The Knowledge Plexus

A systemic view on the economic geography of technological knowledge

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Chapter 2

The emergence of technological knowledge in the mesoeconomic plexus

Introduction

This chapter brings together the previously identified elements of the 'systemic paradigm' in the context of economic geography by connecting the theoretical premises with economic phenomena circumscribed in an *extended geographical space*, i.e. a geographical space with a *relational* dimension. Geographical space had hitherto been purged from mainstream economic theory, and even when it was re-introduced in certain 'peripheral' subfields of the discipline (e.g. urban, regional and geographical economics), it was in the form of an abstract, immaterial, Euclidean space – a space which was more geometrical than geographical. Moreover, economic geography (with few exceptions reviewed here) has traditionally limited itself in the study of socio-economic phenomena related to the physical dimension of space, leaving outside its scope the most rich in economic intuition aspect of space, the relational aspect. The proposed systemic paradigm is intended to reinstate not only the geographical space in economic theory but also the relational dimension of the geographical space in economic geography. By this approach the 'extended' space mediates the interactions of economic agents, and by extension, the formation of economic relationships and of the division of labour.

This chapter also synthesises in the above context a theory of techo-economic cognition aiming to explain how technological knowledge comes about in relational space. The neoclassical paradigm is inherently ill-equipped when it comes to explaining and modelling processes like technological knowledge creation, which is governed by out-of-equilibrium complex dynamics characterised by novelty and structural change. As a result, technological knowledge remains a black box for mainstream economic theory. Neoclassical growth models, for instance, treat technological change as exogenous: In the neoclassical Solow-Swan model, technological progress is the only determinant of the long-run (steady-state) growth rate, but the rate of technological progress itself is exogenously determined, and therefore out of the scope of the model.[1]

More recently, endogenous growth models 'endogenise' technological change by incorporating in the production function important determinants of economic growth relevant to knowledge creation and diffusion, such as human capital and R&D investment, thus allowing for increasing returns and technological knowledge spillovers.[2] Despite the rhetoric about that being the third wave of an 'increasing returns/ imperfect competition revolution' [KRUGMAN, 1998], endogenous growth models are improved extensions of the neoclassical growth model, and still fail to explain why and how economic cognition and technological knowledge emerge in economic systems – these are just taken as given. The 'endogenisation' therefore of technological change in these models is only stylised, not substantial. This limitation results from the fact that they are founded on the same reductionist and equilibrium-centred epistemology as the neoclassical model.

In this chapter it is argued that the emergence of technological knowledge can only be explained when examined at the *meso domain* of the economy – the locus of interactions of economic agents and of articulation of economic relationships. This chapter introduces the concept of *mesoeconomic plexus* as the fundamental ontology of this domain, whose instantiations behave as complex adaptive systems and exhibit a network-like, nontrivial topology. Individual techno-economic cognition is seen in this context as the outcome of a co-adaptation process which takes place inside the mesoeconomic plexus, while collective knowledge creation is treated as a systemic phenomenon of a particular type of mesoeconomic plexus, the *knowledge plexus*. This emergent phenomenon is characterised by co-evolutionary dynamics and *economies of complexity* rather than by traditional economies of scale.

The rest of this chapter is organised as follows: The second section reviews the conceptions of space in different strands of economic geography from traditional location theories and the neoclassical legacy of Isard's 'regional science', through the 'New Economic Geography', to heterodox approaches, including the neo-Schumpeterian evolutionary approach, and the relational approach which lays emphasis on the relational space. The third section re-defines the relational space as the generative structure where the interactions of economic agents take place and proposes the enhancement of the scope of economic geography with its inclusion in the picture. This section then presents the relational space as a nexus of interdependencies where not only production externalities but, most importantly, an *external division of labour* is realised. It then presents the meso domain of the economy as the par excellence relational space, whose fundamental ontological category is the *mesoeconomic plexus*. The rest of the section develops the notion of mesoeconomic plexus, the hypothesis that it behaves as a complex adaptive system, and the premise of *economies of complexity* as a distinct form of increasing returns in certain types of

organisational structures from that of increasing returns to scale. The last section of this chapter begins by presenting a typology of economically relevant knowledge. It then examines the relationship between knowledge management and the organisation of production starting from the 'objectivist' knowledge-based theory of the firm and continuing with the modes of industrial organisation. The chapter concludes by sketching a systemic theory of synergetic, *distributed* knowledge production in economic systems, starting from a 'constructivist' theory of individual cognition by economic agents on the basis of co-adaptation. Here distributed technological knowledge is presented as an emergent phenomenon of the knowledge plexus.

Economic geographies and the conception of space

Mainstream economics has always neglected space. KRUGMAN, 1998, attributes this neglect to the lack, up until the 1990s, of an analytical apparatus for modelling economies of scale, which he identifies as the fundamental mechanism behind the geographic concentration of economic activity. He also claims that all past theories of location entailed implicitly or explicitly the existence of economies of scale, which inevitably undermine perfect competition. In the 1950s and 60s, when location theory was becoming popular in US academia mainly through the work of Isard – the argument goes – no workable model of imperfect competition was known to the economists and, as a result, they simply chose to ignore space, increasing returns and agglomeration economies altogether.

Krugman's justification is rather lame. The real reasons for the a-spatiality of mainstream economic theory are not conjunctural and practical, or even methodological, but substantial and epistemological: In the neoclassical world there is no need for space, since there is no real interpersonal interaction between economic agents; moreover, the economic subject is not an entity bound by physical laws, but rather by the behavioural determinism ensuing from the axioms of the theory. The problem of space in that world enters only tangentially through the issue of land, as a factor of production, and land use, and for this reason spatial economics remains a peripheral sub-discipline of 'orthodox' economic science.

The a-spatiality of neoclassical economics is one more on the long list of its epistemological reductionisms, which ensue from its axioms. This is a substantial reason for a permanent divorce with economic geography, whose subject-matter is precisely the spatiality of economic phenomena and agents.

But the question which naturally emerges is, what type of spatiality? HARVEY, 1973; 2006, distinguishes three construals of space, the *absolute*, the *relative* and the *relational*, which he connects to Descartes, Einstein and Leibniz respectively. This classification is not, however, completely unproblematic: To start with, the concept of 'relative space' lacks theoretical clarity, and is difficult to justify as a distinct category from that of 'relational space', especially in the context of economic geography, as their perceived attributes are almost identical. Moreover, the association of the former with the relativistic space-time is rather crude and seems to have been inspired by popular science.[3] As a result, the distinction between relative and relational, but also between absolute and relative spaces is blurred. I propose a different categorisation of the conceptions of space relevant to economic geography, which distinguishes between the *geometrical* space, i.e. a space conceived as an immaterial, abstract mathematical entity (which can be Euclidean, Minkowskian, Riemannian, etc.); the *physical* or 'cartographical' space, i.e. the reified, material space conceived as a thing-in-itself, and whose properties emanate from physical laws; and the *relational* space – a space shaped by socio-economic relationships, with properties emanating from them.

As we see in the following paragraph, the neoclassical space, whenever it emerges in theory, is predominantly a geometrical space. Physical space is traditionally the subject-matter of physical geography, but very often it is treated as pertaining to the disciplinary domain of economic geography as well. This constitutes what I call a 'physicalist' fallacy – the misconception of economic-geographical space as an ontological category in itself with a priori properties beyond those conferred to it by socio-economic relationships. The approach of this book is that the space of economic geography should be construed as a *relational space*, which may or may not overlap with physical space, depending on the extent to which the generative relationships of the former are conditioned by physical proximity.

The neoclassical space

Regional science and location theories

Isard's 'Location and Space-Economy' is widely acknowledged as the point of departure for a new field in economics known as 'regional science' [ISARD, 1956]. This book aspires to lay the foundations of a general theory for the location of economic activity incorporating the Walrasian general equilibrium and the Ricardian international trade theories; it is therefore vehemently neoclassical. The strand of theory Isard introduced in Anglosaxon academia, as a matter of fact, follows the long tradition of the continental (predominantly German)

'Raumwirtschaft' School of spatial economic theory established more than a century earlier by von Thünen and his successors, Launhardt, A. Weber, Christaller and Lösch. The central problem of this earlier tradition is almost exclusively the optimal location problem vis-à-vis transport costs, mainly for agriculture and industry. All treatments of the location problem in this tradition are predominantly of a mathematical, specifically geometrical, nature. In the still largely agricultural state of Mecklenburg of the early 19th century, VON THÜNEN, 1826, is principally concerned with the optimal use of agricultural land, assuming profit-maximising behaviour of rationally optimising farmers, and a unipolar and totally isotropic in geomorphological terms space resembling an abstract Euclidean space, within an 'isolated state', i.e. a state completely cut-off from external influences. As a result of the farmers' optimising behaviour and the diminishing with distance 'locational rent' of the land, this unipolar space will be organised in concentric rings surrounding a perfectly centrally located city-market, with different land uses determined by the opportunity cost of the corresponding agricultural activities and types of crop.

Later theorists from the same School of thought, having experienced the rapid industrialisation of the Prussian and other German states' economies in the late 19th century, are concerned almost exclusively with the optimal location of industry. WEBER, 1909, drawing considerably on previous work by LAUNHARDT, 1872; 1885,[4] develops a theory of industrial location on the basis of cost minimisation, determined by the material index of the product and the related transport costs,[5] labour costs, and agglomeration economies. He is one of the first to explicitly recognise that "an agglomerative factor […] is an advantage or a cheapening of production or marketing which results from the fact that production is carried on to some considerable extent at one place, while a deglomerative factor is a cheapening of production which results from the decentralisation of production" [WEBER, 1909 (1929: 126, English translation)]. In addition to that, he distinguishes between two types of scale economies, those accruing from the simple enlargement of a productive unit, i.e. a plant, and those from the "close local association of several plants". Weber's space is almost identical to that of von Thünen's, namely isolated and isotropic, the only difference being that the model does not explicitly assume a unipolar configuration, but allows a limitedly polycentric spatial structure in which, however, the location of production factors remains fixed. He additionally assumes explicitly a perfectly competitive market, ubiquity of and unrestricted access to certain natural resources, and the local specificity of labour and other production inputs.

Later in the century CHRISTALLER, 1933, lays the foundations of modern regional planning with his influential 'central place theory',[6] which conceives the spatial configuration of (urban) settlements in a region as a hierarchically nested

system of interconnected entities dominated by a few 'central places', i.e. cities whose centrality is determined by their unique ability to supply goods and services not available in their surrounding settlements. Lösch, who is considered, jointly with Isard, as the founder of 'Regional Science', extends in a formal and mathematically rigorous manner Christaller's ideas of central places, albeit from a totally different perspective: his magnum opus develops a spatially distributed general equilibrium model which assumes the existence of self-sufficient farms located on a spatial lattice, and proves that the optimal configuration of this lattice would be hexagonal [LÖSCH, 1940]. In line with the aforementioned spatial theorists, both Christaller's and Lösch's models assume (the former implicitly and the latter explicitly) a competitive market, distance-dependent exchange and transaction costs, and an abstract and isotropic, despite its polycentricity, geometrical space. As KRUGMAN, 1998, remarks, both models imply the existence of agglomeration economies but, given the lack of analytical tools for economies of scale, "both seem to be describing planning solutions rather than market outcomes".

The New Economic Geography

In more recent times, a response to the absence of space from mainstream economic theory has taken the form of a 'geographical turn' in economics [MARTIN, 1999], most prominently expressed in Krugman's 'New Economic Geography' (henceforth NEG). The subject matter of the NEG is the concentration of economic activity in geographical space, notably the phenomenon of agglomeration, at various spatial scales ranging from that of city neighbourhoods to that of city formation per se, and from that where industrial districts emerge to that where interregional disparities and the core-periphery dual structure of the global economy are generated [FUJITA & KRUGMAN, 2004]. In accordance with Marshall's *Principles of Economics* [MARSHALL, 1920], KRUGMAN, 1992, identifies labour market pooling, the supply of specialised intermediate goods and services, and technological spillovers as the main forces driving the process of agglomeration.

KRUGMAN, 1998, sees the reinstatement of space in economic theory which led to the emergence of the NEG in the 1990s as the fourth wave of the 'increasing returns/ imperfect competition revolution', following the modelling of imperfect competition by the 'New Industrial Organisation', the modelling of international trade in the presence of increasing returns by the 'New Trade Theory', and the introduction of increasing returns in models of macroeconomic growth by the 'New Growth Theory' (i.e. endogenous growth theory). Krugman defines the NEG as "[a] genre: a style of economic analysis which tries to explain the spatial structure of the economy using certain technical tricks to produce models in

which there are increasing returns and markets are characterised by imperfect competition" [Ibid.: 164].

Despite the claims for breaking away from economic orthodoxy, the NEG is still based on an extended neoclassical paradigm, similarly to all other 'waves' of the alleged revolution. All models of NEG, for instance, presented in one of its bibles, FUJITA *et al.*, 1999, are equilibrium-based,[7] and despite being macro-models, they implicitly share the neoclassical commitment to instrumental rationality and methodological individualism, as Krugman himself makes clear elsewhere [KRUGMAN, 1993].[8] As suggested in the previous chapter, increasing returns are not in principle inconsistent with the neoclassical paradigm but only with the specific model of competitive equilibrium, which however is not an indispensable feature of neoclassicism.[9] On the other hand, all three essential underpinnings of the neoclassical paradigm (individualistic-instrumental rationality, ex ante equilibration and reductionist aggregation) are reproduced explicitly in the general theory of location and implicitly in the NEG. The perception of space in the NEG is not very new either: Although this space is not the Euclidean isotropic continuum of regional science, but indeed a space with a variable topology largely shaped by agglomeration effects, it is still a predominantly abstract geometrical space with an a priori physical dimension.

Space in heterodox economic geographies

Despite its affinity to economic theory, economic geography retains a certain degree of autonomy vis-à-vis mainstream economics stemming from its eclecticism and cross-disciplinarity. This epistemological autonomy allows the discipline to be more open to paradigmatic change. Indeed, since the turn of the century a totally new genre of economic geography is emerging, which makes the NEG look like the last pièce-de-résistance of the neoclassical paradigm in economic geography.

Institutionalism and regulationism in economic geography

'Old' and 'new' institutionalism

In economics and political economy a sharp distinction should be drawn between two homonymous but diverging varieties of institutionalism: On the one hand the 'old' School founded on the works of Veblen, Commons, and Mitchell, is the precursor to contemporary institutional political economy and evolutionary institutional economics. This wide and heterogeneous strand includes economists (some of whom are also characterised as 'post-Keynesians') as diverse as Galbraith, Minsky, Myrdal, and more recently Hodgson, and Ha-Joon Chang. The 'old' institutionalist school of thought following the Veblenian

tradition rejects the neoclassical paradigm, acknowledges the inherent instability of the financial markets and of capitalism [MINSKY, 1986], the influence of asymmetric corporate power in society and polity [VEBLEN, 1904; GALBRAITH, 1967], the disposition of socio-economic dynamics to generate uneven development through circular cumulative causation [MYRDAL, 1957], the bounded rationality of economic agents and their inclination to satisficing rather than optimising behaviour [SIMON, 1956], the fact that human choice is mostly based on norms and habits and adaptive learning rather than (global) rationality [HODGSON, 1998].

On the other hand the School of 'New Institutional Economics' embraces the neoclassical paradigm and extends it in the direction of the theory of the firm [COASE, 1937], the allocation of property rights in the face of externalities [COASE, 1960], transaction costs [CHEUNG, 1969; WILLIAMSON, 1979], the impact of institutions and institutional change on growth [NORTH, 1987; 1990], but also bounded rationality and asymmetric information, rent-seeking and public choice [KRUEGER, 1974; TULLOCK *et al.*, 2002], public goods and collective action [OLSON, 1965].

These two strands of institutionalism are fundamentally different: A central premise of 'old' institutionalism, in sharp contrast to neoclassicism, is the inseparability of the economy from the socio-political context in which it is embedded; as a result of this approach, even prices are treated as social conventions formed by institutions [HODGSON, 1998]. As HODGSON, 1998, notes, institutions provide the cognitive framework for interpreting sensory data and routines for transforming information into useful knowledge, while they ensure the stability of socioeconomic systems by constraining the diverse actions of many agents.

The 'old' School's preferred approach to economic phenomena is the historical and case-specific analysis as opposed to the reductionist, deductivist and formalist methodology of neoclassical economics. In sharp contrast to these, neo-institutionalism embraces methodological individualism and aims to explain the emergence of institutions on the basis of individualistic rational choice. As HODGSON, 1998, observes, this approach moves from an initial putative institution-free 'state of nature' in which individual preferences are considered as immutable towards the construction of institutions; institutions, therefore, result from the interactions of individuals, and the individual precedes society.

Institutional economic geography

MARTIN, 2008, identifies the 'institutional turn' in economic geography, i.e. the recognition of the importance of social institutions in conditioning and shaping economic activity in geographical space, as one of its major new directions

following its revival in the last decade. Undoubtedly, the institutional turn in economic geography is not unrelated to the institutional turn in economic theory, which predated the former by almost a century. It can be argued, however, that institutions, both formal and informal, command a central position in mainstream economic geography unlike mainstream economics, and in that sense no separate institutional strand can be clearly identified in economic geography. Besides, identifying a clear-cut epistemological and methodological corpus of 'institutionalism' is difficult even within the discipline of economics, with the exception of the neo-institutional economic theory. In economic geography this task becomes even more complicated by the eclecticism of the discipline.

BOSCHMA & FRENKEN, 2006, consider that a common methodological trait of institutional economic geography is the rejection of formal modelling and econometrics, and the adoption of an inductive approach focusing on the local specificities of 'real places', and particularly on "place-specific institutions at different spatial scales". They observe that an institutional analysis aims at understanding how place-specific institutions determine local economic development starting from the differences between localities. MARTIN, 2008, considers that an institutionalist approach to economic geography would attempt to illuminate the question of how and to what extent institutional structures mediate and shape the process of geographically uneven capitalist economic development. He also associates the institutional turn in economic geography with the widespread adoption by economic geographers of regulationism, which, however, from a strict taxonomical perspective is a separate strand of theory.

Regulationism and 'flexible specialisation'

The 'Régulation' School of political economy is a variant of neo-Marxist structuralism, which has proven to be particularly influential among economic geographers.[10] Regulation theory aims to analyse the long-term, historically specific, dynamic regularities in the reproduction of the capitalist system, which is at least temporarily stabilised and made possible by its regulatory institutional framework, despite the inherent instability of its accumulation process, and its structural contradictions and natural proneness to crisis. Concepts commonly used by regulationists include the 'industrial (or techno-managerial) paradigm', the 'accumulation regime', and the 'mode of regulation'. As JESSOP, 2001, clarifies, an industrial paradigm is "a model governing the technical and social division of labour", and it is primarily a microeconomic concept. An accumulation regime is the long-term pattern of production and consumption, and it is primarily a macroeconomic concept. A mode of regulation is "an emergent ensemble of norms, institutions, organisational forms, social networks, and patterns of conduct that can stabilise an accumulation regime", and it is primarily a

mesoeconomic concept, which however has extra-economic dimensions. It comprises the 'wage relation'; the enterprise form; the nature of money; the state; and international regimes, namely "the trade, investment, monetary settlements, and political arrangements that link national economies, nation states, and the world system". The combination of the other three elements in a way that secures "the conditions for a long wave of capitalist expansion" is the model of development.

The influence of regulationism on economic geography has mainly come through the literature on the Marshallian industrial districts supposedly found in 'Third Italy', a collection of Italian regions in the North-Northeast of Italy (e.g. Emilia-Romagna, Tuscany, Veneto), which, unlike the under-industrialised and largely agrarian South and the highly industrialised North (e.g. Lombardy, Piedmont, Liguria) supposedly dominated by Fordist large-scale mass production industrial conglomerates, exhibit a particular production structure characterised by economies of scope, which originate from a spatially embedded and locally specific division of labour. This structure is dominated by innovative SMEs with a specialised and skilled labour force. This idealised mode of industrial organisation is supposed to embody the post-Fordist 'flexible specialisation' techno-managerial paradigm. The theory, initially developed by a group of Italian social scientists and economists in the late seventies [BAGNASCO, 1977; BECATTINI, 1987], became very popular among economic geographers in the Anglosaxon academia mainly through the work of PIORE & SABEL, 1984. Since then the literature on industrial districts has undergone an explosive proliferation,[11] economic geographers have been scanning the globe for indications of geographical formations complying with the model, and, as MARTIN & SUNLEY, 2003, remark, the vocabulary of economic geography has been enriched with a plethora of neologisms, such as 'new industrial spaces', 'territorial production complexes', 'regional innovative milieux', 'innovative clusters', 'regional clusters', and the like. Many attempts to explain the 'miracle' of the Third Italy focus on contextual and institutional factors such as social capital [PUTNAM *et al.*, 1993], and 'untraded interdependencies' [STORPER, 1997], which together with regional learning and innovation [ASHEIM, 1995] became the new fad of the nineties in economic geography. From this point of view this corpus of literature can be considered as pertaining to the 'institutionalist' strand.

Although it does not propose an explicit model of geographical space – or maybe because of that – the broadly-defined 'institutionalist' strand in economic geography has enriched the sub-discipline with a fertile, realist conception of space, which has nothing to do with the abstract geometrical space of regional science and the NEG. This 'space of places' has a strong physical dimension, but it is also largely shaped by social norms and institutions. As we shall see in the

next section, however, the 'relational' dimension of geographical space in this strand of theory is still dormant, or at least not explicitly and systematically treated.

Evolutionary economic geography

Similarly to the 'institutional' variant of economic geography, it is not very easy to define an evolutionary economic geography (EEG) independently from the corresponding strand of economics. EEG and evolutionary economics share essentially the same fundamental epistemological premises and methodological tools, which the former applies in the study of uneven geographical development [BOSCHMA & MARTIN, 2007], or, seen in the more specific context of the theory of evolutionary selection of organisational routines by NELSON & WINTER, 1982, in the study of the spatio-temporal distribution of these routines, their creation and diffusion in space, and the analysis of agglomerations in terms of the spatial concentration of organisational knowledge embedded in them [BOSCHMA & FRENKEN, 2006]. Under a broader definition, EEG studies the evolutionary dynamics of spatio-economic systems, i.e. systems emerging from the spatial interaction of the underlying populations of economic agents.

BOSCHMA & MARTIN, 2007, additionally identify as the subject-matter of an EEG "the spatialities of economic novelty", the emergence of the spatial structures of the economy from the micro-behaviours of economic agents, the self-organisation of the economic landscape, and the path-dependent shaping of geographies of economic development and transformation. Novelty, emergence, self-organisation and path-dependence are, however, typical systemic properties of complex adaptive systems without an explicit evolutionary tag,[12] and hence more associated with complexity theory rather than with evolutionary dynamics per se. The expansion of the scope of EEG in the direction of complexity theory, emergentism, connectionism, social network analysis, as well as institutionalism is not uncommon for this strand of the discipline [see, for instance, the diverse collection of articles in BOSCHMA & MARTIN, 2010].

BOSCHMA & FRENKEN, 2006, criticise, however, the tendency to convolute the evolutionary with the institutionalist approaches, and emphasise the epistemological and methodological autonomy of the former vis-à-vis the latter, while recognise that their cross-fertilisation is valuable for the discipline. They observe that EEG explains decision-making under bounded rationality in the context of organisational routines, while institutional approaches do that in the context of territorial institutions; as a result, the approach of the former to geographical phenomena is bottom-up, from the micro-dynamics of firms to the spatial macro-economy, while that of the latter is top-down, from the macro-perspective of institutions at the territorial level to the micro-behaviour of

economic agents. The two approaches may converge when institutions are seen as co-evolving with technologies, markets and industrial organisation.

Still, the different conceptualisation of geographical space by the two approaches is harder to reconcile: BOSCHMA & FRENKEN, 2006: 289, note that the geographical space of formal evolutionary models is more similar to that of the neoclassical variants of economic geography, in that it is a 'neutral', abstract space, than that of the institutional variant, which is nothing but the space of the "real places in real-world cases". And while the latter approach implicitly takes these 'real places' as fixed or at least pre-existing ontologies determining spatio-economic processes, EEG "claims that real places emerge from actions of economic agents, rather than fully determining their actions" [Ibid.].

A generic modelling framework of economic development as an evolutionary branching process of product innovations, which allows to obtain firm and city size distributions as aggregates resulting from an evolutionary process, is proposed by FRENKEN & BOSCHMA, 2007. This generic model considers firm-level economies of scope and urban level Jacobs externalities as the principal feedback mechanisms in economic development, which generate path dependencies in the spatial concentration of industries and the specialisation of cities.

MARTIN & SUNLEY, 2006 critically examine the concept of path dependence as a persistent characteristic of and as an approach to economic phenomena in geographical space, and notably its potential meaning in a regional context as 'regional path dependence' (a possible interpretation of which is that of 'regional lock-in'), and its applicability to the study of regional economic evolution. SIMMIE & MARTIN, 2010, examine in a regional context a related systemic concept, that of resilience, which is interpreted as the ability of a regional economy to recover successfully from exogenous shocks threatening to throw it off its growth path, and the applicability of this concept to the study of the long-term evolutionary dynamics of urban and regional economies.

Relational economic geography

One more in a long list of turns in economic geography is the 'relational turn' [BOGGS & RANTISI, 2003; YEUNG, 2005].[13] This involves the adoption of a perspective "concerned with the ways social interactions between economic agents have shaped the geography of economic performance" [BOGGS & RANTISI, 2003: 109], or differently put, "an analytical focus on the complex nexus of relations among actors and structures that affect dynamic changes in the spatial organisation of economic activities" [YEUNG, 2005: 37].

Relational economic geography (REG) shifts the traditional focus of mainstream economic theory and of regional science from the individual

economic agent who operates in an isotropic space of market-mediated interactions to the structure of (direct) interactions among economic agents on the basis of established social relationships.[14] BATHELT & GLÜCKLER, 2003: 123, argue that while regional science treats geographical space as an entity which exists independently from economic action, and which "confines and determines economic action", the relational approach "assumes that economic action transforms the localised material and institutional conditions of future economic action", and "emphasises that the economic actors themselves produce their own regional environments". They identify three conditions for this paradigmatic shift: 'contextuality', i.e. the recognition that economic actors are embedded in a social and institutional context, path-dependence, and 'contingency', i.e. the open-endedness of economic agents' strategies and actions, which remain not fully determined by their context or by path-dependence. They further identify four premises as an analytical basis for a REG: organisation, by which they essentially refer to industrial organisation and the internal (intra-firm) or external division of labour, evolution, innovation, and interaction, by which they refer to economic interactions between agents or groups of agents. In an attempt to define the epistemological scope of REG they contend that research in REG "focuses on processes, such as institutional learning, creative interaction, economic innovation, and interorganisational communication, and investigates these through a geographical lens, rather than uncovering spatial regularities and structures." [Ibid.: 125].

In his critical stance towards REG, YEUNG, 2005, warns against the 'anti-essentialist' tendencies of some (extreme) variants of REG ensuing from the fact that many generic relational concepts commonly used in REG, such as the concept of 'network', are merely descriptive and devoid of explanatory capacity. He proposes the reconsideration of the nature of relationality in REG on the basis of 'relational geometries', which he defines as "spatial configurations of heterogeneous power relations". In a similar vein, SUNLEY, 2008: 3, criticises REG for having "lost sight of many of the valuable insights of institutionalist and critical realist approaches", including the implications of emergence, and for failing "to offer analytical models that prioritise causes and identify causal mechanisms". He contends that "relational insights should be developed within an evolutionary institutionalism that is informed by critical and pragmatic realisms" [Ibid.].

Relational space, industrial organisation and the mesoeconomic plexus

Redefining the scope of economic geography: The relational dimension

Since the contemporary reincarnations of Marshall's industrial districts in the 'Third Italy' and throughout the eighties and nineties, economic geographers have been fascinated by this stylised geographical formation, which was seen as a paradigmatic materialisation of post-Fordist 'flexible specialisation' in space. These highly localised concentrations of economic activity seemed to exist and prosper in the face of increasing globalisation, or so it was thought. The paradigm started to lose some of its allure when it was soon realised, first, that it was not so easily reproducible outside the very specific institutional context in which it emerged, and second, that the most globally competitive production systems did not necessarily exhibit the level of regional closure found in the archetypical industrial districts [STORPER, 1997: 8]. Beyond the raw force of agglomeration, which is traditionally associated with localised economies of scale and production externalities assumed to be present in Marshallian industrial districts, economic geographers began to observe patterns in the internal as well as in the external linkages of these spatial formations, which they diversely described as 'neo-Marshallian nodes in global networks' [AMIN & THRIFT, 1992], 'sticky places in a slippery space' [MARKUSEN, 1996], 'regional motors of the global economy' [SCOTT, 1996], and so on.

Nevertheless, the attempts to present the industrial district as a generalisable model of industrial organisation have been inconclusive. I argue that this discourse has been largely misplaced: The problem here, to use critical realist terminology, is that the model of industrial district describes a 'constant conjunction of events' instead of a transfactual ontology, an isolated empirical regularity made into a stylised archetype, which however originates from a fundamentally open, ever-changing, constantly interacting with its environment, out-of-equilibrium, dynamically evolving complex production system. The patterns identified in an ad hoc manner by geographers are in reality instantiations of the deeper generative structures of the productive systems in question. These generative structures are not necessarily territorially contingent, even though their instantiations are. All production systems, from corporate organisations, through regional 'clusters', industries and national

economies, to the global economy, have internal structures that articulate their micro-elements and external structures that integrate them in higher-level entities. These relational structures are neither isotropic nor random, but have a complex, nontrivial topology, whose study can yield a lot of insight into the deeper generative structures of the production systems.

The 'traditional' geographical approach commits the 'physicalist' fallacy by conceiving the physical space of economic geography as an ontological category in itself – as if this physical space has innate properties (affecting the economy) other than those emanating from the socio-economic ontologies it contains.[15] By reinstating the geographical space as a *relational space*, as a locus of socio-economic interactions, which also has a contingent physical dimension (the latter being a property of the socio-economic entities it contains rather than an innate property of the locus itself), the fallacy can be superseded. The relational space is what CASTELLS, 1991; 2011, calls a 'space of flows', an anisotropic, dynamic space-time with a variable, network-shaped geometry, as opposed to the 'space of places', the static and fragmented collection of physical spaces. It is only within the relational space where questions concerning the deeper generative structures of the production systems can be answered.

External division of labour and the nexus of interdependences

Interdependences as externalities

Externalities in production

In mainstream economic theory, externalities (or 'external economies') are economic effects not captured in the market prices of goods or of production factors. These effects drive a wedge between the private and the social value of a good or of a production factor, and therefore are considered to cause the failure of the first welfare theorem, since in the face of externalities a competitive equilibrium, even if it exists, it will not be Pareto-optimal. Externalities in the neoclassical context, therefore, are thought of as a leading cause of 'market failure' [MASKIN, 1994].

Another instructive definition of externalities is that they occur "whenever the well-being of a consumer or the production possibilities of a firm are directly affected by the actions of another agent in the economy", where 'directly' means "in a way not mediated by the price mechanism" [MAS-COLELL *et al.*, 1995: 352]. In a similar vain, SCITOVSKY, 1954: 144 (following an earlier definition by MEADE, 1952) defines 'technological external economies' as a type of direct (extra-market) interdependence among economic agents, by which the output of an

individual producer depends "not only on his input of productive resources but also on the activities of other firms". He also distinguishes a type of interdependence which has, instead of direct extra-market effect, an effect through the market mechanism, and which he calls 'pecuniary external economies'. Scitovsky, as a matter of fact, replicates VINER, 1932, who distinguishes between technological and pecuniary externalities, of which the former corresponds to the modern concept, whereas the latter, a pseudo-externality, is the scale effect caused by a shift in the level of economic activity of an individual agent, capable of affecting other economic agents.

The concept of 'externality' is imbued with methodological individualism, as it considers the direct interaction of economic agents as an aberration from the norm and a source of market failure. As SCITOVSKY, 1954: 144, expressively observes, "in general equilibrium theory, direct interdependence is the villain of the piece and the cause for conflict between private profit and social benefit". Interestingly, a common theme in all definitions of 'externality' is the implicit assumption that the direct interaction of economic agents which affects their productive possibilities is, in a way, unintended and incidental. Here I propose an alternative explanation of the quantities characterised as 'externalities' within the neoclassical context, starting from the observation that these are phenomena pertaining to the meso domain, given that they involve micro-interactions of individual economic agents. I argue that 'externalities' are nothing but the 'residuals' from the artificial disaggregation at the micro level of otherwise irreducible, nonlinear interactions occurring at the meso level. 'Externalities' are therefore the unexplained (in the context of neoclassical theory) portion of the process of (weak) emergence, and can be considered as emergent phenomena per se.

Externalities as a causal mechanism of agglomeration

A conventional approach to local production systems of all types (including 'industrial districts', 'regional clusters', 'territorial production complexes', etc.), which is consistent with the stylised models of the NEG, is that they are territorial concentrations of economic activity induced by *agglomeration economies*. These accrue from factors exogenous to the agglomerated economic agents, such as physical infrastructure, favourable spatial planning provisions, other localised policy incentives (e.g. special tax regimes), low land rents, and most importantly, proximity to existing labour and consumer markets. The agglomerating factors that glue economic agents together in local production systems are, therefore, either the localised provision of public goods (physical infrastructure, enabling institutional framework, etc.) or territorially specific positive externalities. The former are usually the result of state intervention, while the latter are involuntary and incidental side-effects of economic activity. In this approach a local production system is, therefore, a territorial

concentration of economic agents bound together by economic factors that do not result directly from their deliberate actions but are instead elements of the socio-economic environment in which they operate.[16]

In other strands of literature, *untraded interdependences* have been emphatically proclaimed as the major source of competitive advantage of localities, and, as a matter of fact, the very raison d'être of regional formations [STORPER, 1997].[17] The term 'untraded interdependences', coined by DOSI, 1984, refers, according to STORPER, 1997, to all "conventions, informal rules, and habits that coordinate economic actors under conditions of uncertainty" [Ibid.: 5]. Dosi himself defines untraded interdependences between sectors, technologies and firms as the "technological complementarities, 'synergies', and flow of stimuli and constraints which do not entirely correspond to commodity flows", but "represent a structured set of *technological externalities* which can be a collective asset of groups of firms/ industries within countries/ regions and/or tend to be internalised within individual companies". These untraded interdependences are "the *unintentional* outcome of decentralised (but irreversible) processes of environmental organisation and/or the result of *explicit strategies* of public and private institutions" (emphasis added) [DOSI, 1988: 226].

The nexus of interdependences as an external division of labour

The conventional 'agglomeration economies' approach to local production systems excludes their most important generative factor: the structured socio-economic relationships of economic agents. The 'untraded interdependences' approach improves on this deficiency, but still treats interdependences as a form of externality, i.e. as unintentional, extra-market side effects of economic activity which constitute elements of the socio-economic environment (despite the contradictory last line in Dosi's definition that untraded interdependences can be "the result of explicit strategies").

The approach adopted in this book is fundamentally different: I argue that the most important generative factor of local production systems, and by extension, the major source of their assumed competitive advantage, are the interdependences of economic agents (both traded and untraded, i.e. market-mediated and extra-market) induced by a locally stable *external division of labour*. This defines a *nexus of interdependences* (to paraphrase STORPER, 1995) generated by the interactions, both purposive and unintended, direct and indirect, pecuniary and untraded, of economic agents. In this approach 'traded interdependences', i.e. interdependences that involve pecuniary transactions and potentially formal, contractual relationships, are of utmost importance. On the other hand, the role of untraded interdependences in the form of conventions, informal rules, and habits, as well as formal institutions and mutual trust, is by no means underestimated: Untraded interdependencies are

informational externalities accruing from and contributing to the external division of labour by supporting, as STORPER, 1997, suggests, the decentralised, local coordination of economic agents' actions in the presence of imperfect information and bounded rationality.

The external division of labour itself is not the unintended by-product of economic activity, a collection of externalities, but the result of "consciously pursued joint action" [SCHMITZ, 1999], even though joint action may benefit from existing agglomeration economies and give rise to externalities. According to SCHMITZ, 1999, joint action can be *horizontal*, taking the form of cooperation between competitors for the attainment of scale and scope economies, or *vertical*, in the form of coordination between producers of goods and services that are complementary in the production process, i.e. that belong to the same value-chain. Joint action can be *bilateral*, when individual firms cooperate to achieve a specific goal, such as the development of a new product, or *multilateral*, when groups of firms join forces to form producer consortia, cooperatives, etc. To these I add that joint action can also be *ad hoc*, when it takes place for the realisation of a specific project, or *repeated*, in the case of a cooperative scheme on a more permanent basis. Generally speaking, cooperation in this context does not exclude competition. Joint action is the basis of different forms of industrial organisation in the mesoeconomic domain examined in the next subsection.

The external division of labour generates a flexible form of industrial organisation, which in certain economic environments, for certain market niches and under certain operational conditions can be more efficient and competitive than the internal division of labour found in vertically integrated corporate organisations. This form of industrial organisation enables firms to specialise in specific segments of a complex production process, to product-differentiate and to innovate through gradual adaptation and learning. It also facilitates effective investment in small steps, since, for example, producers do not have to buy equipment or to train labour for the entire production chain but only for the segment in which they specialise. Moreover, it is a well-known risk-pooling device in economic environments of uncertainty, as it gives to smaller firms the opportunity to invest in innovative projects and to introduce relatively risky technical and organisational improvements in their field of specialisation with potential cascading effects on aggregate performance when the innovations in the whole production process become cumulative. It also reduces all types of entry barriers, thus facilitating the entry of newcomers irrespective of their size.[18] This observation shows the important role of this form of industrial organisation as 'enterprise incubator', and its ability to "help small firms to overcome well-known growth constraints and to sell to distant markets, nationally and internationally" [Ibid.: 466]. With regard to innovative activity, there is strong

empirical evidence that it tends to agglomerate, and that this propensity is stronger in the early stages of the business life cycle, while it becomes more dispersed in the mature stages [AUDRETSCH & FELDMAN, 1996].

External division of labour and industrial organisation

Transaction and integration modes of industrial organisation

The nature of the external division of labour can be further elucidated by comparing it to the *internal division of labour* of a corporate organisation in the context of organisation theory. A corporation has a legal personality that secures and a hierarchical administrative structure that regulates intra-organisational transactions among its departments. Transactions take place in an extra-market framework. On the other hand, a local production system with an external division of labour has no legal personality. It is characterised by a heterarchical structure, in which the various production units are interdependent but autonomous. Inter-firm transactions are either governed by contractual arrangements, i.e. legally binding bilateral agreements, or are simply spot-market transactions coordinated through the market mechanism and regulated by the normative 'nexus of untraded interdependencies'.

The prevailing type of transaction arrangements among economic agents, which may take the form of *hierarchies*, *contracts* or *markets*, or indeed any mix of these three, define what I shall call the *transaction mode* of the economic system. The contract-based transaction mode is a 'hybrid' between extra-market and open-market transactions [WILLIAMSON, 2005].[19] With regard to the permanency of the arrangements, a transaction mode can be *perpetual*, *temporary* or *ad hoc*, depending on the types of joint actions it supports. A large complex local production system will most likely involve a multiplicity of coexisting transaction modes. Different mixes of hierarchical, contractual and open-market transactions is one aspect of what generates the variety of economic formations, such as corporate organisations and local production systems. Another aspect is the *integration mode*. By this term I refer to the way elementary or compound microeconomic entities become embedded in the division of labour of a (higher-order) production system. The implementation of an integration mode depends on the underlying *power structure* of the system, which may take the form of (formal) *authority*, *dominance* based on asymmetric dependence, or *interdependence*. The integration mode determines the way the *relational quasi-rent* is allocated and appropriated; this term, introduced by AOKI, 1986, refers to the quasi-rent that is generated by investment in 'relational

assets'.[20] In the context of organisation theory the following integration modes can be distinguished:

Integration and dis-integration

Vertical integration refers to the expansion of corporate ownership into upstream or downstream activities. More specifically, downstream expansion is known as *forward integration* and upstream expansion as *backward integration*. *Horizontal integration* refers to the concentration of units belonging to the same level of the value-chain under a single ownership scheme by internal expansion of the firm or by external expansion through mergers and acquisitions. A vertically or horizontally integrated entity (a corporation) has a hierarchy-based transaction mode and an authority-based power structure. The generation and appropriation of relational quasi-rent is completely internalised.

Horizontal integration may generate economies of scale or scope, increase market power over suppliers and buyers or facilitate international transactions. Vertical integration may reduce transaction costs, stabilise and coordinate the supply chain, increase entry barriers to potential competitors, and internalise the risk of investment in specialised assets and activities, such as capital-intensive R&D activity, which normally would not be taken up by individual upstream or downstream actors. Vertical integration is intensified by adverse factors such as a restrictive tax regime, an unstable macroeconomic environment that increases uncertainty and risk, a weak institutional frame, inadequate social capital and lack of trust that make difficult the enforcement and monitoring of contracts, or just missing upstream or downstream markets. On the other hand, compared to alternative integration modes, vertical integration has a number of potential disadvantages: First, rigidities in the supply chain with regard to adapting to variable exogenous demand, which may cause excess upstream capacity building and bottlenecks; second, managerial diseconomies and potentially increased costs due to lack of supplier competition; third, inflexibility of the innovation-generating structure, which gives rise to diminishing returns to R&D investment. This last limitation is examined in more detail in the next section.

Vertical or *horizontal dis-integration* refers to the reverse process whereby, respectively, upstream or downstream segments of the value-chain or activities belonging to the same level of the value-chain are externalised. The process of disintegration leads to the reorganisation of the supply-chain of the firm by increasing outsourcing. It also leads to switches from hierarchy- to contract- or market-based transaction modes. The transition to the so-called post-Fordist 'flexible' regime of accumulation in the mid-1980s is associated with this tendency [LEBORGNE & LIPIETZ, 1992].

Quasi-integration

Quasi-integration is a decentralised but relatively stable inter-organisational division of labour with a network-like configuration. The power structure within quasi-integrated systems is not based on authority but on dominance or interdependence. The relational quasi-rent generated in the context of joint action schemes is allocated among the partners on the basis of their relative positions within the network. LEBORGNE & LIPIETZ, 1992, distinguish three forms of quasi-integration, namely 'vertical', 'horizontal' and 'oblique', explained below.

Vertical quasi-integration, a term attributed to BLOIS, 1972, is a production system consisting of a dominant firm and its (usually upstream) subcontractors. This corresponds to a hierarchical star-like network structure resembling the *hub-and-spoke* type of industrial district [MARKUSEN, 1996]. In this integration mode the dominant firm sets the rules and the specifications of production to its upstream suppliers and appropriates most of the relational quasi-rent. *Just-in-time* production methods favour this mode of integration over vertical integration. *Horizontal quasi-integration* occurs when there is no dominant partner in the network and the relational quasi-rent is allocated more-or-less evenly among the partners. The network is entirely decentralised, heterarchical, and the power structure is based on interdependence rather than on authority or dominance. Strategic alliances, joint ventures etc. are usual under this mode of integration. *Oblique quasi-integration* is an intermediate integration mode in which the suppliers preserve their autonomy vis-à-vis their customers in that they retain full control of their segment of the value-chain. The transaction mode of this scheme is predominantly contract-based, aiming at eliminating the moral hazard problem which is usual in principal-agent type of interactions with limited monitoring capacities.

Whereas the vertically integrated corporation is considered as an illustration of the Fordist-Taylorist techno-managerial paradigm, quasi-integrated production systems are seen as typical examples of post-Fordist, 'flexible' organisation [PIORE & SABEL, 1984; SABEL, 1989; LEBORGNE & LIPIETZ, 1992]. This mode (even partially) permits the mediation of the market mechanism and of inter-organisational competition. This introduces a local selection process potentially leading to the 'survival of the fittest', most efficient firms and entrepreneurial behaviour, at least within the boundaries of the system. At the same time it reduces the uncertainty and the coordination problems of open-market transactions. As a result, quasi-integrated production systems are supposed to combine flexibility with relative stability in their organisational structures. 'Globalisation' in the sense of increased trade openness is seen as a crucial factor inducing vertical dis-integration and the proliferation of the quasi-integration paradigm [MCLAREN, 2000].

Network representation of industrial organisation

The above descriptions of the integration and transaction modes of industrial organisation imply a network structure of the inter- and intra-organisational division of labour. This implicit reference can be taken further by approaching the different forms of industrial organisation from an explicit network-analytical perspective as instantiations of distinct network types.

A first step in this direction is the observation that in the post-Fordist knowledge-based economies traditional vertically integrated firms exhibit a tendency to transform into what is termed as 'network organisations' [JONES *et al.*, 1997; MILES & SNOW, 1992]. PODOLNY & PAGE, 1998: 59, define the network form of organisation as a "collection of actors that pursue repeated, enduring exchange relations with one another and, at the same time, lack a legitimate organisational authority to arbitrate and resolve disputes that may arise during the exchange". This definition corresponds to the specific modes of quasi-integration examined in the previous paragraph and clearly describes a *heterarchical* network structure. In a similar vein, POWELL, 1990: 313, sees the network as a hybrid form of industrial organisation between hierarchy and market that expands the boundaries of the firm "to encompass a larger community of actors and interests that would previously have either been fully separate entities or absorbed through merger".

I argue that the application of the powerful network paradigm in organisation theory can and should be generalised to encompass all types of organisational structures including the internal division of labour found in corporate organisations. By this approach the firm can be represented as a hierarchical network whose topology is subsumable to the same analytical methods as any other form of industrial organisation, whereas the industrial district as a complex heterarchical network which potentially also embeds various local hierarchies.

The network representation of the various forms of industrial organisation does not provide in itself, however, a complete explanation of how and why they occur and what makes them qualitatively distinct from one another: In the case, for instance, of a corporate organisation, its constituent micro-elements, i.e. individual economic agents, loose their 'ontological' autonomy (as economic agents) the moment they are incorporated in the organisational structure of the firm, unlike firms joining a quasi-integrated external division of labour, in which they retain their ontological autonomy. Moreover, the corporation itself, as already discussed in the previous chapter, is an emergent ontology which manages to exist independently from its constituent micro-elements. As it is more extensively discussed in a following section, technological knowledge and the processes of evolution and emergence are the crucial factors in binding

micro-entities together in productive macro-systems and in shaping the network topologies of the latter.

The network is not only a means of structuring economic transactions but most importantly, a means for the diffusion of economically relevant information, and thus also of technological knowledge. In real economic systems the diffusion of information does not take place in an isotropic continuum, like the one implicit in neoclassical theory, but in an anisotropic space spanned by usually complex networks of variable architecture. Such networks often exhibit a capacity to diffuse information depending on their degree of connectivity: Some studies of social network models, for instance, find that by increasing connectivity, the information diffusion speed in a network also increases, though different types of connections may have different effects [e.g. MIDGLEY *et al.*, 1992; GOYAL & JANSSEN, 1996; CHWE, 2000].

Mesoeconomic plexus and economies of complexity

The mesoeconomic plexus defined

In Chapter 1 it was argued that the meso domain is an indispensable ontological level in a realist theory of economics, and by extension of economic geography: It is a relational space of micro-interactions which lies between and coheres the level of mereologically irreducible (either in the epistemological or in the ontological sense) macro-systems and the level of their constituent micro-parts, i.e. of individual economic agents, and the locus where emergence occurs par excellence.

I call the fundamental ontology of this domain 'mesoeconomic plexus', and I define this to be the cohesive set of all relatively stable micro-interactions which embodies a *complete* external division of labour in a *specific* production process.

This concise definition entails the following: The mesoeconomic plexus is a fundamental ontology in the same sense as individual economic agents are in the micro domain and macro-economic systems, such as national economies, are in the macro domain. The micro-interactions which make up the plexus are neither random nor unintended, but purposive joint actions induced by real and potentially lasting economic relationships. As a result, the plexus itself is a structured system, and as it is postulated in the following paragraph, a complex adaptive one. A mesoeconomic plexus embodies an entire external division of labour in a particular production process, and in that sense it is a superstructure that incorporates diverse forms of industrial organisation; as a matter of fact, given the possibility of network representation of these forms, the plexus can be

conceived as a network of interlocking networks. A plexus is thus a scalable entity encompassing not only territorially embedded productive systems, such as regional clusters or industrial districts, but also various types of supralocal networks of economic activity, all of which are segments or layers of a specific division of labour. Its upper bounds are determined by the extension of the division of labour, by the nature of the production process, but also by the analytical perspective.

The mesoeconomic plexus is proposed as an analytical tool for the systemic paradigm in economic geography because, as it will be made clearer in the remaining of this chapter, it embodies the three proposed fundamental epistemological premises of this paradigm, complexity, evolution and emergence. But before any further development of this concept, the critical reader may justifiably ask what does this concept add to the very similar notions of 'relational space' and 'network' and why do we need to invent this theoretical construct in the first place. An advance answer to these legitimate questions is that 'relational space' is a term referring to the 'vessel' of economic interactions, the locus where they occur (and which is also shaped by them), not to the 'ontological' object itself. 'Network' is a generic term extensively used throughout this book, which does not specifically refer to economic phenomena, does not necessarily embody a complete division of labour, and is not necessarily part of the nested hierarchy of economic domains. A mesoeconomic plexus is an entity that resides in relational space but does not coincide with it. And while a plexus may have a network representation, a specific network need not be a plexus. An example of this last point is the interregional network of patent co-inventors, extensively analysed in Chapters 3 and 4: This knowledge network does not embody a complete external division of labour in itself – it merely is a particular aspect of the division of labour in technological knowledge production. Therefore, it is not a mesoeconomic plexus but merely a component of the 'knowledge plexus' (see below). Another legitimate question would be in what sense a mesoeconomic plexus, which is a complex system in itself, is ontologically distinct from the complex economic systems which reside in the macro domain. The answer is that macro-systems, such as national or regional economies, incorporate several intertwined production processes extending across several mesoeconomic plexuses, and therefore embody a multi-layered division of labour of a higher order of complexity than that of a single plexus.

Three types of plexuses span the macro-economy: the production-exchange (i.e. industry-trade) plexus, the financial plexus, and the knowledge (i.e. science-technology) plexus, which is the focal point of this book. As economic history amply demonstrates, these three types of plexuses are interdependent, and as a matter of fact, co-evolve. Each of these types of mesoeconomic plexuses has its own medium of accumulation, namely physical, financial and cognitive capital

respectively, and a regulatory schema consisting in an explicit institutional and an implicit normative structure (of 'untraded interdependences', i.e. tacit rules, 'social capital', norms, etc.), which co-evolves with the plexus. The knowledge plexus, in particular, embodies the external division of labour in the production of economically relevant knowledge, and therefore supports its reproduction, accumulation and diffusion.

The mesoeconomic plexus as a complex adaptive system

Dissipation and self-organisation

The various instantiations of the mesoeconomic plexuses are open systems in constant exchange of factors of production, commodities and information with their socio-economic environments. During this process of exchange, and depending on their life-cycle stages, these entities become more organisationally complex as the number, the size and the interaction intensities of their constituent elements increase. At the early stages of their life cycle they endogenously expand their internal structure and increase their systemic complexity by developing more interdependences between their constituent elements. At the late stages, their decline, which comes as a result of cumulative diseconomies or technological lock-ins, is marked by their entropic degradation. For all these reasons, the instantiations of a mesoeconomic plexus are dissipative systems in a far-from-equilibrium state, exhibiting self-organisation.

In the process of self-organised expansion, the instantiations of the knowledge plexus, in particular, are able to transform information flows they receive from their environment into new technological knowledge and accumulate it as stocks of *relational cognitive capital* (defined and explained below).

Path dependence, nonlinearities and complex dynamics

An increasing number of studies in the field of economic geography identify path dependence as an essential feature of local production systems, such as industrial districts, regional clusters, regional networks, or, more generally, of the regions.[21] Dynamic increasing returns, the irreversibility of past investment and sunk costs, agglomeration economies, technological lock-ins, institutional inertia, and cumulative causation are among the factors that have been identified in related literature as sources of path dependence in economic geography, as well as in economic history [SAVIOTTI & METCALFE, 1991; KRUGMAN, 1991; STORPER, 1997; GARUD & KARNØE, 2001; FUCHS & SHAPIRA, 2005]. This rich theoretical and empirical evidence supports the view that the evolutionary trajectories of the various instantiations of the mesoeconomic plexuses exhibit the properties of nonergodicity and time-irreversibility.

The mesoeconomic plexus arises from the interactions of micro-parts which, unlike those of physical complex systems, are cognitive economic agents. These agents are heterogeneous, adaptive, and able to learn and even to consciously deliberate on their course of action on the basis of their bounded rationality and their constrained knowledge of their broader economic environment. An instantiation of a plexus is, therefore, a multiagent dynamical system consisting of a large number of heterogeneous adaptive agents.

The heterogeneity in the behavioural patterns of economic agents and their adaptability to their socio-economic environment implies that their set of interactions will be nonlinear. In that sense, the instantiations of the mesoeconomic plexuses are nonlinear dynamical systems. Agents' heterogeneity and systems' nonlinearities are potential sources of endogenous novelty. Of course nonlinear dynamics need not always be complex (class 4) dynamics; they can merely be chaotic (class 3). In the case of evolving mesoeconomic plexuses, however, the generation of new structure implies that their evolutionary trajectories exhibit complex dynamics 'between order and chaos' rather than chaotic ones.

Universality and phase transition

In complex socio-economic systems systemic fitness is not directly affected by or even associated with individual fitness. In the case of the various instantiations of mesoeconomic plexuses, an equivalent statement would be that the competitiveness of these entities as a whole remains unaffected by the competitiveness of their micro-parts: While individual economic agents such as firms may decline or cease to exist, the plexus lives on or even expands, as an illustration of Schumpeterian creative destruction. Moreover, while micro-interactions may be volatile and in a state of constant flux, the cohesion and aggregate properties of the plexus normally remain unaffected. This is a clear indication of the fundamental CAS property of universality, whereby the generic properties of a system are insensitive to variation in its micro-specification.

Phase transition occurs in a system when small shifts in its higher-order parameters cause drastic changes in its qualitative characteristics, such as leaps from one attractor basin to another or regime shifts. Economic history provides ample evidence of phase transitions in all forms of economic systems, including industrial districts, cities, regional or national economies, or even the global economy as a whole, reflected in their sudden wane and wax in terms of their growth dynamics or the discontinuous shifts in their techno-economic trajectories instigated by specific historical contingencies.

Emergence

A mesoeconomic plexus, as it can be directly deduced from the definition, is a mereologically complex entity whose properties supervene on and are irreducible to those of its micro-units: It is precisely the interdependences generated by the external division of labour which are responsible for the fact that the plexus cannot be fully decomposed into its micro-components.

In addition to the interdependences, a number of significant economic phenomena, which occur within the mesoeconomic plexus, such as *economies of complexity* (see definition below), collective efficiency, innovation, as well as various types of production and information externalities and spillovers, are not present at the level of the micro-units, i.e. the individual economic agents. These are clearly (at least weakly) emergent phenomena.

Moreover, the micro-units, the individual economic agents, exhibit behavioural patterns largely determined by their niche in the plexus, i.e. their position in the external division of labour that spans the plexus. This implies that the plexus also has a downward determinative influence on them. Finally, a mesoeconomic plexus is ontologically distinct from both the micro-units and the macro-systems, and its structure and properties are also qualitatively distinct from theirs, supervene on those of the former and subvene on those of the latter. All these characteristics imply that the plexus is an emergent ontology.

Economies of complexity

External economies of scale

The Marshallian concept of 'external economies of scale', i.e. scale economies external to (competitive, non-monopolistic) firms but internal to the entire industry, is a hybrid between externalities and traditional ('internal') economies of scale ingeniously devised by Marshall to reconcile Cournotian increasing returns with the competitive equilibrium framework [SRAFFA, 1926; STIGLER, 1941]. External economies of this kind are supposed to arise from the development of an industry as a whole, unlike internal economies which, according to Marshall, arise, among other reasons, from the intensification of the division of labour within a firm [MARSHALL, 1920].

Agglomeration economies is a territorially specific form of external economies of scale. However, Marshall's concept contains in latent form an idea beyond the traditional concept of externalities which has never been explored: Marshall's account of the sources of external economies of scale leaves out what may be considered as their principal source, namely the external division of labour itself. The 'extensification' of this division of labour (i.e. its deepening by expansion) is

perfectly analogous to and has similar effects as the deepening by intensification of the division of labour within a firm in the case of internal economies of scale.

Scale versus complexity

Here I take this idea further by introducing the important new concept of 'economies of complexity', which bears some similarities to the Marshallian external economies of scale but also has two very fundamental differences: it distinguishes between *scale* and *systemic complexity*, and it is not an externality but the result of purposive joint action of economic agents within an external division of labour.

Consider the complete (industry-level) value-chain of a specific production process as an external division of labour among production units (firms), which has a natural network representation. This, in the terminology introduced in the previous paragraphs, would qualify as a mesoeconomic plexus. There are four ways of expanding the value-chain, and potentially generating increasing returns in the production process within the same technological set: (i) by increasing the scale of operation of the individual production units, i.e. their size in terms of the amount of physical capital and labour they employ; (ii) by increasing the number of the production units in the given value-chain, e.g. as new firms are created or integrated in the division of labour, which is equivalent to adding new nodes to the network; (iii) by establishing new relationships between existing but previously unrelated production units, e.g. through their participation in new joint ventures, which is equivalent to adding new ties between existing nodes in the network; and finally, (iv) by increasing the intensity of collaboration between units, equivalent to increasing the strength of existing ties. With the exception of case (i), which is a traditional internal expansion of scale, and possibly of case (ii), which is an external expansion of scale (but may have structural effects), the other expansions entail a quantitative but also a qualitative change in the structure of the mesoeconomic plexus. Case (i) is a linear physical expansion of the production scale ('physical' in that it involves an increase in tangible factor inputs), case (ii) is a nonlinear physical expansion, while the other cases are nonlinear structural ones. In cases (iii) and (iv), while the micro-units remain the same in terms of number and size (i.e. factor endowments), their interconnections are multiplied and their interactions are intensified; thus the plexus expands in the direction of increasing its internal structure, and hence its systemic complexity, not its scale. This process deepens the division of labour and, most probably, the degree of specialisation of its micro-units. This is a potential source of an increased 'collective efficiency' [SCHMITZ, 1999], which cannot be attributed either to agglomeration economies and network externalities or to increasing returns to scale internal to the constituent micro-units. This is an emergent phenomenon, which I refer to as *economies of complexity* (or equivalently 'increasing returns to complexity').[22] As a matter of

fact, the concept of economies of complexity reflects much more faithfully than the concept of economies of scale the Smithian spirit with regard to the relationship between the division of labour and increasing returns as illustrated in the first three chapters of *The Wealth of Nations* [SMITH, 1776].

Similar conclusions also apply to the phenomenon of diminishing returns, whenever it occurs in this context: Beyond a certain threshold of systemic complexity the entropic degradation of the system begins, and *diseconomies of complexity* in the form of managerial diseconomies, coordination failures, etc., may set in.

Economies of complexity are distinct from 'network externalities' and 'network effects': Network externalities are consumption-side external economies occurring when the utility that a user derives from the consumption of a good increases with the number of other users consuming the same type of good [KATZ & SHAPIRO, 1985; FARRELL & SALONER, 1985], and therefore from the expansion of the scale of a consumer network. Network effects are production-side informational externalities or knowledge spillovers diffused through a network and affecting technological knowledge production [VARGA *et al.*, 2014], localised versions of which are 'Marshall-Arrow-Romer' (MAR) and 'Jacobs'-type externalities [GLAESER *et al.*, 1992].[23] None of these types of external economies is related to the internal structure of a network and the complexity of its division of labour.

In the knowledge economy where the most important factor of production, technological knowledge, is intangible and highly mobile, increasing returns are more likely to ensue from the increased degree of connectivity of the production units, and hence from the 'extensification' of the division of labour and the increased complexity of the network in which they are embedded, rather than from increasing their internal scale of operation. Economies of complexity are therefore particularly prominent in knowledge-intensive economic activities.

Economic cognition and the emergence of technological knowledge in the knowledge plexus

Typology of technological knowledge

Objectivist and constructivist construals of knowledge

Technological knowledge is here broadly defined as knowledge with actual or potential economic effects. By this definition the qualifier 'technological' does not signify 'technical' or 'applied', but rather any form of knowledge (including the purely 'scientific' one), which ultimately has some effect on the means and the process of production, and hence is economically useful.

In this book knowledge is considered to be the outcome of the process of cognition. This may sound as a tautology but the distinction and the causal relationship between cognition and knowledge is anything but trivial – as a matter of fact, it is a deep epistemological issue. Extending this proposition, it is further argued that technological knowledge is the outcome of the process of cognition by adaptive economic agents.

Technological knowledge is an intangible factor of production, which is at the micro level one of the most valuable assets of individuals and organisations, being the main source of their competitiveness, and at the macro level the principal generator of economic growth, being a source of 'absolute advantage' for national economies. The intensified deployment of technological knowledge in the production process in advanced industrial economies has led to an unprecedentedly rapid expansion of the global technological frontier and to the transition to today's 'knowledge-based economy'. Despite its exceptional importance in economic processes, the origins of technological knowledge and the way it determines micro and macro- economic competitiveness remain inexplicable in the context of neoclassical economics; technological knowledge is taken as given, trivially as a 'black box'. This is probably one of the major weaknesses of the theory.

In this section technological knowledge is examined under two different prisms, which I call the *objectivist* and the *constructivist*.

Under the objectivist prism technological knowledge is treated as a cumulable, capital-like asset, and, by extension, as a substance, a stock, and a fungible input in the production process comparable to physical capital. This approach is

compatible with the concept of 'human capital'. In this context, the economic exploitation of knowledge necessitates its extraction from cognitive agents and its objectification, which is achieved by smoothing out its subjective and contextual elements [BONIFACIO *et al.*, 2004]. This approach does not connect technological knowledge with the process of cognition and so, in a way, misses its deeper generative structures.

Under the constructivist prism technological knowledge emerges as a result of the co-adaptation of reflective agents with internal cognitive schemata (explained in a following subsection). This approach draws heavily on Piaget's theory of cognitive development [PIAGET, 1971], and subsequent studies on artificial intelligence.

Types of technological knowledge

In this subsection I develop a taxonomy for classifying the various forms of technological knowledge according to the following criteria:

- the degree of its *embodiment* in economic agents, i.e. the degree to which knowledge may exist independently from its physical bearer or generator;
- its *codifiability*, which measures the degree of its 'objectifiability';
- its *contextuality*, i.e. the degree to which the valorisation of knowledge is context-dependent, and which determines its 'extractability';[24]
- the *appropriability* of its economic effects by individuals or organisations, which determines the degree of its economic exploitability [LEVIN, 1988; GRANT, 1996];
- its *embeddedness* in geographical space with regard to its generation and absorption, i.e. the degree to which it is produced or absorbed locally, respectively.

By these criteria I distinguish the following four types of technological knowledge:

Universal disembodied (also 'scientific', 'generic', 'theoretical', 'basic') knowledge is formal, codifiable, minimally contextual, with the characteristics of a public good (non-rivalry and non-excludability) and hence not directly appropriable on a private basis but with strong social spillovers and hence positive effects on overall economic activity. This type of knowledge constitutes the generic framework in which other types of knowledge are generated. It is produced and effortlessly diffused within global scientific communities and hence it is not territorially embedded. Due to its limited appropriability private economic agents have the tendency to under-produce it and, as a consequence, public investment is required to ensure its sufficient provision for the benefit of the society at large. This type of knowledge is typically contained in scientific publications resulting from basic academic research.

Instrumental disembodied (also 'technical', 'specific', 'applied') knowledge is also codifiable but more contextual than the previous type, as it is produced and deployed in specific techno-economic environments. This type of knowledge prior to the allocation of intellectual property rights (IPR) can be rival and excludable, but with the allocation of IPR it becomes publicly accessible even though its direct utilisation is restricted, while with the expiry of IPR in the longer run its excludability is lifted. It can be considered, therefore, as a 'quasi-private' good. It is not unusual for this type of knowledge to be produced by public institutions, in which case it can be considered as a quasi-public good.[25] The production of this type of knowledge is usually localised but its diffusion and utilisation need not be so. This knowledge is usually the result of applied research and can be found in patents.

Organisational knowledge is embodied in organisation structures [KOGUT & ZANDER, 1992]. Despite its collective production, this type of knowledge is owned, protected and exploited by the organisations which generate it, and therefore it is a private asset which in the short run confers technology rent to its proprietors. In the longer run it becomes accessible to competitors through imitation, reverse-engineering, etc. This type of knowledge is limitedly codifiable, 'discursive' and highly contextual. The generation of this knowledge is usually localised but organisational knowledge is to some extent transferable through intra- or inter-organisation networks or labour turnover, and as a result, its utilisation is not necessarily territorially embedded.

Individual knowledge is embodied in economic agents in the form of technical skills or know-how (as opposed to 'know-what'), and can be developed through learning-by-doing, vocational training or even formal education. This type of technological knowledge is both rival and excludable, and as a result, it is a private good. It is non-codifiable, 'non-discursive' or, according to POLANYI, 1967, 'tacit', and highly contextual. It is also territorially specific both in its generation and utilisation due to physical and institutional constraints in labour mobility. Table 2.1 summarises this taxonomical scheme.

Table 2.1: Types of technological knowledge

Type	Embodiment	Objectifiability		Appropriability	Embeddedness	
		Contextuality	Codifiability		Generation	Absorption
Universal	None	Low	High	Public	Global	Global
Instrumental	None	Medium	Medium-high	Quasi-public/private	Local	Global
Organisational	Collective	High	Medium-low	Private	Local	Local
Individual	Individual	High	Low	Private	Local	Local

Technological knowledge and industrial organisation

Knowledge-based theories of the firm

The corpus of economic and organisational literature known as 'theory of the firm' is actually a heterogeneous group of theories from diverse epistemological backgrounds, aiming to explain the origins, boundaries, structure, purpose and objectives of the firm as an extra-market formation with own internal structure which operates within the market. Certain strands of this corpus, for instance the neo-institutional transaction cost [COASE, 1937; WILLIAMSON, 1971; 1981], principal-agent, or contract [ALCHIAN & DEMSETZ,1972] theories of the firm, extend the rudimentary neoclassical theory of the firm by incorporating incentives, strategic considerations, asymmetric information and transaction costs, while others place the whole discourse in a different frame, such as the evolutionary neo-Schumpeterian.

A strand within the latter group, which distances itself from the neo-institutional approach and which is particularly relevant to the subject matter of this chapter, is that of the so-called *knowledge-based theory of the firm* [KOGUT & ZANDER, 1992; GRANT, 1996; SPENDER, 1996]. This theory postulates that the raison d'être of any corporate organisation is to combine, coordinate, integrate and structure on the basis of organising principles the 'social knowledge' found in stable relationships of individual economic agents [KOGUT & ZANDER, 1992]. This is considered as a function that the market mechanism by itself is incapable of accomplishing. Organisational knowledge is the most valuable asset of a firm; actually, the firm itself is a collection of cognitive assets embodied in individuals and social relationships, which however is not reducible to those of the individuals [Ibid.]. The firm has the ability to transform its cognitive assets into economic output by applying higher-order organising principles, which eventually determine its organisational capabilities. KOGUT & ZANDER, 1992, distinguish between a declarative and a procedural type of organisational knowledge, which they call *information* and *know-how based* respectively.

The model of organisation-level knowledge integration found in the knowledge-based theories of the firm is not intended to explain the whole range of knowledge-generating capabilities of economic agents and systems, and is compatible with the objectivist construal of technological knowledge.

Knowledge governance and integration modes

A common thread in the extensive literature of 'systems of innovation' shared by this book is that innovation, i.e. the generation of technological knowledge, is a

strongly synergetic and systemic process [DOSI *et al.*, 1988; LUNDVALL, 1992; EDQUIST, 1997; et al.]. Synergetic innovation entails that economic agents combine and eventually integrate their heterogeneous cognitive assets in a common operational framework in order to produce new or to economically exploit existing technological knowledge, without necessarily sharing their ownership or management.

The cognitive assets of vertically or horizontally integrated corporations are under unitary ownership and management. These firms usually have specialised R&D departments and protect their cognitive assets by restricting their use within their confines or by patenting. Firms of this type have both the resources to invest in R&D and the incentives to assume the risk of their investment. The more they rely on own cognitive assets, the more heavily they will have to invest in R&D, but in the case of success, the higher will be the technological rent which they will appropriate.

The exponential growth in technological knowledge output in the second half of the last century and the rising complexity of technologies and of innovation systems make increasingly unaffordable for individual firms to keep the entire R&D process internalised. Moreover, internalisation of R&D also internalises the risk, increases the possibility of technological lock-ins and reduces exposure to technological spillovers. On the contrary, a quasi-integrated R&D process allows the dispersion of risk and of the cost of investment but reduces the fraction of appropriable technological rent for each partner. In a vertically quasi-integrated scheme the dominant partner, the 'hub', sets the rules and specifications of production to its upstream suppliers and has at its disposal the know-how of the subcontractor [LEBORGNE & LIPIETZ, 1992: 341]. As a consequence, the subcontractor may be locked-in in a particular technology and dependent on the dominant partner, the distribution of knowledge will be asymmetric and so will be the allocation of the technological rent. In an oblique quasi-integrated scheme the subcontractor possesses the know-how and the technology to produce according to customer's order autonomously. This allows a more even distribution of the technology rent according to the partner's position in the value chain. In a horizontally quasi-integrated scheme a group of firms linked by partnership jointly undertakes R&D projects and shares the risk. The cognitive assets of the partners are complementary, and the technological rent is allocated more-or-less symmetrically. The shift to flexible quasi-integrated schemes in R&D by participating in knowledge networks which exhibit collective efficiency in the generation and diffusion of innovation is supposed to transform the traditional firm into what has been termed a 'virtual', 'modular' or 'network' organisation.[26]

It seems reasonable to assume that different types of technological knowledge would favour different modes of organisational integration. Generic

disembodied knowledge which is codified and non-contextual can be produced and diffused within globally networked scientific communities. Applied disembodied knowledge is produced in integrated or vertically quasi-integrated systems with centralised structures, but its diffusion can be assumed to be more open and decentralised. Organisational knowledge is produced and diffused within integrated systems that internalise the accruing technology rent. The correspondence of the knowledge governance regimes to the integration and transaction modes and the patterns of allocation of technology rent are summarised in Table 2.2.

Table 2.2: Knowledge governance regimes

Integration mode	Knowledge governance		Transaction mode	Power structure	Rent allocation
	Ownership	**Control**			
Vertical integration	Unitary	Unitary	Hierarchy	Authority	Full appropriation
Horizontal integration	Unitary	Unitary	Hierarchy	Authority	Full appropriation
Vertical quasi-integration	Principal	Principal	Contract	Dominance	Asymmetric
Oblique quasi-integration	Agent	Principal	Contract	Interdependence	Proportional
Horizontal quasi-integration	Distributed	Distributed	Contract / Market	Interdependence	Symmetric

Inevitably, the transition to the post-Fordist knowledge economy has increased the tendency of firms, including multinational corporations, to externalise entire R&D modules or sub-processes through R&D cooperation, with various degrees of externalisation of ownership and control. Cooperation may be equity-based (e.g. joint ventures, cross-equity holdings, etc.), contract-based (joint R&D agreements, customer-supplier relations, and bilateral or unilateral technology flows including cross-licensing, technology exchange agreements, licensing, etc.), or spot-market (or 'arms length') agreements [HAGEDOORN & SCHAKENRAAD, 1994; MOWERY *et al.*, 1996; NARULA & HAGEDOORN, 1999].

Even when large corporations have the resources to invest in R&D projects, radical innovations are sometimes introduced by small start-up firms with specialised cognitive assets occupying very specific technological niches, which are not locked-in in existing firm routines. Such firms may play a vital role in the innovation process and may also act as intermediaries between institutionalised research in universities and public research centres and large corporations.

SAXENIAN, 1996, argues, for instance, that the small firms of the Silicon Valley have been more innovative than the large firms of the East Coast because of their ability to develop multiple connections in dense networks of knowledge, which allows rapid transfer of information and innovative ideas. However, there is also evidence that in some economic sectors quasi-integration, especially among low-tech SMEs, is not conducive to the generation of radical technological discoveries, and that technological lock-in is not an unusual phenomenon in mature quasi-integrated systems of this kind; incremental innovations in such cases are more usual than radical innovations.

Technological knowledge as capital

Forms of cognitive capital

The objectivist approach to technological knowledge entails its conception as a cumulable asset similar to physical capital. This approach implicitly assumes that technological knowledge is a divisible and fungible, albeit intangible, 'substance' rather than a context-specific process. The objectivist approach is currently dominant in economic theory, precisely because it allows the incorporation of technological knowledge in conventional economic models as a form of capital with familiar behaviour. It cannot be denied that the objectivist conception of technological knowledge in certain analytical contexts is useful, and it is partially adopted in the empirical models of Chapter 4 of this book.

From this point onward I shall use the term '*cognitive capital*' to refer to technological knowledge conceived as a cumulable factor input in the production process.

In mainstream economics cognitive capital, as defined here, is taken to be equivalent to 'human capital', namely "knowledge, skills, competences and other attributes embodied in individuals that are relevant to economic activity" [OECD, 1998: 9]. By this definition, human capital is a factor of production consisting in the stock of all forms of individual knowledge) embodied in economic agents (the labour force),[27] which enables them to create economic value. Human capital nevertheless represents only a fragment of the stock of cognitive capital in an economy. Previously we saw that individual knowledge, which is 'objectified' as human capital, is just one out of four types of technological knowledge. But how about the relational dimension of technological knowledge?

Social capital and relational cognitive capital

Definitions and varieties of social capital

BURT, 2001: 32, contends that "social capital is the contextual complement to human capital". In this vein, social capital in an economic context can be defined as an intangible resource consisting in the stock of collective intelligence embodied in social relationships (rather than in individuals), including institutions, norms, values and understandings, trust, reputation, etc., which contributes to the creation of economic value. This definition, however, is by no means agreed upon by everyone.

The vast literature on social capital which currently exists is predominantly sociological. The origins of the term 'social capital' can be traced back to Bourdieu's pioneering anthropological and ethnological work [BOURDIEU, 1972]. COLEMAN, 1988, popularises the term by reintroducing it in Anglosaxon literature in the context of social networks as a 'resource for action', an intangible, non-fungible relational asset embedded in social relationships, reproduced through social norms, trust and obligations, generated by 'network closure',[28] and contributing to the formation of human capital.

An opposite approach to Coleman's perception of social capital as a synergetic asset is found in BURT, 2007: 4, who refers to social capital as "the advantage created by a person's location in a structure of relationships". This is clearly a conception of social capital as an antagonistic asset, a "metaphor about advantage" [BURT, 2001: 31], which confers an exclusive competitive advantage to its possessor. From that perspective, Burt goes on to argue that social capital is formed around 'structural holes',[29] as network-embedded agents "broker connections between otherwise disconnected segments" of the network [Ibid.]. In a more neutral fashion, LIN, 2002: 19, defines social capital as "investment in social relations with expected returns in the marketplace" and also as "resources embedded in a social structure that are accessed and/or mobilized in purposive actions" [Ibid.: 29].

The following characteristics of social capital qualify it as a form of capital similar to physical:

- It is a manmade factor of production; it generates worth.
- Its production involves investment with expected returns.
- It is collectively produced and, often, individually owned. Moreover it is not necessarily owned by those who produce it but by those who are able to exploit it, i.e. to strategically access or mobilise it for their (pecuniary or otherwise) benefit.
- It is a cumulable asset; its locus of accumulation is the social structure.

Particular characteristics of social capital, which distinguish it from physical capital, are the following:

- It is intangible and disembodied.
- It is generated through joint rather than individual action.

However, on this last point the literature, as we already saw, is divided: In Coleman's synergetic perspective, social capital is the result of cooperation and sharing. In Burt's antagonistic perspective, it is the result of an advantage of an individual over others created by her position in a social structure.

Technological knowledge as individual and as relational cognitive capital

In all the above definitions the exact relationship of social capital to (technological) knowledge is not explicit. The reason is that the concept of social capital has not been devised in the first place specifically to refer to knowledge but rather more generally as a metaphor about the economic value of social relationships.

Here I introduce the concept of *relational cognitive capital*, the counterpart to *individual cognitive capital* (which is a different term for 'human capital'), as a specific type of social capital which embodies technological knowledge. This form of cognitive capital bears all the characteristics of social capital: it is an intangible asset embedded in social structures and the product of purposive joint action. In addition, it is an objectified representation of distributed knowledge (explained below). Since it is the product of micro-interactions, it resides in the meso domain and, more specifically, it is embedded in the knowledge plexus. In analogy to social capital, agents have differential access to it depending on their relative position in the structure of the knowledge plexus; agents connecting otherwise disconnected clusters of specific technological knowledge, i.e. structural holes, are in the particularly privileged position of the broker.

Relational cognitive capital is a clear manifestation of emergence: As a relational phenomenon it does not pertain to the level of micro-entities but to the meso level of the knowledge plexus. Contrary to human (or 'individual cognitive') capital it is non-decomposable, as it cannot be fully imputed to a single economic agent independently from others. Finally, it exercises downwardly causal influence on the micro-entities, by which it is also upwardly determined.

The concepts of individual and relational cognitive capital are extensively used in the empirical models developed in Chapter 4. There it is hypothesised that the relational form of cognitive capital may exercise an influence on the knowledge

production process equal as or even stronger than the individual one, given that technological knowledge is systemically produced.

Technological knowledge as systemic phenomenon

The process of technological knowledge production is par excellence synergetic. In modern knowledge-based economies firms cannot conduct research exclusively by relying on own resources in isolation from their technological environment. Indeed, their innovative capacities are largely determined by their ability to position themselves in the knowledge plexus and to tap economies of complexity in knowledge production. As a result of this, firms increasingly adopt 'open innovation' practices [CHIAROMONTE, 2006; CHESBROUGH, 2003], and choose to collaborate with organisations, such as other private firms, universities, research institutes, public bodies, etc. Theoretical and empirical evidence points to the growing tendency among 'post-Fordist', knowledge-economy firms, including multinational corporations, to externalise their R&D functions by shifting from vertical integration to more flexible integration modes and to the 'network type of organisation' in knowledge production. In order to interpret these transitions and also to assess the wider role of technological knowledge in economic processes it is necessary to understand technological knowledge not only as an objectified factor of production but also through the 'constructivist' prism as a systemic phenomenon emerging from cognition by adaptive economic agents.

Cognition by adaptive agents

Structure of adaptive agents

The key to the 'black box' of technological knowledge as a systemic phenomenon is the intricate relationship between cognition and adaptation, first at the micro-level of individual adaptive agents and then at the macro-level of multiagent adaptive systems. Despite the significant progress in the field of artificial intelligence, cognitive theories of adaptive agents are still in their infancy. Here the causal relationship between adaptation and cognition is explored, without examining the ontological dimensions of knowledge.

An 'adaptive agent' is an entity that interacts with its environment and tries to accomplish a set of goals – such as the maximisation of his payoff function or the increase of his fitness; in other words, it is an entity that conducts *search in a fitness landscape* in order to optimise his objective function. The adaptive agent interacts with his environment in two fundamental ways: He can sense the environment through his 'detectors' and act upon the environment through his

'effectors' [BOOKER *et al.*, 1989]. These two functions are mediated by the agent's internal information-processing and decision-making mechanism. As the capacities of his information-processing apparatus are limited and the information signals he receives from his environment are noisy, the adaptive agent cannot function as a hyperrational global optimiser with perfect foresight. For this reason, the adaptive agent needs an internal, finite representation or 'model' of reality, which functions as an inference-making apparatus and provides him with anticipatory and predictive capacities. An element of this apparatus is the capacity to store structured information in 'memory', in the form of 'knowledge' that is recalled and used during the inference-making process and the formation of expectations. This apparatus is referred to as *internal model* by HOLLAND, 1996, or *schema* by GELL-MANN, 1994.

Schemata and constructivism

The notion of mental *schema* is essentially drawn from modern cognitive theory.[30] This strand of theory considers that knowledge stored in memory is structured as a set of discrete schemata, i.e. mental representations of types of objects or events of the environment reached through the sensory apparatuses. Knowledge is, therefore, an internalised representation of reality constructed by agents and not simply acquired from the environment – hence the term *constructivism* to refer to this strand of theory. The process of filtering sensory stimuli received from the environment, and structuring and storing in memory their information content is known as 'bottom-up processing'. The use of knowledge already stored in memory for inference-making purposes is known as 'top-down processing'. Schemata operate as top-down processing apparatuses that have been generated and are updated through bottom-up processing.

Schemata are internalised models of reality. These models are not necessarily 'correct' or optimal and for this reason they are constantly revised during the accumulation of new experiences and learning. Learning is the process by which the symbolic representations of reality become embedded into memory and by which new experiences are incorporated in existing cognitive structures. The updating of the schemata is the quintessence of the process of adaptation through learning: The agents' success in achieving their goals, in increasing their fitness and, eventually, in surviving depends on their ability to improve their internal models through the process of learning. According to HOLLAND, 1996, an agent's 'performance system' is a collection of rules with a given syntactic structure and a mechanism for updating the relative strength of the rules according to their payoffs, called 'credit assignment'. This is essentially a fundamental learning process based on trial-and-error.

Schemata are not exhaustive representations of reality but rather a set of generic rules that can be evoked and applied contingently to external stimuli.

These schemata have a *modular structure*: they consist of simpler 'modules' or as HOLLAND, 1996, calls them, 'building blocks'. The updating of schemata is essentially a process of recombination of existing modules or, less frequently, the discovery of new ones.

In socio-economic systems the adaptation of an agent's schema by recombining existing modules would correspond to incremental innovation, while the introduction of new modules to radical innovation. In biological systems, the first process corresponds to crossover, while the second to mutation. The fitness of an agent endowed with a particular schema can be calculated by genetic algorithms that make use of the two genetic operators, namely the crossover and the mutation operator, together with a fitness function.[31] Cognition by an agent can also be represented by information processing models, whose updating rules are given by genetic algorithms.

Cognition in complex adaptive systems

Meta-agents' schemata and co-adaptation

Adaptive agents are often by themselves aggregations of lower-order adaptive agents, which can be modelled as multiagent systems or networks. When such compound entities are not simply resultant but emergent, they will be referred to as 'meta-agents'.[32] We have already seen, for instance, that corporate organisations can be conceived as emergent networks of individuals who themselves are reflective agents, while trivially, mesoeconomic plexuses and macro-economies also fall into this category when treated as entities.

Being adaptive agents in themselves, meta-agents should have their own schemata determining their operational regimes. Given that, by definition, meta-agents are ontologically distinct from the constituent lower-order agents, a meta-agent's schema cannot simply be an aggregation of the schemata of its lower-order components. A challenging issue in the study of complex adaptive systems is to understand and model the way these schemata and, more generally, the operational macro-regimes of meta-agents emerge from that of lower-order agents.

According to their internal architecture I distinguish two general types of meta-agents: First, hierarchical networks with unitary architecture and predetermined or fixed macro-structure, such as corporations, or, in biology, multicellular organisms, which I refer to as *integrated systems*. Lower-level agents in such systems are fully and irreversibly specialised with relatively fixed in-between links. Such systems have a unique centralised schema unrelated to the schemata of its constituent micro-units. Second, heterarchical networks with open architecture and evolving macro-structure, which I refer to as *distributed systems*. This type includes mesoeconomic plexuses, cities and industrial

districts when considered as complex adaptive systems, or, in biology, colonial organisms and other localised symbiotic ecosystems. In these systems, lower-order agents are semi-specialised and semi-autonomous with relatively stable but flexible in-between links. These links are made possible by the development of complementarities in the schemata of the lower-order agents that favour symbiotic relationships. Systems of this type do not have a unitary, centralised schema, but instead their operational macro-regime is determined by a collective schema ensuing from the co-adapted schemata of their constituent micro-units.

Complementarities are the result of *co-evolution* and *co-adaptation*. In the case of biological systems, the development of complementarities is mainly a long-run inter-generational, inter- or intra-specific co-evolutionary process, which involves the mechanisms of selection and inheritance applied to whole populations rather than individuals. In the case of socio-economic systems, complementarities are mainly generated by the intra-generational process of co-adaptation applied to individual members of a population. Similarly to co-evolution, co-adaptation can be *competitive*, *mutualistic* or *exploitative*; as a matter of fact, mesoeconomic plexuses exhibit all three types of interactions. The co-adaptation process involves the exchange of large information flows between individual agents, ranging from simple sensory stimuli to structured knowledge; these information flows are processed by agents' schemata but also cause their updating, and hence the development of complementarities.

Heterarchies and distributed cognition

In the previous section we saw how knowledge is constructed within the schemata of adaptive agents. Technological knowledge, in particular, is the product of the schemata of economic agents. This cognitivist approach explains how knowledge accrues to individual agents; it does not explain, however, how knowledge accrues to multi-agent systems. Since technological knowledge is by nature predominantly systemic and synergistic rather than individualistic, a theory that explains how it emerges in systems is essential for understanding its deeper generative mechanisms.

The concept of *distributed cognition* is directly relevant to the above question [ROGERS & ELLIS, 1994].[33] This concept stems from a relatively new branch of cognitive science, which examines how cognitive processes are distributed across social groups and how internal (such as schemata) and external (environment, artefacts, etc.) cognitive structures are coordinated. In the case of socio-economic systems, distributed cognition can be perceived as emanating from the integration of individual agents' 'intersubjective' knowledge through the division of labour.

Distributed systems are inherently capable of handling distributed cognition. The collective schemata of this type of systems are the results of emergence and self-organisation, and, as already noted, have decentralised and open-ended architectures. Knowledge generation in this type of systems is a multi-domain emergence process involving adaptive agents interacting at different ontological levels, from that of the neurons of the nervous system of individuals, to groups of individual researchers in organisations, up to the mesoeconomic plexus. Knowledge generation in these systems is, therefore, a genuinely synergetic, complex process shaped by the relational structure in which it emerges rather than by individuals.

Cognitive domains and intersubjective knowledge

The knowledge generated within an agent's schema can be partitioned in three distinct subsets, depending on its relevance to the agent as an individual or to the system where the agent belongs, which I refer to as *cognitive domains*: The cognitive domain in the agent's schema that is not reproduced in other agents' schemata and, therefore, is relevant exclusively to the agent as an individual will be called 'the domain of *subjective knowledge*'. The cognitive domain that is replicable in all agents' schemata within a system will be referred to as 'the domain of *objective knowledge*'; this is the subset of codifiable and reproducible knowledge. Finally, the cognitive domain in an agent's schema that is *isomorphic* to similar domains in other agents' schemata without being replicated in them will be referred to as 'the domain of *intersubjective knowledge*'.[34] This domain consists of tacit, imperfectly codifiable segments of the agents' schemata, which are systemically integrated despite the fact that they cannot be directly replicated and transmitted.

There is a certain correspondence between the three cognitive domains and the four types of knowledge identified previously: The universal and instrumental types generally fall in the domain of subjective knowledge; both 'embodied' types fall in the domain of intersubjective knowledge, with the exception of the segment of individual knowledge that is not directly relevant to the economic system in which the agent operates, and hence belongs to the domain of subjective knowledge. This correspondence is presented in Table 2.3.

Table 2.3: Cognitive domains and types of technological knowledge

COGNITIVE DOMAIN	TYPE OF TECHNOLOGICAL KNOWLEDGE	(OPTIMAL) LOCUS OF SYSTEMISATION
Objective	**Universal**	Distributed systems
	Instrumental	Integrated systems
Intersubjective	**Organisational**	Integrated systems
	Individual	Integrated / distributed systems
Subjective	**Individual**	

Systemic knowledge, according to this classification scheme, involves the domains of objective and intersubjective knowledge.

A fundamental question is how intersubjective knowledge of individuals becomes 'systemised', i.e. internalised in the schema of a multiagent system. The answer is that this happens through the process of mutualistic co-adaptation: It has already been observed that co-adaptive dynamics create complementarities among individual agents' schemata; these complementarities are *isomorphic mappings* between the corresponding domains of intersubjective knowledge of the adaptive agents.

Cognition as competitive co-adaptation

Of the three types of co-evolutionary relationships previously presented, namely competition, mutualism and exploitation, the synergetic generation of technological knowledge has been so far attributed mainly to one, namely mutualistic co-adaptation. In this paragraph the emphasis shifts to competitive co-adaptation as the driver of technological dynamics in the knowledge economy.

The frontier of inter-firm competition in the knowledge economy is continuously shifted through the intensification of product-differentiation by innovation and the shortening of the product life-cycle. By innovating, firms constantly create new niches of absolute advantage and temporarily secure their market power and share against potential imitators. This has become a generalised corporate strategy aiming at rendering mature products obsolete and thereby reducing their profitability, so that potential market entrants would not be able to compete in terms of production costs with incumbent firms.

The phenomenon of innovation-based (instead of price-based) competition among firms in a continuous effort to simply maintain market shares and to avert product imitation by rivals evokes the *Red Queen principle* from evolutionary biology. This 'innovation arms race', as termed by BAUMOL, 2004,

transforms the nature of competitive advantage and, consequently, the organisational structure of the firm: Traditional competition is based on cost reduction and economies of scale and scope. By contrast, innovation-based competition is based on flexibility and rapidity in searching, tracking down, tapping, transforming and utilising new knowledge, and on the ability to generate and exploit economies of complexity. Whereas the realisation of economies of scale and scope requires vertical and horizontal integration respectively, economies of complexity are better supported by quasi-integration, or more generally, by network organisational structures.

The Red Queen principle applied in the economic context provides an alternative explanation for the empirical failure of the R&D-based endogenous growth models [ROMER, 1990; GROSSMAN & HELPMAN, 1991; AGHION & HOWITT, 1992] demonstrated by JONES, 1995b. According to Jones' famous critique, the postwar exponential growth in R&D employment in the US is in sharp contrast to the stationarity of the US macroeconomic growth rates during the same period (and indeed the same applies to most other OECD countries), contrary to the predictions of the above models.[35] During the historical period studied by Jones, R&D investment in all industrialised countries follows a competitive arms race, which undeniably accelerates the global pace of scientific and technological progress (measured in R&D employment, as well as in knowledge output such as patents, scientific publications, technological products, etc.). This is, however, not translated in macroeconomic growth as technological competition erodes the margins of profit and the technology rent of the firms in a spiral of Red Queen dynamics. Moreover, radical innovations and shifts in technological paradigms, as the ones occurring in the postwar period, require heavy investment in the initial stages with uncertain economic outcomes – in many cases the research projects simply fail to have a market impact. In the case of mature technologies and established technological paradigms investment is less risky and its outcome more predictable. The postwar R&D arms race in industrialised economies, during which radically new technologies driven by scientific breakthroughs were explored and established, should be seen in this context.

Conclusion

The reinstatement of the relational space is the first step towards the establishment of the new systemic paradigm in economic geography based on the premises of complexity, evolution and emergence, as proposed in Chapter 1.

The second step is the recognition of the importance of the meso level as an ontological domain which articulates and coheres the nested hierarchy of

domains of the economy from that of micro-economic agents to that of macro-economic systems. The meso domain is a relational space where the interactions of economic agents take place; as such, it is also the locus where the division of labour unfolds. Many essential economic processes occur there, but most importantly the production of technological knowledge.

The fundamental ontology of this domain is defined to be the 'mesoeconomic plexus'. This entity is a new analytical tool for systemic economic geography, representing the embodiment of a complete external division of labour in a specific production process. This entity exhibits many of the macro-properties of complex adaptive systems, and can also be conceived as an emergent heterarchical network of adaptive micro-units or, equivalently, as a meta-agent with the qualities of a distributed system. A specific type of mesoeconomic plexus is the *knowledge plexus*, which embodies the division of labour in the production of technological knowledge.

In mainstream economics and economic geography technological and informational externalities of various forms, including network effects, as well as external economies of scale, e.g. in the form of agglomeration economies, are thought of as typical economic phenomena occurring in local or supra-local formations of interconnected productive units, such as industrial districts, regional clusters, or various types of economic networks. All these are implicitly or explicitly treated as unintended 'by-products' of the economic activity. There is however a different dimension of the 'collective efficiency' exhibited by mesoeconomic plexuses which is not imputable either to traditional economies of scale and scope or to externalities but to the division of labour itself: the *economies of complexity*. In general these economies are common in distributed systems, and particularly prominent in knowledge-intensive industries.

The third step towards the systemic paradigm is the creation of a theory that explains how technological knowledge – probably the most important factor of production in modern economies – is generated in relational space, and, in turn, how it shapes geographical space. Technological knowledge may be treated as a capital-like *substance*, i.e. 'cognitive capital', or as a *systemic process*. As a substance, technological knowledge in its relational dimension is similar to social capital. As a process, technological knowledge emerges in multiagent systems through mutualistic as well as competitive co-adaptation of reflective (i.e. boundedly rational, adaptive and possessing own cognitive schemata) economic agents. The process of co-adaptation essentially connects, aligns and 'systemises' technological knowledge that belongs to the 'intersubjective domain' of individual agents' schemata (i.e. economically relevant individual knowledge).

Mesoeconomic plexuses can be modelled as 'meta-agents' possessing collective schemata with open, evolving architecture. From this perspective, the above described process of co-adaptation is instrumental in shaping the collective schemata of the mesoeconomic plexuses, which in turn determine the techno-economic trajectories of the macro-economies. In this context, competitive co-adaptation plays a crucial role in shaping the techno-economic trajectory of the 'post-Fordist' knowledge economy: This is characterised by a rapid expansion of the technological frontier and Red Queen-type of dynamics, which erode technological rent and push firms to compete in terms of innovation just for survival and for preserving their market shares. It is also characterised by the transition from the *closed* to the *open* model of innovation. Under the former the whole knowledge production process is internalised within the firm and protected; firms benefit only from rapidly exhaustible internal economies of scale. Under the latter the knowledge production process is externalised, and firms benefit from non-exhaustible economies of complexity.[36] In this context, strategic alliances, joint ventures and other forms of inter-firm collaboration are becoming increasingly important for the survival of the firms, and so collaboration happily co-exists with competition contrary to the mainstream perception of competition as the (only) primum mobile of the capitalist economy. The tendency towards the open model of innovation favours the flexible open architecture of heterarchical, quasi-integrated, network-shaped, distributed systems, over the closed and hierarchical architecture of integrated systems, such as the traditional 'Fordist' corporations, especially in the production of technological knowledge. Distributed systems are capable of internalising knowledge spillovers and generating economies of complexity more than integrated systems. However, their comparative efficiency in generating technological knowledge depends on the type of knowledge in question: Integrated systems may still perform relatively well in handling knowledge with limited spillovers and high degree of appropriability. In the modern knowledge economy, however, the main volume of knowledge produced does not fall under this category.

Supported by modern telecommunication technologies, the division of labour, which the mesoeconomic plexus embodies, may extend in geographical space almost without physical barriers. The plexus is not, therefore, a territorially embedded entity, but a supra-local heterarchical network, which occasionally incorporates locally embedded clusters of economic activity wherever territorial proximity is necessitated by the type of economic interaction – a structure which resembles the 'small-world' networks presented in Chapter 3. Relational rather than territorial proximity is, therefore, the determining geographical characteristic of the mesoeconomic plexus.

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Notes

[1] As BARRO & SALA-I-MARTIN, 1995: 11, observe, "we end up with a model of growth that explains everything but long-run growth, an obviously unsatisfactory situation."
[2] Examples include UZAWA, 1965; LUCAS, 1988; ROMER, 1986; 1990; JONES, 1995a; AGHION & HOWITT, 1992.
[3] The Minkowskian space-time of special relativity is not a 'relative space', it is just a mathematical model of a physical space subject to the universal laws of classical (i.e. non-quantum) physics. Moreover, the typical relativistic phenomena, notably time dilation and Lorentz contraction, which characterise this space are perceivable when travelling close to the speed of light, and therefore are totally outside the scope of economic geography.
[4] Launhardt was a Hanoverian mathematician, whose work is considered as one of the earliest in mathematical economics [SCHUMPETER, 1954].
[5] The ratio of the weight of raw materials used in the manufacture of a product to the weight of the finished product.
[6] It should be noted that this has been an indispensable part of the Nazi state apparatus, which Christaller loyally served as a planner in Himmler's SS Planning and Soil Office, entrusted with the task of 'rationalising' spatial planning and reshaping and incorporating the annexed territories of the 'East' (Poland, Czechoslovakia and, as it was then envisaged, the USSR).
[7] To do justice to Krugman and his co-authors, a common characteristic in the collection of diverse models in FUJITA *et al.*, 1999, is the emphasis on adjustment dynamics, the existence of bifurcations in the dynamical systems describing agglomeration processes, and hence the possibility of multiple, unstable or punctuated equilibria, and phase transitions. Clearly, these characteristics are totally atypical of the neoclassical tradition, and in that respect the dynamic NEG models constitute a significant methodological (but not epistemological) departure from those of the static Walrasian general equilibrium.
[8] See MARTIN & SUNLEY, 1996, for a critique on this point.
[9] The presence of non-convexities in production, such as increasing returns to scale, makes even the *existence* of a Walrasian general equilibrium uncertain [ACKERMAN, 2002], and hence increasing returns is not a 'desirable' characteristic of 'well-behaved' economies. KALDOR, 1972: 1241, considers "the absence of increasing returns one of the basic axioms of the system" in the theory of general equilibrium.
[10] Aglietta, Boyer and Lipietz are prominent representatives of the Parisian School of 'Régulation'.
[11] Indicatively: SCOTT, 1988; STORPER & HARRISON, 1991; HARRISON *et al.*, 1996; SIMMIE & SENNETT, 1999.
[12] A CAS may or may not exhibit evolutionary dynamics (as defined in Chapter 1), and this ultimately depends on the internal structure of the lower-level adaptive agents, which may be much simpler and more 'primitive' than the minimum requirement for evolution to emerge. Conversely, a population in which evolutionary dynamics emerge may but need not be a CAS.
[13] Oddly, YEUNG, 2005, sees this turn as the enhancement with social actors and their network relations at different geographical scales of an earlier undercurrent of 'relational thought' in economic geography, as he puts it, mainly expressed by the 'social relations of production framework', which he inadequately criticises for "overemphasising the structural determination" of spatial phenomena on the basis of class and division of labour. This misplaced critique seems to miss the point that the 'social relations of production framework' is in fact the centrepiece of Marxist political economy, whose fundamental ontology is social class, and whose epistemological and methodological foundations are, from a taxonomical perspective, totally unrelated to those of 'relational economic geography', by any tenable definition of the latter.
[14] BOGGS & RANTISI, 2003: 110, wrongly, in the author's opinion, claim the exact opposite, namely that "the relational turn enters the structure-agency debate by ascribing a greater role to agency as opposed to structures in analyses of economic behaviour". They

confusingly misidentify 'structure' as the immutable, teleological regularities allegedly found in a large number of heterogeneous theories, from Marxist political economy to neoclassical economics, naïvely subsumed under the banner of 'models sharing a teleological bent', which they then unjustifiably and vaguely criticise for neglecting "the range of socio-political constellations with which economic forces engage and by which varied outcomes develop".

[15] Here a clarification is needed: I do not claim that the physical space *per se* does not have innate properties, I only argue that the physical space *of economic geography* should not be thought of as having innate properties other than those conferred to it by the economic entities and processes it contains. A similar view is expressed in BATHELT & GLÜCKLER, 2003.

[16] Labour pooling and market size effects are, as clearly shown in NEG models, the results of cumulative causation, and hence self-reinforcing 'endogenous' processes; still, they are externalities, by-products of the economic activity, and hence elements of the socio-economic environment.

[17] These roughly correspond to what Alfred Marshall called an 'industrial atmosphere' that was supposed to be present in the English industrial districts of Lancashire and Yorkshire, which he extensively studied.

[18] The usual entry barriers are *product differentiation* and *economies of scope*, *absolute cost advantages*, and *economies of scale*.

[19] Many concepts used in this subsection are drawn from the theory developed by WILLIAMSON, 1979; 1985; 2005 (which in turn has built on earlier work by COMMONS, 1936 and COASE, 1937). His approach is known as 'transaction costs economics', and in his more recent work as 'economics of governance'. The 'governance structure', according to him, depends on the frequency of transactions, uncertainty and the specificity of the assets involved. A 'hybrid governance structure' is one based on contractual arrangements.

[20] *Quasi-rent* value of an asset is defined as "the excess of its value over its salvage value, that is, its value in its next best use to another renter" [KLEIN *et al.*, 1978: 298].

[21] See MARTIN & SUNLEY, 2006 for a critical view on this topic.

[22] Throughout this book the term 'economies of complexity' is used interchangeably with 'increasing returns to complexity', in analogy to the commonly in economic literature interchangeable use of 'economies of scale' and 'increasing returns to scale'. Nevertheless, the author is aware of the subtle difference between the two terms, the former referring to cost savings due to increases in the scale of production, while the latter to output increases and hence productivity gains due to unspecified, usually exogenous, 'technological improvements' in relation to a (neoclassical) production function, ceteris paribus (see for instance, BELL, 1988, for a detailed account on the issue). Outside the neoclassical framework the distinction between the two terms is less meaningful, as 'technological improvements' can be identified, endogenised and thus associated with the scale of the factors of production.

[23] MAR-type externalities are dynamic localisation economies caused by intra-industry, vertical knowledge spillovers within the same value chain, while Jacobs-type externalities are dynamic urbanisation economies caused by inter-industry, horizontal knowledge spillovers between parallel value chains. Both types of externalities are induced by the collocation of economic agents in a specific locality.

[24] Universal, theoretical or generic knowledge is mostly non-contextual; instrumental, practical or applied knowledge is mostly contextual.

[25] I use the term 'quasi-private' to denote a good that in principle is rival and excludable, but with spillovers that in the longer run erode its excludability, and consequently, its private nature. In existing literature this term is sometimes used differently, to denote private goods provided by the government. 'Quasi-public' are publicly provided and socially beneficial goods, which however are neither fully non-rival nor non-excludable.

[26] See DAVIDOW & MALONE, 1992; MILES & SNOW, 1992; SANCHEZ & MAHONEY, 1996; JONES *et al.*, 1997.

[27] 'Know-what', 'know-why', 'know-how' and 'know-who', according to LUNDVALL & JOHNSON, 1994.

[28] This is similar to the network-analytical concept of *clustering* (see Chapter 3, Appendix 1, for a definition).
[29] See Chapter 3, Appendix 1, for a formal network-analytical definition of the term.
[30] In a different epistemological context, Kant first introduced the notion of *schema* in his *Kritik der reinen Vernunft*. This notion was later introduced in psychology by BARTLETT, 1932, and later used in a structuralist context by PIAGET, 1970; 1971. Modern cognitive theory is mainly based on Piaget's theory of cognitive development, and has also received strong influence from Gestalt psychology, Chomskyan linguistics and Broadbent's information processing model.
[31] FLAKE, 2000, gives the following definition for genetic algorithms (GA): "A method of simulating the action of evolution within a computer. A population of fixed-length strings is evolved with a GA by employing crossover and mutation operators along with a fitness function that determines how likely individuals are to reproduce. GAs perform a type of search in a fitness landscape." A simple genetic algorithm combining crossover with mutation is given by Holland's 'schema theorem' [HOLLAND, 1996].
[32] This term is originally found in HOLLAND, 1996: 11, without the distinction between resultant and emergent entities.
[33] The term 'distributed cognition' was introduced by HUTCHINS & NORMAN, 1988. A pioneer of the distributed cognition paradigm was VYGOTSKY, 1978, followed by MINSKY, 1985. The *distributed processing model* is directly related to *parallel distributed processing* and to *connectionism*, the strand of cognitive science that treats cognitive processes as emergent phenomena of *neural networks*. A standard reference in parallel distributed processing is MCCLELLAND & RUMELHART, 1988.
[34] In algebraic topology *isomorphism* is a bijective morphism. In non-technical terms, this means that "two complex structures can be mapped onto each other, in such a way that to each part of one structure there is a corresponding part in the other structure, where 'corresponding' means that the two parts play similar roles in their respective structures" [HOFSTADTER, 1979: 49].
[35] JONES, 1995a proposes alternative, data-consistent model specifications, which offset the R&D scale effects of the ROMER, 1990 model by assuming 'diminishing technological opportunities'. In these quasi-endogenous models the steady-state growth rate of the knowledge stock is proportional to the population growth rate.
[36] Non-exhaustible because the open model favours the recombination of existing knowledge, the re-utilisation and marketisation of unused inventions, the involvement of exponentially more actors in the innovation process (including SMEs and academia), a better matching of research skills with problems, distributed cognition, etc.