which any system of socio-economic interdependencies must work. Briefly, structural dynamics focuses on the relatively persistent interdependencies characterizing any given system and explores the motion of systems subject to those interdependencies under certain idealized conditions (such as full employment, full utilization of productive capacities, or full investment of available surplus). On the other hand, evolutionary dynamics focuses on the actual working out of interdependencies through the complementarities (bottlenecks and opportunities) that characterize the motion of any given system in specific contexts. Hicks's view of a theory of economic history provides a cue into the relationship between the two approaches (see above). For structural dynamics focuses on a type of 'normal'

development, which allows analysis of interdependencies between component parts of the economic system through ad hoc assumptions bringing the underlying *causal mechanism* into full view (see above). Evolutionary dynamics takes a distinctly different route as it focuses on patterns of 'historical' development triggered by specific impulses under given conditions. This allows the analysis of connected stages of transformation and brings out *causal processes* through which one or more causal mechanisms may work themselves out[2]. Causal processes that may appear to be 'exceptions' from the point of view of the paths of 'normal development' considered in structural dynamics can often be explained in terms of the original conditions and path dependencies highlighted in the evolutionary approach; while the causal processes at work behind evolutionary paths may often be interpreted as resulting from the working out of mechanisms of interdependence that may be best highlighted by examining one or another path of structural dynamics. This argument suggests the existence of important, yet seldom explored connections between the two analytical traditions. The following two sections will examine those connections from the complementary viewpoints of evolutionary and structural dynamics.

## *3. From connected stages of transformation to structural dynamics*

[2] The above distinction between *causal mechanism* and *causal process* goes back to the distinction between the counterfactual interpretation of causation and the concept of 'actual cause'. In this connection, Judea Pearl has argued that 'actual causation requires information beyond that of necessity and sufficiency; the actual process mediating between the cause and the effect must enter into consideration' (Pearl, 2000, p. 309; see also Bianchi, 1984, pp. 23-27, for a discussion of Smith's analysis of the sequential process of adjustments in productive structures triggered by changes in final demand).

As pointed out in many contributions to the 'Understanding Economic Change' session of this Conference, the bridge between economic change at the micro level and economic transformation at the systemic (macro) level is the critical interface at which triggers of change bring about specific patterns of structural dynamics. Richard Nelson's paper drew attention to three interconnected issues at the juncture between micro and macro analysis: (i) the rise and fall of different technologies, firms and industries in a historical evolutionary process; (ii) the actors and processes triggering innovation and structural change in the economic system; (iii) the institutional conditions providing adequate social embedding to innovative actors and processes (Nelson, 2014). According to Nelson, the fitting together of those three features are a yet unsolved puzzle in economic research. In particular, contemporary theory of economic growth has distanced itself from the understanding of historical processes by focusing on long-run trajectories independent of short-run fluctuations of output and employment. On the other hand, addressing short-term problems of under- or over-utilized productive capacity (the cases of economic slack or inflationary pressures respectively) cannot be separated from the Schumpeterian argument connecting the wave-like character of long-term dynamics with the existence of shorter run business cycles. In Nelson's view, however, a unified theory of economic dynamics would probably have little explanatory power since it will have to be too abstract and removed from actual processes.

Giovanni Dosi suggested a way to bridge the divide between the micro-processes shaping technological evolution and the macro-processes characterizing systemic dynamics by combining Keynes's effective demand analysis, Schumpeter's investigation of technology-driven economic growth, and a Minsky-type analysis of credit flows (Dosi, 2014). Building on the view that the direction of technological change is significantly affected by levels of aggregate demand and other socio-economic factors (see also Dosi and Nelson, 2010), Dosi outlines an agent-based model in which the matching or mismatching between innovative exploration of new technologies and the conditions of

effective demand leads to the identification of two distinct dynamic regimes characterized by different short-run fluctuations and unemployment levels. In particular, Dosi argues that economic systems characterized by a more unequal distribution of income are subject to more severe fluctuations of activity levels, higher levels of unemployment, and higher probability of crises with respect to economic systems characterized by a less unequal distribution of income. In policy terms, the model draws attention to the existence of lower and upper thresholds beyond which interest rate tuning has non-detectable or perverse effects. It also highlights the role of fiscal policies in dampening economic fluctuations and improving long-term growth prospects.

The micro-macro interface is also at the centre of Michael Landesmann's contribution. However, Landesmann's investigative strategy is different. For Landesmann avoids introducing a *direct connection* between micro-processes and macroeconomic dynamics, and calls attention to the intermediate levels of aggregation at which many structural change processes take place (Landesmann, 2014a, 2014b; see also Goodwin and Landesmann, 1994, 1996). In particular, Landesmann focuses on three features of macrodynamics that cannot be adequately investigated without structural change analysis: (i) compositional change of macroeconomic aggregates; (ii) structural breaks/shifts in behavioural relationships; (iii) studying processes that overcome relative structural invariances and the associated resistances to change. Landesmann's contribution calls attention to manifold overlaps between structural change analysis and the study of evolutionary processes. The persistent evolution of heterogeneity (for example through technological differentiation) calls attention to the existence of evolutionary features in structural change processes, while the technological interrelatedness opportunities and/or constraints due to (changing) sectoral interdependencies point to the role of structural conditions in determining the shape of Schumpeterian-type dynamics.

The interface between micro-processes and macrodynamics is also central to the contribution by Mario Pianta, who emphasizes the need of integrating the analysis of

structural change with evolutionary perspectives on innovation and growth as a means to bring back in focus the causal mechanism behind economic fluctuations (Pianta, 2014). Pianta draws attention to the fact that fluctuations are a fundamental component of the development process and that they cannot be reduced to the consequences of exogenous shocks. In particular, Pianta argues that virtuous and vicious circles of employment and growth dynamics can be identified if the heterogeneity of production structures, lags, path dependency, simultaneous and recursive links are considered. The complexity of these structural interdependences over the expansion and contraction of activity levels explains the asymmetry of certain causal relationships. For example, the virtuous circle between research and development efforts, innovation and competitiveness seems to hold for Northern European economies only, while the economies of Southern Europe economies have failed to translate innovation efforts into export competitiveness. In Pianta's view, the dynamics of distribution and demand provides the missing micro-macro link by explaining the dissimilar effects of innovation-driven changes in the supply structure in terms of differences in overall macrodynamics between the two country groups.

The principal lesson from this session has been recognition of the central importance of the causal mechanism linking micro dynamics with macroeconomic evolution. At the same time, contributions have acknowledged that this is a relatively unexplored and undertheorized field in current research. This situation is somehow paradoxical seeing that it is precisely this causal mechanism that attracted most interest in the economic studies spanning from classical political economy up to the Keynesian Revolution. In fact, this stage in the evolution of economic analysis provides conceptual tools that may be important building blocks in the construction of a theory highlighting both the 'bottom-up' linkage from microevolutions to systemic changes and the 'top-down' linkage from systemic changes to transformations in the microeconomic behaviour of firms and consumers. As Michael Landesmann pointed out in his contribution, the 'lessons of structural change' are manifold and require the development of task-specific

tools that cannot be provided by only focusing on the micro or on the systemic levels of aggregation (Landesmann, 2014a). Indeed, the exploration of structural economic dynamics may take advantage of analytical tools focusing on a *variety* of units of investigation (such as commodity-specific industrial sectors, vertically integrated sectors, etc.), on their interdependence, and on the ways in which different patterns of interdependence may arise depending on the units of investigation being considered (see Landesmann and Scazzieri, 1996; Andreoni, 2014; Andreoni and Scazzieri, 2014). This point of view has noteworthy implications for what concerns the role of institutions and policymaking. For it calls attention to the need of opening the black box of policy making by addressing the variety of interests compatible with certain structural change trajectories but not with others. This brings to the fore the structural political economy of economic change (Cardinale, 2015, 2016; Cardinale and Landesmann, 2016) and makes policy making to be at least partially endogenous to the structural opportunities that existing complementarities bring about.

Evolutionary processes are structural change processes, but they are not always recognized as such (see also Arena and Porta, 2012). However, increasing recognition that economic evolution can be meaningfully addressed on condition of considering connected stages of transformation characterized by features of sequential causality has brought to the fore the *asymmetries* of transformation paths between different components of any given economic system, and has highlighted that complementarities between those components may be consistent with *increasing differentiation* in levels of development, speeds of adjustment, and so forth. The evolutionary approach to economic dynamics emphasizes the connectedness of stages of transformation affecting relatively persistent conditions of the economic environment, such as technology and institutions. In either case, connectedness is associated with the fact that 'extraneous features of the initial conditions, the historical context in which [technology], institutions or organizations are formed, can become enduring constraints. They can result in the

selection of a particular solution for what is then perceived at the time to be the crucial generic function […] In this way the organizational structure can become "locked in" to a comparatively narrow subset of routines, goals and future growth trajectories' (David, 1994, p. 214). An important feature of this type of sequential connectedness is that '[h]istorical precedent […] can become important in the shaping of the whole institutional [or technological] cluster, simply because each new component that I added must be adapted to interlock with elements of the pre-existing structure –unless the whole is to be abandoned and replaced in its entirety' (David, 1994, p. 215). More recently, David has called attention to the relationship between the process of innovation diffusion and productivity growth arguing that the consideration of innovation as a trigger of technological change should not lead to a 'neglect of attention to the role of conditions affecting access to knowledge of innovations and their actual introduction into use' (David, 2015, p. 38). In particular, David emphasizes cases in which structural changes induced by the diffusion process make 'the new technological system to become attractive to an increasing proportion of a heterogeneous population of rational and already informed economic agents' (David, 2015, p. 50).

The emphasis on 'humanly devised constraints that shape human interaction' (North, 1990, p. 3) is a distinguishing feature of the evolutionary approach to economic change, and it partly explains the evolutionary interest in the evolution of technology and organizations (see also North, 2005). In particular, important features of economic change as visualized in this approach have to do with the fact that both production techniques and organizations 'can be conceptualized as role structures that render the interactions of their constituent elements functional' (David, 1994, p. 218). What the evolutionary approach does not explicitly theorize is that a system of interdependent components subject to *distinct* sources of path dependence (different from one component to another) is likely to develop a systemic path dependence showing significant features of structural change (see, for example, Mauro Baranzini's analysis of the endogenous formation of socio-economic classes in Baranzini, 1991). This means that, once path dependence is visualized

by moving beyond the microeconomic or industry perspective, the overall economic system appears to follow a dynamic path in which both path dependence and structural change are present (see, in this connection, Scazzieri, 2014a for a structural analysis of increasing returns trajectories). In short, the resilience of 'humanly devised constraints' is conducive to structural dynamics once the economic system is visualized as a system of distinct but interdependent components. The principle of *relative structural invariance* is key to the complementarity of path dependence and structural change. According to this principle, 'any given economic system subject to an impulse or force is allowed to change its original state by following an adjustment path that belongs to a limited set of feasible transformations. In fact, the set of feasible transformations is the consequence of both the characteristics of certain elements of an economic system that are taken as constant and certain patterns of interrelationships among the different components that are assumed as invariant in the structural specification of the system' (Landesmann and Scazzieri, 1990, p. 96). A noteworthy consequence of this boundedness of the set of feasible transformations is that 'the impulse from which the original state of the economy is modified may be purely exogenous but the actual process of transformation can explained in terms of the "dynamic" characteristics of the existing structure (that is in terms of the specific paths of feasible transformations that are compatible with its description)' (Landesmann and Scazzieri, 1990, p. 96). Path dependency, which is at the root of evolutionary dynamics, lends itself to the consideration of structural dynamics once the economic system is represented as a collection of subsystems subject to different dynamic impulses. For different subsystems are likely to be associated with different path dependencies, and changes of proportions between subsystems are likely to follow,

## *4. From structural dynamics to sequential processes of change*

The economics of structural change sets itself the task of investigating changes in the relative proportions between the component parts of any given economic system, as well as changes in the relative weight of different sources of motion for the economic system under consideration[3]. Its analytical core has its roots in the theory of a multisectoral economic system in which intersectoral relationships provide proportionality conditions that have to be satisfied by the economic system if the latter is to be 'viable' (self-replacing) and /or such as to achieve full employment and full capacity utilization. This analytical core has led to a variety of theoretical formulations depending on the way these formulations represent economic sectors and their interdependence (Scazzieri, 2011, 2012). On the one hand, emphasis on the circular features of interdependence has led to theories focusing on the conditions for economic systems to be in a self-replacing state (von Neumann, 1937; Sraffa, 1960; Pasinetti, 1975; Quadrio Curzio, 1967). On the other hand, emphasis on the vertical features of interdependence has led to theories focusing on the conditions for economic systems to achieve full employment and full utilization of existing capacity (Pasinetti, 1965, 1981, 1993) or on the conditions for economic systems to achieve maximum accumulation of net outputs (Quadrio Curzio, 1975; 1986; Quadrio Curzio and Pellizzari, 1999). Finally, the interplay of horizontal and vertical constraints and opportunities is central in Adolph Lowe's analysis of the classical theory of economic growth (Lowe, 1987 [1954]), and in his analysis of structural change trajectories triggered by changes in labour supply, natural resources supply, and technical progress (Lowe, 1976; Nell, 1976; Scazzieri, 1998).

The treatment of structural dynamics has been distinctly different depending on whether the circular or vertical representation of sectoral interdependence is privileged.

[3] An early criticism of the relevance of aggregate analysis in the investigation of economic dynamics is in the classic paper by Luigi Pasinetti and Luigi Spaventa 'Verso il superamento della modellistic aggregate nella teoria dello sviluppo economico' (Pasinetti and Spaventa, 1960). In that contribution, Pasinetti and Spaventa argue out that '[i]t is necessary to acknowledge the continuous mutability of reality, and thus to give up any attempt to explain that reality as if it were a process taking place under conditions of continuous equibrium between aggregate variables of uncertain meaning […] [I]t is clear […] that in order to analyze the behaviour, not necessarily an equilibrium behavior, of individual vaiables and parameters, aggregate analysis is entirely insufficient *as it would by its nature conceal the object itself under scrutiny*' (Pasinetti and Spaventa, 1960, p. 1766, added emphasis; see also Baumol, 2012 for a recent reappraisal of this view).

In the circular approach, such as the one followed by Quadrio Curzio, the analytical attention focuses on conditions for the accumulation of the net products in a system of interdependent production activities. In this case, interdependence is the source of bottlenecks and/or production opportunities that may in turn generate structural changes (such as changes in the proportions between production sectors) once a 'law of motion' for the economic system is selected (such as the requirement that the system should grow at the maximum growth rate allowed by the existing technology (that is, by the existing set of sectoral interdependencies). In the vertical approach, such as the one followed by Luigi Pasinetti, the analytical attention is focused on conditions for the full employment of labour and the full utilization of productive capacity given the evolution of technology (producers' learning) and the evolution of consumers' preferences (consumers' learning). In this case, the co-evolution of producers and consumers' learning is the source of proportionality constraints, in the sense that the economic system should follow a given trajectory of structural dynamics (a given trajectory of changes in proportions among productive sectors) as a condition for full employment and full capacity utilization. In both the circular and the vertical cases the theories of structural dynamics have called attention to features of sequential causality, and thus to evolutionary processes that may be associated with structural constraints and opportunities.

Circular theories of structural dynamics derive the analysis of connected stages of transformation from the interdependence of production processes and the associated conditions for the sustainability ('viability') of a dynamic path subject to given assumptions on the 'law of motion' of the economic system (such as the assumption of maximum capital accumulation under evolving resource bottlenecks and technological opportunities). Quadrio Curzio's investigation of a structural dynamics path is a case in point. Here, a growing economic system is faced with a sequence of resource bottlenecks that may lead the system to follow a decreasing returns or an increasing returns trajectory depending on the type of residuals (unutilized intermediate commodities) that the

economic system may generate as it moves from one technological structure to another (Quadrio Curzio, 1975, 1986, 1990, 2011; see also Scazzieri, Baranzini, Rotondi, 2015). More generally, the circular approach emphasizes technological interdependence may be at the root of 'compulsive sequences' of transformation generated by triggers of change working themselves out within a system of production processes that supply each other's means of production. The vertical theories of structural dynamics follow a different route. In that case, connected stages of transformation may arise from the need to avoid mismatches between different triggers of change, such as producers' and consumers' learning (Pasinetti, 1981, 1993, 2007; Leon, 1967; Cozzi, 1969) or from the need to respond to the temporal asymmetries between 'short' and 'long' processes of production (Hayek, 1941; Hicks, 1970, 1973; Amendola and Gaffard, 1988, 1998, 2012). In either case, external impulses drive sequential processes of change. These impulses generate asymmetries, but well-defined and connected stages of transformation may compensate these asymmetries by taking advantage of the hierarchy of motions embedded in any existing economic structure (Landesmann and Scazzieri, 1990; Scazzieri, 1998; Hagemann and Scazzieri, 2009; Scazzieri, 2014b, 2014c, 2015), and sometimes also taking advantage of the opportunities for technological and organizational innovation that those asymmetries and bottlenecks may disclose (Rosenberg, 1968; Andreoni, 2014, 2015). We can see this approach at work both in Pasinetti's sequential dynamics of structural changes in an economic system subject to technical change and changes in consumers' preferences under full employment/full capacity utilization conditions (Pasinetti, 1981, 1993, 2007) as well as in Hicks's structural dynamics paths along traverses defined by full employment or fixwage conditions (Hicks, 1970, 1973).

## *5. Conclusion*

To sum up, both the circular and the vertical theories of structural economic dynamics allow for connected stages of transformation (evolutionary paths) driven by triggers such as population growth, technical progress, or maximum capital accumulation. Dynamic triggers acting on specific complementarities and hierarchies of motions generate those sequential processes of change. It is worth noting that here we are dealing with a causal mechanism that may generate sequences of connected stages of transformation but *not* with actual (historical) paths of structural change. However, the identification of trajectories of this type may be necessary to explain historical trajectories of structural change. As we have seen when examining Smith's comparison between the natural and the actual 'progress of opulence' (see section 2), knowledge of natural dynamics may be essential in order to disentangle the indirect ways by which an economic system may be able to grow even when the conditions for it to follow the 'natural course of things' (Smith, 1976 [1776], iii.i.8) are not satisfied. In short, the configuration of a causal mechanism should not be confused with its mode of operation under specific conditions. The evolutionary approach takes a different stance as far as it emphasizes unfolding processes of causation rather than the set of structural constraints making certain dynamic paths feasible and others unfeasible. In spite of these important differences, the structural and the evolutionary approaches share an interest in the historical dynamics of economic systems. In a sense, they both suggest a theory of economic history, while adopting different routes in its formulation. The evolutionary literature takes history at its face value and derives a theory of economic history from detection of commonalities and differences across observed dynamic paths (see section 3). The structural literature outlines the 'normal' dynamic path the economic system should follow under given structural and behavioural conditions, and focuses on comparison between this virtual path and actual historical dynamics. A theory addressing the actual dynamics of economic systems cannot explain the specific features of those dynamics without referring to a hierarchy of relative motions between the different components of the given system. On the other hand, any such hierarchy

of motions would generally lead to different historical trajectories depending on initial conditions and context-specific triggers of change along any such trajectory. Both evolutionary and structural dynamics point to the need of a comprehensive analytical framework for the investigation of economic dynamics. However, identification and comparison of their distinct intellectual origins and analytical strategies are important prerequisites for their complementarities to become fully visible. This is an important avenue of future research.

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## ABSTRACT

BOTH THE STRUCTURAL AND EVOLUTIONARY APPROACHES TO ECONOMIC CHANGE RESPOND TO THE NEED OF MOVING BEYOND THE QUESTIONS TRADITIONALLY ADDRESSED IN EQUILIBRIUM GROWTH MODELLING. THE EVOLUTIONARY APPROACHES HIGHLIGHT THAT INTERDEPENDENT COMPONENTS OF THE ECONOMIC SYSTEM TEND TO RESPOND TO THEIR RESPECTIVE MOTIONS IN A MUTUALLY REINFORCING WAY (POSITIVE FEEDBACK MECHANISMS) THEREBY LEADING TO THE CONTINUOUS FORMATION OF NEW STRUCTURES. THE STRUCTURAL APPROACHES HIGHLIGHT THE ASYMMETRIES BETWEEN RESPONSE PATTERNS OF DIFFERENT SYSTEM COMPONENTS (RELATIVE STRUCTURAL INVARIANCE) AND ADDRESS THE ECONOMIC CRISES ARISING FROM THE MISMATCH OF DIFFERENT TYPES OF MOTION OR THE COMPENSATORY POLICIES NEEDED TO ALLOW FULL EMPLOYMENT UNDER CONDITIONS OF STRUCTURAL CHANGE. THE TWO APPROACHES STEM FROM DIFFERENT INTELLECTUAL TRADITIONS BUT MAY COMPLEMENT EACH OTHER. THE STRUCTURAL

APPROACH PROVIDES TOOLS TO THE INVESTIGATION OF EVOLUTIONARY PROCESSES IN WHICH THE FORMATION OF NEW STRUCTURES IS AFFECTED BY BOTTLENECKS AND ASYMMETRIES, WHILE THE EVOLUTIONARY APPROACH PROVIDES TOOLS TO THE ANALYSIS OF CHANGES LEADING TO THE IRREVERSIBLE TRANSFORMATION OF ECONOMIC STRUCTURES.