WHEN COMPETITION MAY HINDER TECHNOLOGY DIFFUSION: THE CASE OF INTERNET ACCESS SERVICES IN BRAZIL

Marcelo de Carvalho Pereira
Doutorando
Instituto de Economia da Universidade Estadual de Campinas

Abstract

This paper analyzes the differentiated profile of access technologies diffusion in the Brazilian internet sector, through the application of History-friendly agent-based simulation methodology. The focus of analysis is the diffusion of new technologies – embedded in the telecommunication equipment employed by internet access providers to build their service networks – and the relationship between diffusion and interfirm competitive dynamics. Empirical evidence seems not adequately explained by the usual theoretical approaches, like Industrial Organization or Evolutionary Economics, once institutional characteristics appear to be relevant. We propose that the integration of a dual, co-evolutionary theoretical perspective will allow the proper handling of stylized facts stemming from empirical data. Our hypothesis is that specific features of the institutional environment in the internet sector were determinant for the observed diffusion dynamics of access technology, leading to somewhat unexpected outcomes. A modeling solution using computer simulation is presented, in order to support the analysis of the internet access market, formed by heterogeneous providers interacting in complex patterns. Model results show that the proposed approach is compatible with stylized facts, exposing the critical role of institutional mechanisms in this case.

Keywords: technology diffusion, competition, agent-based simulation, institutional economics, internet access, Brazil

JEL classification: L19, B52, C63, L86

Resumo

Este trabalho analisa o padrão diferenciado da difusão das tecnologias de acesso no setor de internet brasileiro, por meio da aplicação da metodologia History-friendly de simulação *agent-based*. O foco de análise é a difusão de novas tecnologias – incorporadas nos equipamentos de telecomunicação utilizados pelos provedores de acesso à internet para construir suas redes de serviço – e a relação entre a difusão e dinâmica competitiva interfirma. A evidência empírica setorial não parece ser adequadamente explicada pelas abordagens teóricas habituais, como a organização industrial ou a economia evolucionária, uma vez que as características institucionais parecem ser relevantes. Propomos que uma perspectiva teórica coevolucionária permitirá o tratamento mais adequado dos fatos estilizados provenientes dos dados empíricos. Nossa hipótese é que características específicas do ambiente institucional do setor de internet foram determinantes para a dinâmica observada da difusão das tecnologias de acesso, proporcionando resultados de certo modo não esperados. É apresentada uma solução de modelagem utilizando simulação em computador, a fim de permitir a análise do mercado de acesso de internet, composto por provedores heterogêneos interagindo em padrões complexos. Os resultados do modelo apontam que a abordagem proposta é compatível com os fatos estilizados, expondo o papel fundamental dos mecanismos institucionais neste caso.

Palavras-chave: difusão tecnológica, concorrência, simulação *agent-based*, economia institucional, acesso internet, Brasil

Área ANPEC: Economia Industrial e da Tecnologia

When competition may hinder technology diffusion: the case of internet access services in Brazil

Marcelo C. Pereira

1. Introduction

The internet sector is one key element of what some authors call the transition to the "information economy". The sector was originated from the revolution of the information and communication technologies (ICT) in the 1980s. The telecommunications industry, a key component of the internet sector[1] from its inception, became an even stronger driver of innovation from the 1990s, after the privatization, deregulation, and competition introduction processes occurred in most countries. In this scenario, superficial analysis would envisage the resulting internet access services market[2] (IASM) operating under strong competition and fast technology diffusion, due to the promising association of low barriers to entry, rapidly growing demand, and significant technological opportunities. However, in countries like Brazil, the IASM seems better described by comparatively slow technical diffusion and moderate competition. Indeed, diffusion has become significantly slower over newer technology generations. At the same time, market concentration increased to very high levels. The apparent contradiction between the fast pace of technological advance and its slow diffusion in a potentially competitive market is our central question.

Empirical research suggests that adequate answers for this question require a somewhat deeper than usual analytical approach, as usual methods like standard industrial organization could provide only partial answers at best. We advocate that one critical reason for the observed outcomes is the importance of institutional phenomena for the dynamics of innovation diffusion. Furthermore, empirical evidence points also to the importance of fast evolving technology in the shaping of the internet sector as a whole. In principle, this would suggest a neo-Schumpeterian evolutionary approach as appropriate to justify sectoral competition as the main driver of innovation diffusion. Most of the technological innovation in the IASM is embedded in capital equipment developed by a few large multinationals and made available to domestic internet access service provider (IASP) firms operating in markets all over the world. Nonetheless, the competitive configuration of the IASM seems to be country specific, notwithstanding the broad technology availability. This advises that innovation dynamics, despite significant, may have limited potential to explain the large asymmetries experienced in new technology diffusion among different national IASMs.

Our key analytical hypothesis, to supplement an innovation-driven evolutionary approach, is that observed country-specific differences are to a large extent due to the relatively heterogeneous institutional frameworks. An institutional perspective seems to articulate well with an evolutionary approach, given the potential complementarity between them as indicated by the literature. An institutional line of inquiry allows for the improved consideration of intra-sector interactions and the role of relevant social factors, like culture, shared cognitive frameworks, social networks, power and the state. Nevertheless, as evoked by Dosi *et al.* (2005), this articulation is not without risks. On the one hand, if it avoids an innocent perspective of technological determinism, often attributed to Schumpeterian reasoning, on the other hand, it opens space for a radical form of social constructivism where agency and strategic questions are undervalued.

With those issues in mind, we propose modeling both the institutional and evolutionary mechanisms, supposed to be in action in the IASM, by adopting agent-based simulation techniques to investigate the complex processes that organize diffusion and competition. Obviously, the main task of the model is to test how well our institutional dominance hypothesis holds. From a methodological standpoint, we embrace the History-friendly approach, proposed by Malerba *et al.* (1999), as general guidance. On the empirical side, we selected data from Brazil to set up the model. We believe Brazil is a compelling case to start with because of the reasonably complex institutional scenario and the availability of detailed data. From there, it should be straightforward to reconfigure the model to handle conditions applicable to other countries.

[1] Segments of the internet sector include: access services, equipment manufacturing, systems development and content provision.
[2] Internet access services provide bi-directional transport of information (data, sound and images) on top of the physical network infrastructure owned by service providers, between the end-user location and the final destination service or person, within the worldwide internet.

Diffusion and competition are broad themes, so it is necessary to define our targets clearly. This paper represents only a first step of research, presenting the initial results produced by a model designed to answer different questions about the IASM. Further refinement and detailing of the analysis is definitely necessary. Here, we propose focusing on the general processes driving firms' decisions in terms of technology adoption and the resulting market organization. Under a somewhat restricted approach, innovation diffusion is measured as the time from availability to adoption and its dispersion among IASPs. Market organization is evaluated in terms of market share concentration evolution and IASP entry/exit dynamics.

The paper is organized as follow. Next section presents the literature supporting the theoretical framework employed. Section 3 offers an appreciative empirical analysis of the IASM in Brazil, providing an overview of the key stylized facts identified. Section 4 presents some key specifications of the simulation model. In section 5, the main model results are analyzed and brief explanations for the stylized facts are proposed, based on the model's internal mechanisms. The paper closes with a review of the main conclusions.

2. Background literature

It is widely accepted that diffusion of technical innovation is an essential factor to economic development and social change (Pavitt 1984). A growing literature on the relevance of innovation and its diffusion was stimulated by Arrow's 1962 seminal article. There, he discusses the imperfect allocation nature of innovative knowledge and the tendency to its diffusion over time given some "hard" limits to appropriability. In this perspective, technology is a sort of imperfect information that is generated when a prearranged set of notional opportunities, exogenously produced (e. g., by scientific discovery), are explored according to a particular incentive structure by somewhat heterogeneous agents (Dosi 1991). Theoretical models of diffusion, such as Arrow's, often embrace an equilibrium approach assuming the existence of a long term steady-state configuration for technology adoption. Thus, the diffusion patterns reflect a sequence of shifting equilibria. The steady-state equilibrium justification may be originated from observed empirical regularities or due to micro optimizing behavior of fully rational agents under imperfect information (*ibid.*). Diffusion timing is then mainly dependent on the level of heterogeneity of agents' information as well on the relative costs attached to technological alternatives (Metcalfe 1988). While most equilibrium approaches modeled innovation as driven by exogenous events, approaches like endogenous growth theory (Aghion and Howitt 1998) offered frameworks for endogenous treatment of general technological change, still in an equilibrium framework.

Notwithstanding some relevant insights, equilibrium approaches have important shortcomings when handling complex dynamics processes like innovation diffusion as pointed by several authors (Nelson and Winter 1982, Dosi 1982, Arthur 1988, Kirman 1997, Metcalfe 1998, Pyka and Fagiolo 2005). This is particularly critical when one has to handle innovation diffusion as a process that may lead to structural economic change – and not only incremental improvements. In this case, the adoption of out-of-equilibrium approaches is suggested as more adequate representation of diffusion processes (Metcalfe 1988). A disequilibrium perspective usually assumes endogenous innovation sources as more relevant, without discarding the possibility of exogenous influence, bringing the analytical focus to the mechanisms driving innovation. In such perspective, competition between firms is usually considered one of the key sources of the innovative behavior of agents (*ibid.*).

Based on Schumpeter's (1943) *creative destruction* perspective of capitalist interfirm competition, Nelson and Winter (1982) proposed evolutionary theory as an alternative to explain competition by means of out-of-equilibrium analysis. In an evolutionary perspective competition is not directly related to static efficiency because of innovation – technical or organizational – and its diffusion. Innovation relentlessly changes the competitive environment by dynamically redefining the relative advantages hold by competing firms (Dosi and Nelson 2010). By its own nature, evolutionary processes – including innovation diffusion – are open-ended, being not entirely random nor utterly predetermined (Loasby 1999). Evolutionary theory is particularly adequate to explain sectors driven by the technological innovation dynamics and where the interaction of the agents beyond pure market transactions is relevant (Malerba 2006).

When Schumpeterian competition takes place, market organization becomes endogenous (Nelson and Winter 1982) presenting itself as an emergent property of the differential innovation capabilities among firms (Metcalfe 1998). Competing firms have different capabilities on top of what they try to adapt continuously to the competitive scenario by innovating (Teece *et al.* 1997). Innovation creation and diffusion take place on top of processes of variation generation of firms and selection by the market of the fitter ones (Metcalfe 1998). Successful innovators grow and eventually increase their profits; others shrink and may get out of the market. In this scenario, fitness represent the set of capabilities (skills) that *bounded rational*[3] firms have to solve the specific problems – technical, organizational or political – they face in the competitive selection process (Cyert and March 1963, Nelson 1995). Heterogeneous innovation capabilities represent contradictory forces leading, at the same time, to oligopolistic markets and to turbulent competitive dynamics. The sector-specific balance between both is determinant to industry organization (Dosi 1982).

However, the coexistence of markets under highly distinct competitive and innovative profiles within the same sector, as in the case of the internet, is not straightforward to grasp from a pure evolutionary analytical standpoint. Considering that components of a sector usually share a technological regime[4] (Malerba and Orsenigo 2000), as it seems to be the case, some broad similarities would be expected. This is suggested by the typologies proposed by Schumpeter (1942), Pavitt (1984), Breschi *et al.* (2000), or Klepper (2006). For example, in sectors where technological opportunities are high and appropriability is low, like the internet, the archetypical features expected are frequent technological innovation, fast innovation diffusion, high turbulence (intense entry and exit), and constant erosion of incumbents' market shares. Despite this being a reasonable description of most segments in the internet sector (e.g., equipment, software, content), it may not be applicable to the access market in all situations as discussed in next section. Further theoretical refinement seems to be necessary in this particular case.

The application of concepts derived from institutional theory, in particular the approach proposed by the organizational studies (DiMaggio and Powell 1983), seem adequate to clarify some points not addressed by evolutionary theory. Under this approach, institutions have a role in the economy beyond the usual normative and regulatory functions; a *cultural-cognitive* instance is also essential to fully understand the effect of institutions on economic behavior (DiMaggio 1988, Powell 1991). Cognitive structures shared among actors are also institutions because they generally condition – and sometimes strictly constrain – the behavioral alternatives available to agents (Scott 2008). Institutionalization, in such context, is the process where patterns of behavior or thought become shared by actors (Jepperson 1991, Dequech 2009). In addition to the instrumental and formal institutions considered by new institutional economics (North 1990, Williamson 2000), the organizational studies approach grants analytical emphasis to the roles of culture, cognition and social interaction in producing informal, *taken-for-granted* types of institutions (DiMaggio 1988, Thornton and Ocasio 2008). Because cultural-cognitive elements are based on preconscious, taken-for-granted premises, they constitute the deeper level of the institutional framework (Beckert 1999) and so cannot be understood simply as an instrumental tool created by agents (Battilana *et al.* 2009) as usually presumed by new institutional economics.

Consequently, all three elements – regulatory, normative and cultural-cognitive – are essential constitutive blocks of institutions (Scott 2008) and their alignment is critical to institutional persistence (Tolbert and Zucker 1996). When misaligned, these elements represent a resource to agents willing to change the institutional framework for its own purposes, in what is frequently called *institutional entrepreneurship* (DiMaggio 1988, Garud and Karnøe 2001). Culture and mental models provide the cognitive elements required by agents to provide sense to the actions of other individuals with whom they interact (DiMaggio and Powell 1983) as well to perceive the prevailing institutions and their changes (Denzau and North 1994, Dobbin 2004). As a result, agents adopt shared mental models to structure their action and interaction besides taking into account their own objectives. The existence of taken-for-granted institutions is not entirely disconnected from purposeful action (DiMaggio and Powell 1983).

[3] Bounded rationality is a residual category proposed by Simon (1979), characterized by any form of rationality inferior to omniscience, or substantive rationality, due to cognitive limitations of individuals under a strong form of uncertainty.

[4] As defined by the relevant technological features, like the available opportunities, the appropriability conditions, the knowledge cumulativeness profile and the nature of the knowledge base (Pereira 2012).

A common cultural-cognitive context is required to enable interaction within a *field*[5], thus associating an institutional framework with the context of the social interactions in that field (Bourdieu 1972). Fields – of which markets are a particular type – are made of specific social networks and such networks generate differentiated power positions to be fulfilled by agents (Hardy and Maguire 2008, Beckert 2010). This implies the consideration of power relations in the establishment of cognitive structures that are the foundation of taken-for-granted institutions (Dobbin 2004). As a consequence, it is expected that different social network arrangements produce distinct field organizations and institutions (Fligstein 2001b). Institutional dynamics is a complex phenomenon, depending on several mechanisms, where the survival of agents and the reduction of social uncertainty are some of the most prevalent (DiMaggio and Powell 1983, DiMaggio 1988). However, general and social mechanisms are not the only ones involved. Institutions are also the result of individuals acting socially in their creation, reproduction, or change (Dequech 2006) given that distinct cognitive representations among actors stimulate institutional innovation processes (Dequech 2009). Particular interests and purposeful agency leverage remain key drivers of institutional dynamics, despite inherently conflictive (Battilana *et al.* 2009).

New institutions depend on agents with adequate social skills. They are able to introduce new ideas and meanings in their networks of influence and induce cooperation and accommodation between potentially competing groups (Fligstein 2001b). Ideas – mental schemes or premises – are powerful tools to the institutionalization process because they provide actors with cognitive frames that justify and legitimate action (Scott 2008). Institutionalization and legitimation are critical steps of institutions development, allowing their gradual transition from conscious habituation to cultural objectification, when social consensus is achieved once institutions become taken-for-granted (Tolbert and Zucker 1996). However, this development is not automatic; conflicts, contradictions, and ambiguities are intrinsic to the process (DiMaggio and Powell 1991). Failure in conciliating interests or identities may block institutional consolidation or accelerate its decline (Fligstein 2001b); there is no structural "guarantee" of institutional permanence (Storper and Salais 1997). Despite their more frequent restraining role, under certain conditions institutions may become enablers of skilled challengers to the existing institutional order (DiMaggio 1988, Hwang and Powell 2005). In a perspective of intrinsically "unstable" institutions relying on social networks, powerful actors depend on institutional stabilization to keep their power (Thornton and Ocasio 2008). Consequently, incumbents have a common interest to minimize institutional entrepreneurship coming from challengers (Fligstein 1997, Hardy and Maguire 2008). Formal or tacit agreements between capable incumbents are a strong form of collective action to allow for a stable order under their control. Thus, stabilization and reproduction of fields – and markets – are crucially dependent on the social skills of such players (Giddens 1984, Powell 1991).

Market interactions rely on – and are part of – the existing structure of social relations, expressed by Granovetter (1985) as the *embeddedness of markets*. Markets are themselves institutions, as shared sets of rules and mental and behavioral practices that make recurring transactions possible (Fligstein and Dauter 2007, Hodgson 2008). Accordingly, the market as a field includes all organizations that take part of it in some way, including firms, competitors and suppliers, users and the state (DiMaggio and Powell 1983). Economic processes are simultaneously "constrained and carried by networks defined by recurring patterns of interaction among agents" (Arthur *et al.* 1997:6). By "absorbing" individual agents, "social networks are the carriers of new economic practices and new ideas of what it means to be rational and efficient" (Dobbin 2004:5). They relativize the role of agency in its stronger forms and create framework for diffusion of knowledge and innovation. When markets are analyzed as organizational fields (Bourdieu 1972), it becomes also evident that hierarchical networks may foster specific taken-for-granted market institutions, usually aligned with the interests of incumbents (Fligstein 2001a). Therefore, field theory helps us to understand how heterogeneity, conflicts and strategic actions of agents may be reconciled with stable markets as more frequently observed in practice (Powell 1991, Fligstein 1997).

Market development is in part a product of historically created institutional and political arrangements (North 1990, Storper and Salais 1997). The appearance of formal and informal governance structures, that regulate cooperation and competition in a sector, is the outcome of active institutional entre-

[5] Institutions promote conformity of – or cooperation between – agents not only through sanctions or incentives, but mainly because different forms of behavior are not conceivable to the actors as routines become implicitly assumed as "the way we do these things" (Scott 2008:58).

preneurship during its emergence or transformation (Coriat and Weinstein 2005). In this perspective, the neoclassical pure price competition mechanism becomes representative of the failure of the governance construction process, where the absence of coordination among agents turns aggressive price competition the *de facto* mode of governance (Powell 1991). On the other hand, successful governance institutionalization may help reducing price aggressiveness of firms and easing market stabilization (Fligstein 2001a). The key aspect of governance institutionalization is the emergence of an informal and gradually taken-for-granted *conception of control*, borrowing the expression proposed by Fligstein. A conception of control is a shared cognitive framework of "how things work" established among the players in the market, allowing them to mutually understand the meaning of the strategic moves of others – and direct their own. As any institutionalization process, the creation of a conception of control is a competitive and conflictive interaction between agents, occurring in the historic time, where the network hierarchy comprised in the field is fundamental (Tordjman 2004).

Finally, an institutional perspective allows for a better understanding of the role of the state in the sectoral processes. Particularly when one considers the possibility that, under certain conditions, the state-promoted institutional arrangement may (unintendedly) reduce competition, even when formal governmental action goals are in the opposing direction. This seems to be the case in the internet access market as presented later. The critical influence of the state on institutional development of markets is probably out of question (Nelson 2005a, Greif 2006). First, because the enabling institutional infrastructure provided by the state usually cannot be provided adequately by private means (Fligstein 2001a). Second, for the action of the state being in general non-neutral, agents compete for the definition of government policies that are more convenient to them (Hwang and Powell 2005). Modern markets are decidedly different among them, requiring different levels of state intervention and distinct capabilities from governmental agents to do so (Nelson 2005a). However, to acquire such capabilities these agents have to internalize the ruling conceptions of control to some extent. As parts of a complex field, internalization is essential to enable these agents to interact in the market where they are trying to intervene. Yet, doing so they risk getting "captured" by the taken-for-granted sectoral cognitive framework and being inadvertently influenced by the power structure embedded in it (Fligstein 2001a).

In summary, the proposed theoretical framework for sectoral analysis is based on the premise of a dual dynamics, where technological and institutional vectors simultaneously drive market organization and technology diffusion[6]. Both vectors have evolutionary nature, in the sense they involve trials, errors and learning along path dependent trajectories in historic time (Nelson and Winter 1982, Storper and Salais 1997). When new technologies are introduced, the higher productivity prospect represents a major impulse in the techno-economic dimension towards acceptance and adoption. However, other mechanisms operating in the socio-institutional dimension may need more time before accepting the required social, organizational or institutional changes, delaying adoption and slowing diffusion (Castellaci *et al.* 2005). Therefore, the coevolutionary approach is suggested by authors from both traditions (Hodgson 1988, Nelson and Sampat 2001, Fligstein and Dauter 2007, Scott 2008) as a more comprehensive analytical perspective in certain scenarios.

The adoption of simulation models, as analytical devices, is a feature of evolutionary theory from its inception (Nelson and Winter 1982, Garavaglia 2010). On the other hand, simulation usage is less frequent in institutional studies, despite several recent advances (Arthur 2000). Complex economic systems are usually better modeled by agent-based simulation, notwithstanding the incipient methodological standardization in comparison to other alternatives (see Metcalfe and Foster 2004, Arthur 2005, Tesfatsion 2006). The complexity perspective, which theoretically backs agent-based modeling as a formal analytical tool, privileges the inquiry on the "meso"-level phenomena essential to represent the heterogeneous networks of social relationships that are present on real markets (Potts 2000, Colander 2005). This perspective provides superior insights on emergent events generated by the dynamic configuration of network connections, under the strategic action of agents and the institutional environment they are immersed (Holland 1988). The History-friendly modeling methodology proposed here represents the second

[6] This is not a new proposition. Some early evolutionary authors had already explicitly considered both evolutionary dimensions – techno-economic and socio-institutional – when analyzing capitalism in broader terms (Perez 1983), despite several recent authors don't.

generation of evolutionary agent-based simulation models. It is focused on the study of specific industrial sectors and their time trajectories, at a more limited level of generality (Pyka and Fagiolo 2005).

3. Empirical analysis[7]

Borrowing the fortunate concept of Breschi and Malerba (1997), we suggest that a *sectoral system of innovation and production* perspective of the internet is an adequate approach to the sectoral appreciative analysis (Edquist 2004). Analysis should then focus on the system formed around a given group of close products, in our case the internet access services. Empirical investigation shall try to explore the relationships and interactions among agents (supply and demand), knowledge (including technologies) and institutions materializing the system (Malerba 2005).

Internet revolutionary technologies and innovations created a new economic sector based on the convergence of the knowledge bases and capabilities originated from several sectors, like telecommunications, information technology and media (Corrocher 2001). One prominent characteristic of the internet are its governance organizations. Derived from innovative institutional entrepreneurship, internet's regulation and standardization bodies are powerful, mostly non-governmental and open to the majority of the sectoral actors (Mowery and Simcoe 2002). These organizations were crucial to the required coordination of agents, in a complex and uncertain technological environment, leading to the construction of highly sophisticated knowledge and production networks (Kavassalis *et al.* 1996). Because of this unique institutional setup, to a large extent technical innovation and diffusion processes in the sector took a collective prospect that defined key properties of its knowledge base (Cerf *et al.* 2000). Despite the enormous cumulativeness of the knowledge base required to implement the physical internet and the services around it, the collective dimension of its construction, associated with mostly explicit (non-tacit) standardization, resulted in relative low levels of appropriability (Greenstein 2010). This potent mechanics offered vast technological opportunities for an unusual large number of competing agents. In summary, both collaboration and competition processes were key factors to the fast development of the internet and its supporting technologies (Corrocher 2001).

Simultaneously with internet development, the telecommunications sector went through a significant change process during the 1990s. State owned monopolies all over the world were swiftly privatized, frequently at the same time when competition was introduced in those markets (Edquist 2004). Considering the huge growth required in data communications volumes, telecom operators' legacy physical networks naturally became the most important fabric of the internet at least in its early stages (Dalum and Villumsen 2003). Remarkably, physical networks were not the only legacy from the telecom sector to the internet. Taking advantage of their early hold of essential components of the new sectoral system, privatized telecom operators typically leveraged their position in the florescent IASM (Davies 1996) obtaining significant competitive advantage during the critical market formation period (Edquist 2004). This particular scenario is markedly different from the experience of other segments in the internet sector, like hardware, software or content, where many prominent firms were relatively young, originated inside or around these segments. Here, in principle competition is strong and compatible with the usual evolutionary taxonomies (Pavitt 1984, Breschi *et al.* 2000, Klepper 1996). Older incumbent firms on the IT or media sectors usually have a comparatively modest participation in their counterpart markets in the internet sector, entry/exit turbulence is high and technical diffusion is very fast. This configuration is markedly dissimilar from the IASM situation in several countries, but not all (for a comparison in the OECD countries, see Wallstem 2007). When present, IASM market concentration has some distinctive characteristics from the situation prevailing during old-time telephony monopolies. Owing to the mostly nonproprietary and non-tacit nature of internet knowledge base and technologies, based on the strong standardization efforts of its governance organizations (Funk 2009), interconnection among competing physical networks are almost universal and costless[8]. Consequently, the significant network externalities offered by the internet as a whole do not provide larger IASPs with relevant competitive advantages in most situations[9].

[7] For details on all empirical data presented in this section, and the respective sources, see Pereira 2012.

[8] At least among same tier IASPs, but anecdotal evidence is that, even for smaller players, interconnection costs are not significant barriers for domestic competition in most countries.

[9] To the majority of users it is irrelevant if accessing the internet from a large or small IASP, assuming both adopt the same technical quality parameters, once all networks are interconnected.

Thus, differently from the *natural monopoly* case of telephony (Shy 2001), it is in principle possible to entrant IASPs to challenge incumbent operators successfully (Noam 1994), as demonstrated by relevant examples in many countries[10].

Regardless of the competition enablers available, internet access services became a highly concentrated business in Brazil. The 4 incumbent IASPs, originated from the privatization of the telecommunications monopoly, dominate almost 80% of the national IASM. If we exclude dial-up services (technically obsolete), their joint market share goes over 90%. All the usual indicators (HHI > 0.25, C4 > 0.85) point to high market concentration at the national level, in a scenario of market share stability and limited competition among the incumbents, which historically focused in different geographical regions. When analyzed at the state level[11], concentration is even higher: the local privatized incumbent IASP alone holds in average 60% of market share. Despite the formally open market and the 1900+ small firms providing internet access services in Brazil (as of March 2011), only one new company successfully managed to enter the IASM and became a significant player (see note 10). The impact of the IASM organization on prices is evident. Minimum access prices are 32% higher than the OECD average. The 2011 ITU price ranking shows Brazilian fixed broadband in position 56 among 165 countries (higher ranks represent more expensive services), above most OECD countries. Mobile broadband took the top position (most expensive) among the 21 countries considered. In a similar survey, done by UNCTAD in 2010, mobile broadband prices in Brazil also got the least affordable place among 78 countries. On the other hand, Akamai (2012) quality survey classified the country's access services in position 40 among 187 countries in 2011, below all OECD members. Nevertheless, price markups on internet access services were kept by incumbents at a relatively stable level, consistently above 50%. Incumbents' financial statements seem to indicate that capital restrictions should not be a major constraint for new technology adoption or to prevent fast diffusion when new investment is necessary.

The exponential rise in data volumes transported by the internet over time placed in evidence the question of diffusion of new data communication technologies[12]. Diffusion pace became crucial to the continued and accelerated growth of the internet, both in terms of supporting new users and enabling innovative applications. There were at least three milestones in access services technological trajectories, all of them representing an important break with prior technologies. *Dial-up* access was the initial "narrowband" technology available to most internet users during the 1990s. Based on a direct overlay usage of the existing telephony network, its implementation was painless and to a large extent not dependent on telecom operators collaboration. Not surprisingly, this was the most competitive phase of the IASM in many countries[13]. *Fixed broadband* was the second mainstream technological step, introduced in the late 1990s over telephony (xDSL) or cable TV (DOCSIS) wireline networks. Contrary to dial-up, fixed broadband technologies where specifically designed to take advantage of incumbents' network physical infrastructure, making their offer hard to be replicated by entrants without explicit support from legacy telecom operators or the state[14]. *Mobile broadband* is the latest form of internet access. It is based on government-allocated radio spectrum to provide wireless cellular services over two mainstream overlapping technologies: 3G/UMTS and 4G/LTE. Notwithstanding existing infrastructure and user base provide an edge to incumbent telecom operators, wireless technologies open more competitive opportunities for entrants. There are other niche access technologies available, like satellite and fiber optics, but they have relatively small penetration in most countries.

In most OECD countries, each consecutive technological generation – or network equipment vintage – has diffused in decreasing timeframes. While dial-up access took 5 years from the launch of the first technical solutions to the beginning of massive adoption, fixed broadband poured out in less than 4 years and mobile broadband took between 3 (3G) to 2 (4G) years to achieve mainstream market penetration. On the other hand, in Brazil the same process has taken the opposite direction. From 5 years for dial-

[10] Even in the very concentrated Brazilian access market, one aggressive challenger (GVT) succeeded in entering the access market, acquiring more than 6% national market share in less than 5 years. However, it was a unique case.
[11] Brazil is divided in 26 states plus the federal capital district.
[12] Telecom physical infrastructure for data communications rapidly evolved, from metallic wireline and microwave radio to satellite, fiber optics and wireless cellular systems.
[13] In Brazil by 1998, the largest IASPs had around 10% market share, while the top 10 firms controlled less than 50% of the access market.
[14] Usage of incumbent's networks by entrants requires any kind of *unbundling*, usually mandated by some form of state regulation.

up diffusion, it took 6 years for fixed broadband and 8 years for 3G mobile broadband (no 4G yet) to get to the mainstream. Figure 1 presents this remarkable inverted lag configuration. As mentioned before, new access technologies are embedded in new network equipment and terminals, developed and sold by a few large competitive multinational firms, in a "supplier dominated" configuration in Pavitt's (1984) terms. Hence, new technology availability is relatively universal to both large and small IASPs. However, new technology diffusion is critically connected to domestic IASPs decisions, associated with the availability of some required complementary assets, like government-granted radio spectrum or access to existing infrastructure. It should be noted that minimum deployment sizes or scale constraints usually does not apply in our case; the Brazilian IASM is at least comparable in size, if not larger, to markets where diffusion advanced much faster (the benchmark countries). Neither special requirements in terms of absorptive capacities seem to play a critical role here, as indicate the frequent launches of the newest technologies all over the world by large and small players indistinctly.

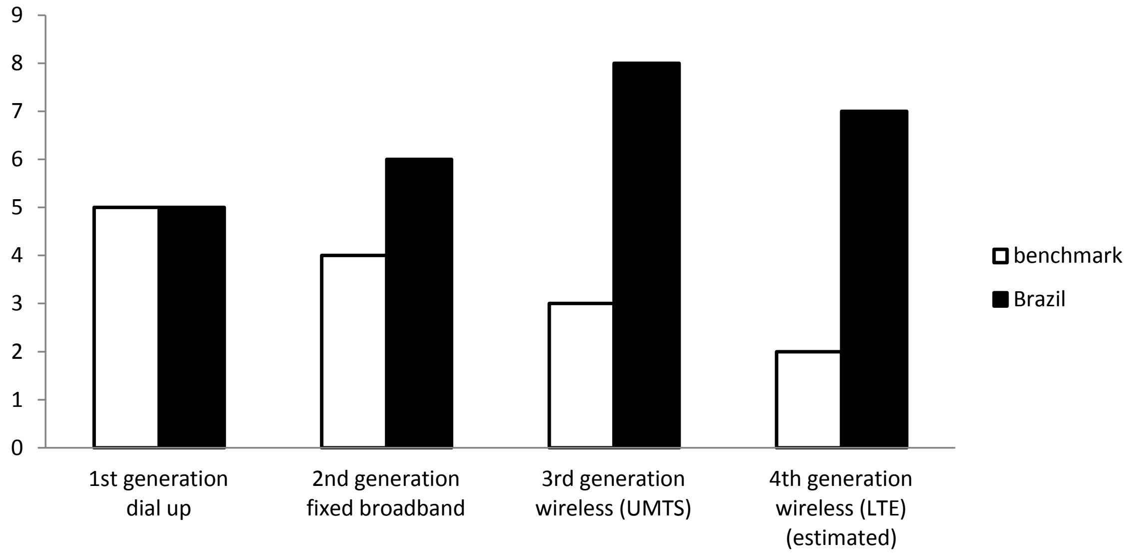

Figure 1 – Initial diffusion periods of new access technologies en Brazil and selected benchmark countries (in years between technology introduction and initial mass deployment).
SOURCE: Pereira 2012.

Anecdotal evidence shows that the particular diffusion pattern observed in Brazil was not fortuitous. Nor it is the almost complete synchronization of new technologies launch among incumbents. Intense action by the incumbents was targeted on the regulatory agency to postpone the issue of licenses to new operators, either for existing networks unbundling or new radio spectrum. The intimate cultural-cognitive and personal connections between incumbent telecom operators' representatives and the government agents, usually coming from monopoly period, enabled the establishment of a harsh regulatory environment to entrant IASPs. This effectively prevented any new competitor to anticipate the launch of both fixed and mobile broadband all over internet history in Brazil. Each time when new technologies where finally "allowed" by the government, the incumbents were in the right timing to embrace them. This was particularly evident in the case of mobile internet where 3G/UMTS and 4G/LTE radio spectrum auctions were kept on hold for more than 4 years. Auctions were postponed based on the *general understanding* – between incumbents and administration, but also among pundits – that adequate depreciation of existing networks was necessary before introducing new technologies. In our view, this was not a "regular" situation of regulatory capture. At the time, even market analysts and specialized journalists used that same argument to justify the regulatory agency "moderation". No relevant debates on the subject of the eventual consequences to the competition – one of the pillars of the formal regulatory regime – took place then. After all – this is our hypothesis – that was the way telecom infrastructure was operated in the past 100+ years. Under the state monopoly regime, it was perfectly rational to maximize the lifetime of scarce capital; for a long time, delayed introduction of new technologies was a sensible practice. Thus, it seems reasonable to suggest, *ex post*, that this same worldview was taken-for-granted as part the new institutional framework at least during the first years after privatization. Change in stable fields requires not only skilled challengers, but also time, so the institutionalization and legitimation processes can effectively modify taken-for-granted cognitive mental schemes of agents.

In summary, the evidence gathered in empirical research can be synthesized in two key stylized facts at least for the scope of this paper. First, Brazilian access services present *persistent market concentration* with the dominance of legacy incumbents – originated from the privatized public monopoly – and restricted room for new competitors. Second, *longer than expected technological diffusion cycles* have characterized the introduction of new generation services, even though the required technical artifacts were readily available to both incumbents and entrants, in a pattern of succeeding longer diffusion cycles when compared to other markets abroad.

4. Model specification

The next analytical step is the specification of the simulation model. The main objective of a History-friendly model is to test if its theoretical hypotheses are logically compatible, and to what extent, with the empirical stylized facts (Malerba *et al.* 1999, Windrum *et al.* 2007). However, the purpose of the model goes beyond hypothesis testing. In general terms, it intends to select, submit, and combine ideas and hypotheses – including causal relations between variables – while staying compatible with stylized facts (Pyka and Fagiolo 2005). Furthermore, the model may generate results that are not immediately or readily derived from theory, enabling deeper understanding of fundamental causal mechanisms of complex systems. On the other hand, a model is just an auxiliary artifact to the analytical process; it is not capable of proposing explanatory hypotheses or, in general terms, move beyond the scope of the theoretical framework that supports it (Axelrod and Tesfatsion 2006).

The model was specified to study the interactions among sets of users, IASP firms, technologies, and critical institutions, as pointed by the theoretical and empirical analysis, to enable the identification of the main features of an artificial representation of the IASM. The proposed specification is based on a set of difference equations describing discrete time series for selected state variables of the model. Each simulation run is then defined by a set of times series from all state variables. The model is time driven and all contemporaneous events are supposed to take place simultaneously in each time step t (t = 1, 2, 3,… N, where N is the simulation length). Such contemporaneous time convergence requires that the order of equations valuation be specified properly to avoid ambiguities. This is achieved through the careful specification of the lag structure of each variable and the definition of a fixed evaluation order for the equation set.

Behavioral difference equations are processed in the following sequence: (a) the proxy monolithic network equipment vendor performs technology search trying to increase the productivity of existing equipment vintages and eventually adopt new, more productive ones, subject to institutional constraints ("license synchronization"); (b) prospective entrant IASPs evaluate convenience (profitability and opportunity) of entry and, if so, select initial network capacity and strategy; (c) IASPs select prices and investments for the period given the (myopic) expectations of increase (or decrease) in the number of users; (d) new potential users come to the market while market saturation is not reached; (e) users whom do not have an assigned IASP (new comers or insufficient budget) search for a new IASP according to their preferences, budget and the influence of other users; (f) IASPs decide about investment financing and use of profits if any; and (g) bankrupt or too small IASPs leave the market.

Full model documentation is available at http://sites.google.com/site/modelosetorinternet. Model was coded in C++ using the Laboratory for Simulation Development (LSD) version 6.1 created by Marco Valente (2002). The model is composed of 42 main equations of which 25 are critical because of the incorporation of key theoretical premises. The model was originally designed to investigate several questions about the internet sector beyond the scope of this paper. Next, we briefly introduce some equations that model critical features of the model in two areas: demand and supply clearing and technological innovation. Full explanation for each behavioral difference equation in the model is presented in Pereira (2012).

Demand is modeled with users heterogeneous in two main dimensions: budget and preferences. User k is interested in contract internet access services for multiple time steps paying a fixed price P_t^k each. IASP i offers new users a single combination of access price P_t^i and quality M_t^i in any given time step t.

Every time a user is out of a contract, she ranks all IASPs according to a utility function[15] $U_t^{i,k}$ and selects the IASP with the highest utility considering her budget B_t^k.

$$U_t^{i,k} = \left(\frac{\overline{P}_{t-1}}{P_t^i}\right)^{b_1^k} \left(\widetilde{M}_{t-1}^{i,k}\right)^{b_2^k} \left(s_{t-1}^i\right)^{b_3^k} \tag{1}$$

This mechanism represents an implicit *replicator equation* (Metcalfe 1998) because, as all individual users chose their IASPs, it redefines the resulting market shares for each IASP in every period. Parameters b_1^k, b_2^k and b_3^k represent user preferences weight in terms of price, quality and market share for any IASP. $\overline{P}_t$ is the weighted market price. $\widetilde{M}_t^{i,k}$ is the quality (or merit) of IASP *i* as perceived by user *k* and s_t^i is its market share. The third term in (1) is a proxy to the relational influence of other users' choices on the individual preferences and represents a positive externality to (larger) firms[16]. It should be noted that this is not the classical network externality (Shy 2001), bearing in mind users have no direct benefit in choosing the same IASP as her acquaintances. On the contrary, such a disposition might cause the user to choose an IASP with inferior objective attributes (in price or quality), but more "popular", even in the absence of tangible benefits.

The quality M_t^i offered by the IASP to all its users in *t*, is inversely proportional to the utilization Q_t^i of its network total installed capacity $Q_t^{M,i}$. By definition, the capital equipment vendor designs one unit of network physical capacity in order to meet the demand from one user. Thus, Q_t^i is the current number of users of IASP *i*. *q* is a fixed parameter and accounts for nonlinearity between capacity mismatch and quality.

$$M_t^i = \left(\frac{Q_t^{M,i}}{Q_t^i}\right)^q \tag{2}$$

The total installed capacity depends on the productivity a_t^j and the stock $K_t^{i,j}$ of each technology vintage *j* installed in IASP's network. Every IASP has $N_t^{tech,i}$ distinct vintages in operation at time *t*.

$$Q_t^{M,i} = \sum_{j=1}^{N_t^{tech,i}} a_t^j K_t^{i,j} \tag{3}$$

IASPs assess the need for increasing installed capacity each time step. All required investment I_t^i adopts the most current technology j_c. Firms decide investment I_t^i based on the expected network capacity $Q_t^{P,i}$ required plus the incurred depreciation D_t^i. P_t^{tech,j_c} is the unit price of technology j_c. Investment is subject to a technology-specific minimum scale Q_{min}^j. m_M^i is a parameter defining the target quality of IASP *i*.

$$I_t^i = \begin{cases} \left(m_M^i Q_t^{P,i} - Q_{t-1}^{M,i} + D_t^i\right) P_t^{tech,j_c} & \text{if} \quad m_M^i Q_t^{P,i} - Q_{t-1}^{M,i} + D_t^i \geq Q_{min}^j \\ Q_{min}^j P_t^{tech,j_c} & \text{if} \quad m_M^i Q_t^{P,i} - Q_{t-1}^{M,i} + D_t^i < Q_{min}^j \end{cases}, \tag{4}$$

Firms plan network capacity $Q_{t+n}^{P,i}$ prospectively for *n* periods, by setting myopic expectations for acquisition (or loss) of new users. Smaller firms (market share s_t^i below the parameter s^{inc}) project demand from the customer base evolution in previous planning period. Parameter m_Q^i represents the qualitative expectations about the future ($m_Q^i > 1$ representing accelerating growth). Larger firms ($s_t^i \geq s^{inc}$) evaluate future demand in terms of total market growth ($N_t^{user} - N_{t-n}^{user}$) and on the expectation of relative performance ($m_Q^i > 1$ pointing to market share rise).

[15] The use of continuous utility functions is criticized for its poor adherence to the empirical experience (VALENTE 2009). Nevertheless, the simplicity and familiarity of a traditional Cobb-Douglas function was preferred for the initial research stage.
[16] This takes in consideration empirical evidence on the importance of social influence in consumer behavior (Earl and Potts 2004, Birke and Swann 2006, Morone and Taylor 2010).

$$Q_t^{P,i} = \begin{cases} Q_t^i & \text{if} \quad Q_t^i < Q_{t-n}^i \\ Q_t^i + \dfrac{m_Q^i\left(Q_t^i - Q_{t-n}^i\right)}{n} & \text{if} \quad s_t^i \le s^{inc} \\ Q_t^i + \dfrac{m_Q^i s_t^i (N_t^{user} - N_{t-n}^{user})}{n} & \text{if} \quad s_t^i > s^{inc} \end{cases} \tag{5}$$

When firm has an expectation of reduction in the number of customers, it keeps the existing installed capacity. When necessary, reduction of capacity occurs through depreciation without equipment replacement.

Organizational innovation is modeled as an evolutionary, bounded rational process of strategic search by IASPs that seek “satisficing” rates of return on investment (Simon 1979) under the largest market share compatible with this rate. To pursue it they can adjust their short term goals for price and quality and some other behavioral parameters. The model allows different algorithms to implement strategies, including adaptive mechanisms, i.e., the search for better strategies if current strategy fails. This process is based on the comparison of IASP own results with those of competitors. Thus, the model allows strategies to pass through a selection mechanism based on learning and imitation. IASPs in distinct social groups – incumbents or entrants – have somewhat distinct strategy sets, in a “small world” type of organization (Watts 1999). It is supposed that every firm knows the set of strategic alternatives available in its social group and their average performance over time.

All technical innovation is performed by a proxy monolithic vendor so the technological dynamics remains endogenous to the internet sector. There are two types of technological innovation in the model: incremental, associated to improvements of existing technology vintages, and radical, when new equipment vintages are introduced. Accordingly, two types of search routines are configured, both modeled as two-step stochastic, productivity-enhancer processes. At any time, there is a single best practice in terms of the most productive technology and all IASPs are aware of it. Thus, stochastic components are not present in the technical search of IASPs, since the model assumes that they simply pick the most current equipment available when convenient. So, diffusion is driven by myopic costs reduction.

There is a probability $\Pr\left(d_t^j = 1\right) > 0$ in each time step of a technological advance. This probability has Poisson distribution as presented and p_{incr} (incremental innovation of existing vintages) or p_{rad} (radical innovation, generating new technology vintage) is the success parameter.

$$\Pr_{incr}\left(d_t^j = 1\right) \sim \text{Poisson}\left[\frac{\left(t - t_0^{incr,j}\right)}{p_{incr}}\right], \qquad \Pr_{rad}\left(d_t = 1\right) \sim \text{Poisson}\left[\frac{(t - t_c)}{p_{rad}}\right] \tag{6}$$

Radical innovations depend yet on the “license synchronization” requirement set to wait while most capital stock of incumbents is not depreciated. If first stage spawns an advance, a new potential for productivity $\hat{a}_t^j$ (incremental) or $\hat{a}_t^{j_c+1}$ (radical) is produced with normal distribution based on current productivity a_{t-1}^j or $a_{t-1}^{j_c}$ respectively. Standard deviation of incremental productivity improvement v_t^j is decreasing as technology gets older. v_{incr}, v_{rad} and v_0 are parameters.

$$\hat{a}_t^j \sim N\left(a_{t-1}^j, v_t^j a_{t-1}^j\right), \qquad \hat{a}_t^{j_c+1} \sim N\left[(1 + v_{rad}) a_{t-1}^{j_c}, v_{rad} a_{t-1}^{j_c}\right] \tag{7}$$

$$v_t^j = v_{incr} - \frac{v_{incr}}{1 + \exp\left(v_0\left(1 - \dfrac{t - t_0^j}{p_{rad}}\right)\right)} \tag{8}$$

Technological advance is adopted only if it improves productivity.

$$a_t^j = \max\left(a_{t-1}^j, \hat{a}_t^j\right), \qquad a_t^{j_c+1} = \begin{cases} 0 & \text{if} \quad \hat{a}_t^{j_c+1} \le a_{t-1}^{j_c} \\ \hat{a}_t^{j_c+1} & \text{if} \quad \hat{a}_t^{j_c+1} > a_{t-1}^{j_c} \end{cases} \tag{9}$$

5. Model main results

Most of the model's 41 parameters and 9 lagged variables requiring non-trivial initial conditions were calibrated using empirical data as appropriate in a History-friendly approach. Simulation time was adjusted so 1 time step is equivalent to 1 quarter (3 months) and run for 250 time steps (62.5 years). All model results were evaluated by statistical parameter estimation over samples of 100 simulation runs, due to the presence of stochastic elements in the model. Sample size was selected to ensure at least ±5% precision at 95% confidence level. Statistical distributions of most variables were unimodal and sufficiently symmetrical to justify the adoption of averages and standard deviations as representative parameters of the model results. After initial calibration, sensitivity analysis of all parameters and initial conditions was performed, to identify critical parameters. Parameters and initial conditions were extensively point tested around calibration figures in ranges large enough to encompass maximum and minimum values compatible with reasonably expected empirical magnitudes. Interestingly, only a relative small number of parameters were critical on producing the main model results associated to the simulated market organization. Impact analysis of parameters and initial conditions on 10 selected structural indicators[17] was performed by ANOVA tests at 1% significance. Of 50 parameters and initial conditions, 13 showed overall significant statistical impact, but only 5 were relevant in a qualitative dimension, meaning their variation effectively generated different competitive outcomes. For details on each step of model setup and test see Pereira (2012).

Conforming to empirical data, simulated IASM started with 4 IASPs and 1.8 million potential service users. Potential user growth was modeled as a contagion process, leading to the usual logistic shape, adjusted to Brazilian data. User growth reached saturation around $t = 150$, so analysis was focused in the period $1 \leq t \leq 175$ (43.75 years). Counterfactual experiments on these assumptions did not change results qualitatively. New users had random individual budgets distributed according to real data. They also had heterogeneous preferences defined randomly and uniformly over the allowed ranges. Results were more sensible to these parameters, as shown in Pereira (2012). In general, model outcomes are qualitatively close to the empirical data and, in principle, compatible with the institutional stabilization framework proposed.

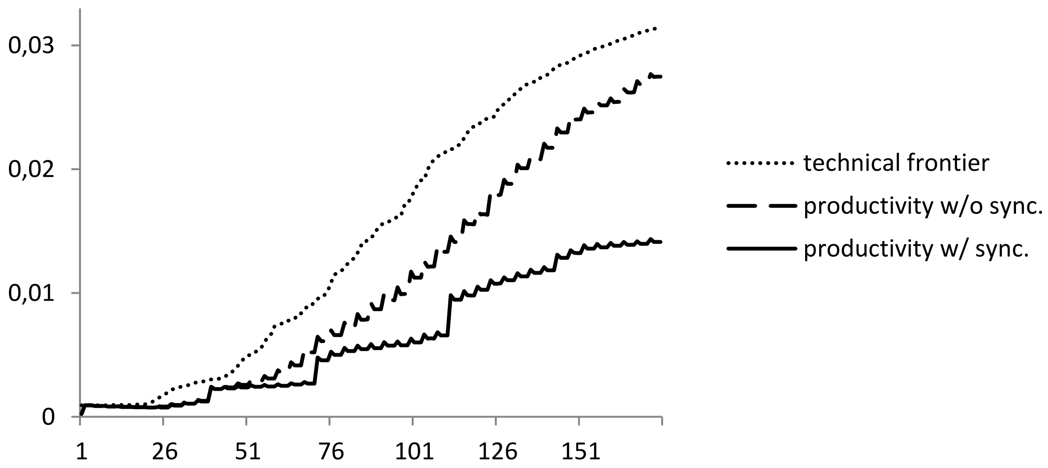

Figure 2 – Weighted average capital productivity of installed network equipment (in units of network capacity per unit of capital along simulated time).

In particular, the model offered additional insight on the effect of the institutional setup on technology diffusion and its impacts on market concentration. Based on empirical data, the average period between new access technologies availability p_{rad} was 28 time steps (7 years) and the average productivity gain v_{rad} of each new vintage of network equipment was 70%. However, new technologies were only allowed to be introduced when at least 50% of the capital stock (networks) of incumbents was depreciated (≥10 years). This simulates the usual practice of the regulatory agency in Brazil which allows for a mini-

[17] Indicators included concentration indexes, number of firms, market size, profitability, age of competitors, and market price and quality weighted averages and variances.

mum average time for the depreciation of existing network infrastructure before issuing further licenses required for new technologies ("license synchronization" or LS). LS effectively reduced the diffusion rate of new technologies as the distance between the curves of actual productivity and the technical frontier – the most productive technology available – shows in Figure 1. During the analyzed period, the weighted industry productivity was in average 52% below the benchmark represented by the technical frontier ("w/ sync." curve). As expected, the underperformance grew over time due to cumulativeness effects. The productivity gap was caused by the usual constraints to new technology adoption (investment cycles, demand growth, financial restrictions etc.) as well LS. In a counterfactual analysis, with only LS removed ("w/o sync." curve), the productivity gap closed to 32% and slowly converged to the frontier as industry matures.

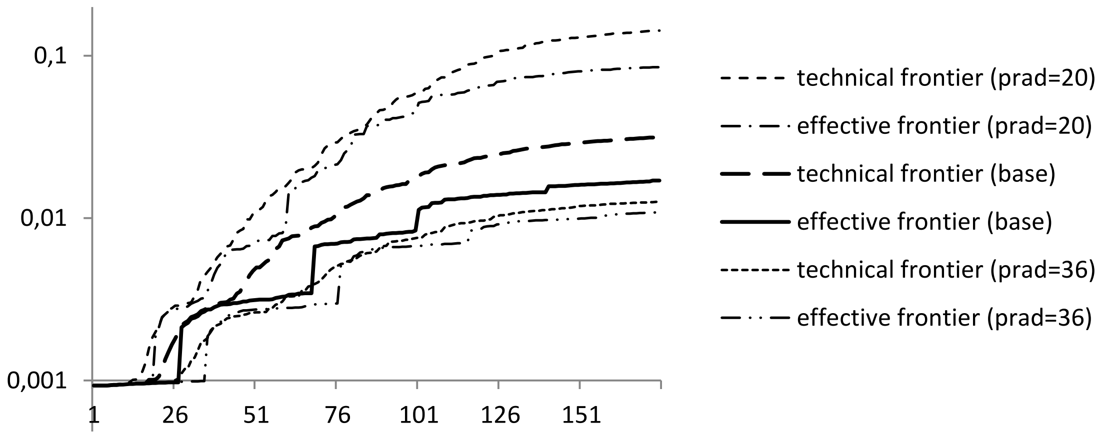

Figure 3 – Weighted average capital productivity of new network equipment[18]
(in units of network capacity per unit of capital along simulated time, log scale).

Model analysis shows LS effectively lowered the achievable technical frontier. The delay on technology deployment prevented diffusion and adversely impacted technical cumulativeness during the most dynamic period of market development. Once demand growth slowed down, the stimulus for further technological innovation also faded away permanently reducing the productivity rise potential. Figure 3 presents the resulting "effective" frontier. Other than the base case ("base" curves, p_{rad} = 28), Figure 3 shows two counterfactual simulation runs for different values of p_{rad}. The negative effect of LS on overall technical frontier advance seems dependent on the innovation cycle length. As the time between radical innovations (p_{rad}) increased the impact of LS quickly reduced. All this suggests the negative role of LS policies exactly during the initial phase of rapid technological development of new markets.

Of course, lower effective technical frontiers increased average costs (+3%) and prices (+11%) in the model. This effectively reduced the penetration of internet services (-4%). Less obvious is the impact of LS on competition. The counterfactual scenario, without LS, presented a very similar Herfindahl-Hirschmann index (HHI) profile when compared to the base case, well above the 0.25 mark – consistent with the *persistent market concentration* stylized fact[19]. While quantitatively similar, competition was qualitatively different between the two scenarios. LS reduced profitability of all IASPs due to the higher cost, but entrants' average profits (-64%) were significantly more affected than incumbents' (-10%). This had substantial impact on the simulated competition development; it is important to use the model to uncover the mechanisms that generate such asymmetry.

Given the always expanding technological frontier, the diffusion of new technologies depended on the decisions of IASPs to adopt them. The model supposes that all entrants deploy the most advanced (i.e., productive) technology available, subject to LS. Incumbents adopt new technologies when expanding their networks, when the existing ones get depreciated, or when the cost of adoption is lower than the

[18] Curves are "smooth" because all data presented is based on averages over 100 simulation runs (using different seeds for the random number generator). When analysed individually, each simulation run presents the familiar radical-incremental productivity growth pattern.
[19] This market profile is not a structural outcome of the model; adequate counterfactual parameter sets can generate remarkably distinct competitive results. Three mechanisms explain the counterfactual results (details in Pereira 2012): (a) socio-institutional issues influencing users' choices; (b) economies of scale; and (c) user acuity on perceived quality of IASPs.

net present value of the gains provided (accelerated depreciation). The resulting average age of incumbents' and entrants' networks is presented on Figure 4. Average network age was significantly higher for incumbent IASPs despite the quick adoption of newer technologies when LS is in place ("w/ sync." curves); in this situation the incumbents usually replaced more than 50% of their network infrastructure immediately after a radical innovation. This scenario changed significantly if there is no LS ("w/o sync." curves), when incumbents tended to have less incentive to quickly jump on newer technologies, resulting in a more stable – and slightly higher (5%) – average network age. Entrant IASPs, as expected, tended to operate significantly newer networks, under an age profile less sensitive to LS. Thus, entrants' unit costs were usually well below that of incumbents.

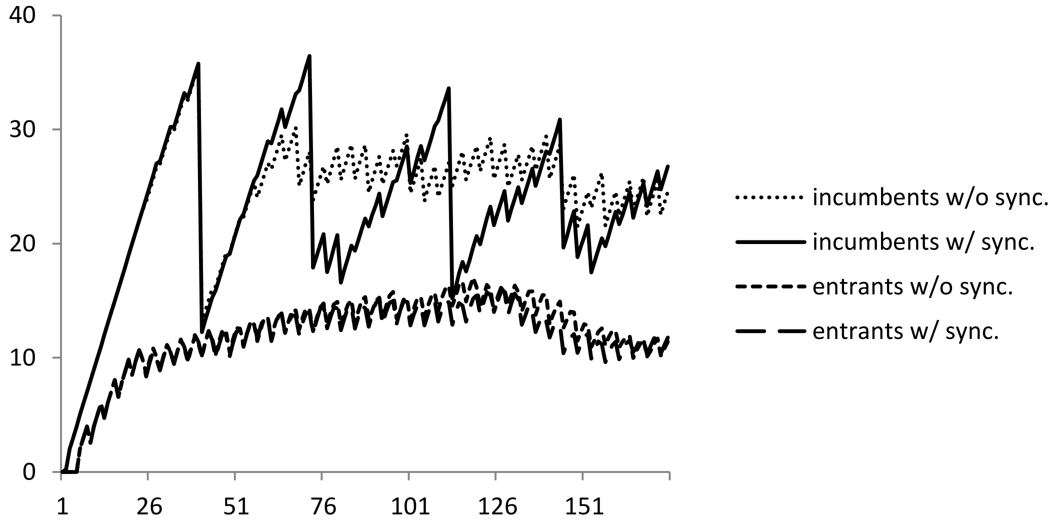

Figure 4 – Weighted average age of network equipment in use (in time steps along simulated time).

Despite lower unit costs, incumbents presented much lower profitability when compared to incumbents (at least 79% less). Model data analysis shows this was due to lower prices set by entrants associated with network capacity underutilization when compared to incumbents. Entrants were forced to underprice and/or technically overperform incumbents to be able to compete effectively, because of the advantage of incumbents in retaining users despite somewhat inferior price-quality offers. This form of "soft" lock-in has socio-institutional origins (see Pereira 2012), based on the preference of users for large IASPs (represented by the third term in Equation 1) and their limited acuity in distinguishing small quality differences among IASPs (q parameter in Equation 2). On the other hand, low profitability of entrants meant they had higher probability of failure when compared to incumbents; LS just aggravated this. This can be seen in Figure 4 ("w/o sync." curves). It shows the effect of this counterfactual experiment. In this scenario, incumbents were usually less responsive in replacing their networks following a radical innovation, while the behavior of entrants barely changed. This move reduced considerably the cost advantage hold by entrants during the critical period that immediately followed a new technology introduction. During this period, entrants lost their unit cost advantage, despite typically maintaining the disadvantages associated with lower prices and economies of scale. Those periodical closures of the "window of opportunity" in the IASM had unequivocal impact on entrants; their lifespan expectancy was reduced up to 25% in regard to the scenario without LS. This last point can be further reinforced by Figure 5 (thicker curves, marked "actual innovation").

Longer diffusion cycles produce more entry/exit turbulence, as the model produced data shows. The total number of IASPs in the market usually grew up to $t = 100$, from 4 to 10 players in average, falling from there on and converging to about 5 firms at $t = 250$. Nonetheless, there was a turbulent process of entries and exits of IASP firms behind those average figures. The persistent low profits captured by the average entrant made it financially fragile, particularly in moments of radical innovations. On the other side, Figure 5 shows the significant positive impact of shorter average times between new technology vintages (lower p_{rad}) on entrant average lifespan. Notwithstanding every individual entrant was more exposed to incumbents competition during new technology introduction, the shorter the innovation cycle, the larger was the survival expectancy of entrants as a population, because of the financial strain imposed on incumbents to accelerate their network depreciation. Accordingly, associated to the previous discussion on profitability, it seems clear the causal relation of longer technological diffusion cycles with lower rates of successful entry identified in the simulation results and, probably, in the real world data. This naturally leads to the discussion of the convenience of longer diffusion cycles for incumbents. Assuming that new network technology vintages are created exogenously to the IASM, the only lever available to incumbents on this subject is the regulatory agency policy on LS – and the influence they may exert on it. Therefore, it seems reasonable that an institutional entrepreneurship perspective is as reasonable explanation to justify the otherwise unexpected stylized fact of *longer than expected technological diffusion cycles* verified in the Brazilian IASM.

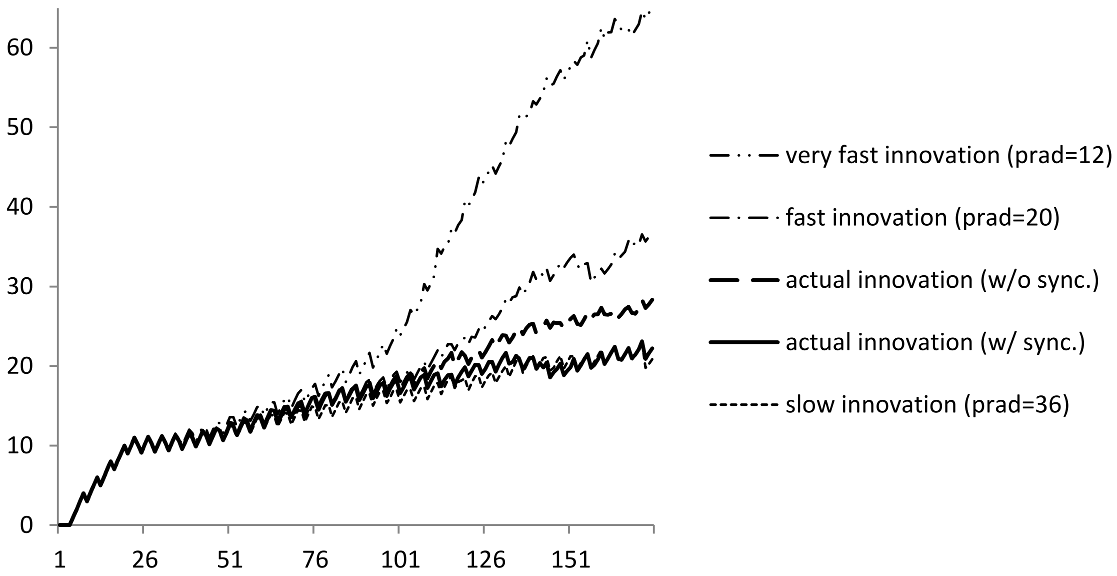

Figure 5 – Average lifespan of entrants operating in the IASM
(in time steps along simulated time).

The consequences of institutional entrepreneurship targeting diffusion slowdown are unmistakable. Detailed investigation of model results leads to the conclusion that the restless turbulence of fragile entrants, associated to relative stability among incumbents, had unequivocal outcomes: the tendency of lasting concentration of the IASM in the hands of few incumbents (usually one to three), the increased efficiency of non-price strategies for larger players, higher than expected prices, and lower than potential service penetration among users. In summary, this seems to characterize the institutional stabilization of access services as a market field, as verified in the virtual IASM, and may provide a good explanatory candidate to the similar features of the real IASM.

Lastly, it is important to investigate other possible explanations for the observed results, in particular the persistent high concentration. Two strong candidates are economies of scale (ES) and network externalities (NE). Both are well established in the literature about the telecommunications sector. Nonetheless, ES alone were not capable of changing the model results in any qualitative way, in spite of its modest quantitative relevance. Even when ES were completely eliminated (a counterfactual scenario), HHI was reduced by less than 0.20, at most. As discussed before, NE does not seem to apply in this case (see note 9) nor was it modeled in the simulation.

6. Conclusions

The rapid convergence of multiple and heterogeneous agents to the internet sector represented a complex institutional building project. The new institutional environment then developed, equally cooperative and competitive, was a collective form of mitigation of the strong uncertainties, associated with a new environment like the internet, allowing increased investments and attracting new entrants to the industry. However, different cooperation-competition profiles among industry segments were established.

In Schumpeterian terms, time trajectories guided markets like equipment, systems and content to a more creative destruction-type dynamics while others, like access services, apparently took a creative accumulation path in some countries. In our perspective, to a large extent this was due to the persistence of certain institutional characteristics of the former telecommunications monopoly regime. This legacy, we argument, facilitated the dominance of the internet access services market by telecom operators originated from the privatizations of the 1990s. Such circumstances seem to fit nicely the case of Brazil, as empirical research presented. Appreciative analysis suggests the description of the arrangements in the Brazilian case by at least two stylized facts: persistent market concentration and longer than expected technological diffusion cycles. To further investigate these issues, an agent-based simulation model was built.

The proposed History-friendly model produced results that were quite close, in qualitative terms, to those observed in the actual economic system. Some of the main reasons for market concentration and limited competition were partly identified with emergent institutional phenomena. Of particular interest is the strong impact of other users' choices in the setting of user preferences (downward causation) and the effects of relational networks of firms on adaptive strategic learning and aggressiveness profiles. The model also provided explanations on some mechanisms softening competition, highlighting the sometimes crucial effects of social networks, established conventions or cognitive frames of governmental agents. The role of technological dynamics for the IASM organization was clarified, including how its diffusion effects are potentially contradictory in case of successful institutional entrepreneurship of incumbent access providers. Despite the importance of innovation diffusion processes to the development of the internet sector, their slowdown may also be instrumentally useful to reinforce acquired dominant positions. As suggested by Silverberg (1988:549), "a complex tension can exist between individual behaviors and aggregate outcomes, which may indeed be the most interesting feature of social systems". On the other hand, the possible dominance of institutional processes does not mean that traditional elements of industrial analysis, such as those from industrial organization or evolutionary theory, have not played their expected role. However, as the model demonstrated some of the results, usually explained exclusively by these traditional elements, depended crucially on the concurrence of institutional factors. For example, the model rejected the hypothesis that the removal of economies of scale, in isolation, would be enough to change market concentration in qualitative terms.

The combination of appreciative and model-based analysis seems to offer more comprehensive and robust hypotheses about the concentration of the internet access market in Brazil – and possibly in other countries. Evolutionary dynamics and institutional stabilization represented two powerful forces running along the entire internet sector but felt with imbalanced intensity in the access segment. The vigorous technological dynamics experienced by the sector accounted for three huge innovation cycles in less than 20 years. This profoundly reshaped the access market. However, new technologies – embedded in equipment developed outside the access segment – did not create opportunities of significant technological differentiation for entrant IASPs. Given the almost universal availability of technologies to all players, the usual role of the innovative entrant was severely limited. On the contrary, technological dynamics was favorable to the incumbents, as some features of new technologies have leveraged their legacy capabilities. Disadvantage of entrants was further aggravated, in several situations, by the operation of some institutional mechanisms that eased users lock-in to incumbents, constrained price-based competition among them and allowed for the unintended support of the state to the status quo.

Acknowledgments

I wish to thank David Dequech, José Maria Silveira, Marco Valente, Esther Dweck, Paulo Fracalanza, Mariano Laplane, Thadeu Silva, and André Gimenez for their helpful comments on earlier versions of this work or otherwise their invaluable support to it. I am responsible for all remaining errors. The financial support of the Universidade Estadual de Campinas is also gratefully acknowledged. This work was done with the support of CNPq, Conselho Nacional de Desenvolvimento Científico e Tecnológico – Brasil.

References

Aghion P, Howitt P (1998) *Endogenous Growth Theory*. Cambridge: MIT Press.
Akamai (2012) *The State of the Internet* 4(4).

Arrow KJ (1962) Economic Welfare and the Allocation of Resources for Invention. In *The Rate and Direction of Inventive Activity*: Economic and Social Factors. Cambridge: NBER.
Arthur WB (2005) Interview. In Finch J, Orillard M (Ed.) *Complexity and the Economy*: implications for economic policy. Cheltenham: Edward Elgar.
______ (2000) Cognition: The Black Box of Economics. In Colander D (Ed.) *The Complexity Vision and the Teaching of Economics*. Northampton: Edward Elgar.
______ (1988) Self-Reinforcing Mechanisms in Economics. In Anderson PW, Arrow KJ, Pines D (Ed.) *The Economy as an Evolving Complex System*. Reading: Addison-Wesley.
Arthur WB, Durlauf S, Lane DA (1997) Process and Emergence in the Economy. In Arthur WB, Durlauf S, Lane DA (Ed.) *The Economy as an Evolving Complex System II*. Reading: Addison-Wesley.
Axelrod R, Tesfatsion L (2006) A Guide for Newcomers to Agent-Based Modeling in the Social Sciences. In Tesfatsion L, Judd K (Ed.) *Handbook of Computational Economics*, Vol. 2: Agent-Based Computational Economics. Amsterdam: North-Holland.
Battilana J, Leca B, Boxenbaum E (2009) How Actors Change Institutions: Towards a Theory of Institutional Entrepreneurship. *The Academy of Management Annals* 3(1):65-107.
Beckert J (2010) How Do Fields Change? The interrelations of Institutions, Networks, and Cognition in the Dynamics of Markets. *Organization Studies* 31(5):605-627.
______ (1999) Agency, Entrepreneurs, and Institutional Change: The Role of Strategic Choice and Institutionalized Practices in Organizations. *Organization Studies* 20(5):777-799.
Birke D, Swann P (2006) Network effects and the choice of mobile phone operator. *Journal of Evolutionary Economics* 16(1-2):65-84.
Bourdieu P (1972) *Esquisse d'une théorie de la pratique*. Genève: Droz.
Breschi S, Malerba F (1997) Sectoral systems of innovation: technological regimes, Schumpeterian dynamics and spatial boundaries. In Edquist C (Ed.) *Systems on Innovation*. London: Pinter.
Breschi S, Malerba F, Orsenigo L (2000) Technological regimes and Schumpeterian patterns of innovation. *Economic Journal* 110(463):388-410.
Castellacci F, Grodal S, Mendonça S, Wibe M (2005) Advances and Challenges in Innovation Studies. *Journal of Economic Issues* 39(1):91-121.
Cerf, V et al. (2000) Brief History of the Internet. www.internetsociety.org/internet/internet-51/history-internet/brief-history-internet.
Colander D (2005) The future of economics: the appropriately educated in pursuit of the knowable. *Cambridge Journal of Economics* 29(6):927-941.
Coriat B, Weinstein O (2005) The social construction of markets. *Issues in Regulation Theory* 53:1-4.
Corrocher N (2001) The Internet services industry: Sectoral dynamics of innovation and production and country-specific trends in Italy and in the UK. www2.cespri.unibocconi.it/essy/wp/corroch.pdf.
Cyert RM, March JG (1963) *A behavioral theory of the firm*. Cambridge: Blackwell.
Dalum B, Villumsen G (2003) Fixed data communications: challenges for Europe. In Edquist C (Ed.) *The Internet and Mobile Telecommunications System of Innovation*: Developments in Equipment, Access and Content. Cheltenham: Edward Elgar.
Davies A (1996) Innovation in Large Technical Systems: The Case of Telecommunications. *Industrial and Corporate Change* 5(4):1143-1180.
Denzau A, North D (1994) Shared Mental Models: Ideologies and Institutions. *Kyklos* 47(1):3-31.
Dequech D (2009) Institutions, social norms, and decision-theoretic norms. *Journal of Economic Behavior and Organization* 72(1):70-78.
______ (2006) The New Institutional Economics and the theory of behaviour under uncertainty. Journal of Economic Behavior and Organization 59(1):109-131.
DiMaggio PJ (1988) Interest and agency in institutional theory. In Zucker L (Org.) *Institutional Patterns and Organizations*. Cambridge: Ballinger.
DiMaggio PJ, Powell WW (1991) Introduction. In Powell W, DiMaggio P (Org.) *The New Institutionalism in Organizational Analysis*. Chicago: University of Chicago Press.
______ (1983) The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review* 48(2):147-160.
Dobbin F (2004) The Sociological View of the Economy. In Dobbin F (Org.) *The New Economic Sociology*: A Reader. Princeton: Princeton Press.
Dosi G (1991) The Research on Innovation Diffusion: An Assessment. In Nakićenović N, Grübler A (Ed.) *Diffusion of Technologies and Social Behavior*. Berlin: Springer-Verlag.

______ (1982) Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy* 11(3):147-162.
Dosi G, Nelson RR (2010) Technical Change and Industrial Dynamics as Evolutionary Processes. In Hall B, Rosenberg N (Eds.) *Handbook of the Economics of Innovation*, Vol. 1. Amsterdam: Elsevier.
Earl PE, Potts J (2004) The market for preferences. *Cambridge Journal of Economics* 28(4):619-633.
Edquist C (2004) The fixed Internet and mobile telecommunications sectoral system of innovation: equipment production, access provision and content provision. In: Malerba, F (Ed.) *Sectoral Systems of Innovation*: Concepts, Issues and Analyses of Six Major Sectors in Europe. New York: Cambridge Press.
Fligstein N (2001a) *The architecture of markets*. Princeton: Princeton Press.
______ (2001b) Social Skill and the Theory of Fields. *Sociological Theory* 19(2):105-125.
______ (1997) Social Skill and Institutional Theory. *American Behavioral Scientist* 40(4):397-405.
Fligstein N, Dauter, L (2007) The Sociology of Markets. *Annual Review of Sociology* 33:105-128.
Funk JL (2009) The co-evolution of technology and methods of standard setting: the case of the mobile phone industry. *Journal of Evolutionary Economics* 19(1):73-93.
Garavaglia C (2010) Modelling industrial dynamics with “History-friendly” simulations. *Structural Change and Economic Dynamics* 21(4):258-275.
Garud R, Karnøe P (2001) Path Creation as a Process of Mindful Deviation. In Garud R, Karnøe P (Org.) *Path Dependence and Creation*. Mahwah: Lawrence Erlbaum Associates.
Giddens A (1984) *The Constitution of Society*. Berkeley: Univ. California Press.
Granovetter M (1985) Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology* 91(3):481-510.
Greenstein S (2010) The emergence of the Internet: collective invention and wild ducks. *Industrial and Corporate Change* 19(5):1521-1562.
Greif A (2006) *Institutions and the Path to the Modern Economy*. Cambridge: Cambridge Press.
Hardy C, Maguire, S (2008) Institutional Entrepreneurship. In Greenwood, R et al. (Org.) *Handbook of Organizational Institutionalism*. Thousand Oaks: Sage.
Hodgson GM (2008) Markets. In Davis JB et al. (Org.) *The Handbook of Socio-Economics*. Aldershot: Elgar.
______ (1988) *Economics and Institutions*. Philadelphia: Univ. Pennsylvania Press.
Holland JH (1988) The Global Economy as an Adaptive Process. In Anderson PW, Arrow KJ, Pines D (Ed.) *The Economy as an Evolving Complex System*. Reading: Addison-Wesley.
Hwang H, Powell WW (2005) Institutions and Entrepreneurship. In Acs Z, Audrestsch D (Org.) *Handbook of Entrepreneurship Research*. New York: Springer.
ITU (2011) *Measuring the Information Society*: 2011. Geneva: ITU.
Jepperson R (1991) Institutions, Institutional Effects, and Institutionalization. In Powell WW, DiMaggio PJ (Ed.) *The New Institutionalism in Organizational Analysis*. Chicago: Univ. Chicago Press.
Kavassalis P, Solomon RJ, Benghozi PJ (1996) The Internet: a paradigmatic rupture in cumulative telecom evolution. *Industrial and Corporate Change* 5(4):1097-1126.
Kirman A (1997) The economy as an evolving network. *Journal of Evolutionary Economics* 7(3):339-353.
Klepper S (1996) Entry, exit, growth, and innovation over the product life cycle. *American Economic Review* 86(3):562-583.
Loasby BJ (1999) *Knowledge, Institutions and Evolution in Economics*. London: Routledge.
Malerba F (2006) Innovation and the evolution of industries. *Journal of Evolutionary Economics* 16(1-2):3-23.
______ (2005) Sectoral Systems of Innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technology* 14(1-2):63-82.
Malerba F, Nelson RR, Orsenigo L, Winter S (1999) ‘History-friendly’ Models of Industry Evolution: The Computer Industry. *Industrial and Corporate Change* 8(1):3-40.
Malerba F, Orsenigo L (2000) Knowledge, Innovative Activities and Industrial Evolution. *Industrial and Corporate Change* 9(2):289-314.
Metcalfe S (1998) *Evolutionary Economics and Creative Destruction*. New York: Routledge.
______ (1988) The diffusion of innovation: an interpretative survey. In Dosi G, Freeman C, Nelson R, Silverberg G, Soete L (Ed.) *Technical Change and Economic Theory*. London: Pinter.
Metcalfe S, Foster J (2004) Introduction and overview. In Metcalfe S, Foster J (Ed.) *Evolution and Economic Complexity*. Cheltenham: Edward Elgar.
Morone P, Taylor R (2010) *Knowledge Diffusion and Innovation*: Modelling Complex Entrepreneurial Behaviours. Cheltenham: Edward Elgar.
Mowery DC, Simcoe, T (2002) Is the Internet a US invention?: an economic and technological history of computer networking. *Research Policy* 31(8-9):1369-1387.

Nelson, RR (2005) Physical and social technologies, and their evolution. In Nelson, RR (Org.) *Technology, Institutions, and Economic Growth*. Cambridge: Harvard Press.

______ (1995) Recent Evolutionary Theorizing About Economic Change, *Journal of Economic Literature* 33(1):48-90.

Nelson RR, Sampat B (2001) Making sense of institutions as a factor shaping economic performance. *Journal of Economic Behavior and Organization* 44(1):31-54.

Nelson RR, Winter SG (1982) *An Evolutionary Theory of Economic Change*. Cambridge: Harvard Press.

Noam EM (1994) Beyond liberalisation: From the network of networks to the system of systems", *Telecommunications Policy* 18(4):286-294.

North DC (1990) *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge Press.

OECD (2010) Price ranges, Monthly subscriptions, with/without line charge. www.oecd.org/sti/ict/broadband.

Pavitt K (1984) Sectoral patterns of technological change: Towards a taxonomy and a theory. *Research Policy* 13(6):343-374.

Pereira MC (2012) O setor de internet no Brasil: uma análise da competição no mercado de acesso. Dissertação de mestrado, Universidade Estadual de Campinas, Campinas.

Perez C (1983) Structural Change and Assimilation of New Technologies in the Economic and Social Systems. *Futures* 15(5): 357-375.

Potts J (2000) *New Evolutionary Microeconomics*: Complexity, Competence and Adaptive Behaviour. Cheltenham: Edward Elgar.

Powell WW (1991) Expanding the scope of institutional analysis. In Powell WW, DiMaggio, PJ (Ed.) *The New Institutionalism in Organizational Analysis*. Chicago: Univ. Chicago Press.

Pyka A, Fagiolo G (2005) Agent-Based Modelling: A Methodology for Neo-Schumpeterian Economics. Working Paper 272, Institut for Volkswirtschaftslehre, Universitaet Augsburg.

Schumpeter JA (1943) *Capitalism, socialism and democracy*. New York: Routledge.

Scott WR (2008) *Institutions and Organizations*, 3 ed. Thousand Oaks: Sage.

Shy O (2001) *The economics of network industries*. Cambridge: Cambridge Univ. Press.

Silverberg G (1988) Modelling economic dynamics and technical change. In Dosi G, Freeman C, Nelson R, Silverberg G, Soete L (Ed.) *Technical Change and Economic Theory*. London: Pinter.

Simon HA (1979) Rational decision making in business organizations. *American Economic Review* 69(4):493-513.

Storper M, Salais R (1997) *Worlds of Production*, Cambridge: Harvard Press.

Teece DJ, Pisano G, Shuen A (1997) Dynamic capabilities and strategic management. *Strategic Management Journal* 18(7):509-533.

Tesfatsion L (2006) Agent-Based Computational Economics: A Constructive Approach to Economic Theory. In Tesfatsion L, Judd K. (Ed.) *Handbook of Computational Economics*, Vol. 2: Agent-Based Computational Economics. Amsterdam: North-Holland.

Thornton P, Ocasio W (2008) Institutional Logics. In Greenwood R *et al.* (Org.) *The Sage Handbook of Organizational Institutionalism*, Thousand Oaks: Sage.

Tolbert PS, Zucker LG (1996) The Institutionalization of Institutional Theory. In Clegg SR, Hardy C, Nord WR (Ed.) *Handbook of Organization Studies*, Thousand Oaks: Sage.

Tordjman H (2004) How to study markets? An Institutionalist Point of View. *Revue d'Economie Industrielle* 107(3):19-36.

UNCTAD (2010) *Information Economy Report 2010*: ICTs, Enterprises and Poverty Alleviation. New York: United Nations.

Valente M (2009) Markets for Heterogeneous Products: a Boundedly Rational Consumer Model. *LEM Working Paper Series* 2009/11.

______ (2002) Simulation Methodology: an Example in Modeling Demand. Mimeo.

Wallsten S (2007) Whence Competition in Network Industries? Broadband and Unbundling Regulations in OECD Countries. http://www.techpolicyinstitute.org/publications.

Watts DJ (1999) Networks, Dynamics, and the Small-World Phenomenon. *American Journal of Sociology* 105(2):493-527.

Williamson O (2000) The New Institutional Economics: Taking Stock, Looking Ahead. *Journal of Economic Literature* 38(3):595-613.

Windrum P, Fagiolo G, Moneta A (2007) Empirical Validation of Agent-Based Models: Alternatives and Prospects. *Journal of Artificial Societies and Social Simulation* 10(2):8-37.