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CATCH-UP AND CONVERGENCE: MECHANISM DESIGN FOR ECONOMIC DEVELOPMENT*

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Abstract

This paper identifies factors that promote long-run sustainable economic growth and industrial catch-up in achieving superior performance. An informationally efficient mechanism design of the Hayek-Hurwicz type would contain as essential elements allocative efficiency with a limited state role, fostering of private entrepreneurship for high intensity dynamic competition through industry specific 'technological racing' within a supporting market structure, free trade and intellectual property rights (IPRs), flexible labour markets, low taxes on labour, capital income and profits. Emphasis on high value-added network industries directed toward increasing returns. If resource endowment among countries are similar these factors would eventually lead to convergence through catch-up performance, otherwise they would lead to divergence.

Key words

Catch-Up; Convergence; Mechanism Design; Economic Development

Taking a philosophical point of view, this may be seen as the mechanics for the implementation of Adam Smith's invisible hand: despite private information and pure selfish behavior, social welfare is achieved. All the field of Mechanism Design is just a generalization of this possibility. – Noam Nisan (2007)

INTRODUCTION

What are the major factors for economies to succeed on catching-up in terms of GDP or GDP per capita (of purchasing power parity PPP) as an indicator of prosperity? As has been broadly covered in the economic growth and development literature (Gottinger & Goosen, 2012), there have been convergence theories on advanced (developed) economies that have been partially verified for some OECD economies, but equally there have been observations of divergence among some developed and developing (transitional) economies that appear to show a growing gap. Technology adoption within regions of a national economy (say , China) were a major factor of less developed regions to catch up. Catch-up metrics could also be identified in disaggregated form next to aggregates such as GDP (total), GDP per head, Human Development Index (HDI), for example, industry/technology index, infrastructure indicator (transportation, communication networks), R&D expenditure (government, private industry) and competitiveness (global market share of key industries). A process of catching up induced by industrial races may tend to converge over time within a bloc of similar countries if technological and educational endowment is similar as covered by Abramovitz' (1986) famous 'social capabilities', as key industries engage in more incremental and complementary innovation that through international trade and foreign direct investment (FDI) spread to emerging industries in likewise developing economies. In the post World War II history what was the mechanism that induced Japan to be on a path of catch-up growth in the 1960s and 1970s in terms of per capita income growth? As suggested in the Asian miracle (Krugman, 1994), one factor was input growth in key value-added industries through capital expansion, the other cumulative technological advancement through largely incremental innovation leading to superiority in some industries. But as soon as the technological frontier was close to be reached it became increasingly difficult to dominate the market. Also in a wide array of high-tech markets it became increasingly decisive to have integrative technologies to catch complementary and increasing returns markets.

The paper shows that catch-up processes should be primarily understood as technological races, establishing new industries that allow free flow of information through entrepreneurial activity and innovation. Under these circumstances, it is more likely that an economic mechanism design generating more information, choices, economic freedom and market transparency supported by democratic institutions, will have a better economic performance record, in a sustainably long run, than any other that fails on the information distribution and strategic incentive side, which would coincide with various types of socialist systems.

The content of the paper is as follows. Section 2 gives a brief historical outline on the interrelation between economic development and catching-up paths. Section 3 sketches the basic structure of algorithmic mechanism design (AMD) as it pertains to computational economic systems, in particular to superior performance of decentralized (distributed) dynamic systems. Section 4 shows the connection between industrial competition and ist aggregation to macro competition on a national or regional level – in view of technological racing. Section 5 identifies technological frontiers on the firm level (FTF) as embedded on the industry level (ITF), amenable to a statistical profiling of technological evolution and innovation. It shows some rules of technological race behaviour resulting in statistical indicators on an industry level. Sec. 6 looks at industrial (in)efficiencies in catch-up countries as benchmarked against the industrial leader. Conclusions follow and open problems are discussed in the last section.

A BRIEF HISTORICAL REVIEW

In a historical context, a catch-up process becomes multidimensional, emerging with England, moving to the US and a few European economies, Germany, France, later to Japan and the newly industrialized economies (NIEs) in Asia overlapping the BRICs. The argument is that due to expansion of trade through globalization the catch-up process is multidimensional and multispeed (Wan, 2004). Even for a few increasing in overall speed the benchmark of catch-up keeps shifting from one or a few to many more. For example, in the past WW II period, industrial and economic growth of Japan was driven toward the US economy less so toward Europe; the pattern of growth and catch-up of China hits many more emerging economies with significant potentials. We have modelled this by a more complex differential game as in Gottinger and Goosen (2012).

As a precursor of economic mechanism design, from an economic history perspective, we first identify Gershenkron (1962) who emphasized state action on industrialization setting free guided entrepreneurial activities through targeted industrial policy (along the line of Japan and later South Korea, Taiwan) (Lee, 2013). This compares to Abramovitz' (1986) and Abramovitz and David's (1992) catching up process where self-reinforcing, industry specific, competitive market forces, rather than state action, would initiate and sustain a technological race resulting in leadership positions across a range of industries. Here the roots of growth rest in the microeconomic industry structure and new industry creating high technology entrepreneurship as conceptionally and empirically explored by Scherer (1992, 1999).

The World Bank in the past takes a middle ground, propagating the state's role to develop social capital which then by itself creates social capability to induce an upward potential through market forces. A more activistic role has recently been favoured by Justus Lin (2013), the former Chinese Chief Economist of the World Bank. Amsden's development statism is a further extension of Gershenkron, catching-up as a process of learning how to compete through 'Late Industrialization' (Amsden, 1989). Other than the main catchup processes listed here have been reviewed by Burkett and Hart-Landsberg (2003), and Fagerberg and Godinho (2004).

In 'Achieving Rapid Growth' Sachs and Warner (1996), in comparing growing middle income countries identify major factors such as allocative efficiency (with government interaction low, markedly less regulation), high degree of competition, free trade. flexible labour markets, low taxes on labour, capital income and profits. While convergence among developing economies may be facilitated by becoming more alike in terms of sources of growth such as technological progress, innovation, levels of physical capital, labour productivity, quality of human capital, extent of trade openess, industrial structure and institutional framework, one clear distinguishing factor may involve increasing returns mechanisms (IRMs). IRMs eliminate any kind of convergence and allow for ongoing quasi-linear growth. Anecdotal observations as put forward by Easterly and Levine (2002) can be summarized as stylized facts on growth mechanisms.

(1) Factor accumulation does not account for growth differences but total factor productivity does for a substantial amount;

(2) There are hugely growing differences in GDP per capita. On a global scale divergence and not conditional convergence is the major concern in development policy; and

(3) Among developing economies growth is not persistent over time.

If movable through market forces all factors of production flow to the same places suggesting important externalities.

A SIMPLE MECHANISM DESIGN FOR CATCH-UP AND DEVELOPMENT

A simple mechanism design emanates from the following paradigmatic situation: Let there be *k* agents in an (Internet) economy that collectively generate demand competing for resources from a supplier. The supplier herself announces prices entering a bulletin board accessible to all agents (as a sort of transparent market institution). In a simple form of a trading process we could exhibit a "tatonnement process" on a graph where the agents set up a demand to the suppliers who advertise prices on a bulletin board which are converted to new prices in interaction with the agents.

The tatonnement process in economics is a simple form of an algorithmic mechanism design (AMD) (Nisan & Ronen, 2001), which in modern computer science (CS) emerges as an offspring to algorithmic game theory (Nisan et al, 2007).

Algorithmic ingredients apply to rational and selfish agents having well defined utility functions repesenting preferences over possible outputs of the algorithm. A payment ingredient motivates the agents. Mechanism Design Theory (MDT) aims to show how privately known preferences of the entire population can be aggregated towards a 'social choice' that drives the mechanism of the whole economy.

(i) Each agent or group of agents have some some private input represented by its type. Its type is embedded in public knowledge or resource endowment as the 'social environment';

(ii) There is a production function (or output specification) that associates each type $t = t^1, \ldots, t^n$ with a set of socially allowable outputs (productions) $o \varepsilon O$; and

(iii) Each agent's preferences are codified as real-valued utility functions noted by $u^i (t^i,o)$.

The universal function is specified in linear terms as $u^i = r^i + v^i (t^i,o)$ where $r^i \geq 0$ is the initial endowment (or resource), or the agent's wealth, which the agent attempts to optimize.

If we assume that the mechanism is truthful to the extent that the agents report their real type then truth-telling is the only dominant strategy. This is considered a truthful implementation. The societal objective function is simply the aggregation of all agents valuations. A 'maximizing mechanism design process' (MDP) is called utilitarian or 'Hayekian' if its objective function is the sum of all agents' utilities.

In the context of the internet economy an MDP would enable users of network applications to present their 'quality of service' demands via utility functions defining the system performance requirements (Gottinger, 2013). The resource allocation process involves economic actors to perform economic optimization given scheduling policies, load balancing and service provisioning.

Distributed algorithmic mechanism design (DMD) for internet resource allocation in distributed systems is akin to an equilibrium converging market based economy where selfish agents maximize utility and firms seek to maximize profits and the state keeps an economic order providing basic public goods and public safety (Feigenbaum et al, 2007). A distributed algorithmic mechanism design thus consists of three components: a feasible strategy space at the network nodes for each agent (or autonomous system), an aggregated outcome function computed by the mechanism and a set of multi-agent prescribed strategies induced by the mechanism.

For such DMDP in place an internet economy can be shown computationally and informationally efficient in the sense of Hurwicz and Reiter (2006), corroborated from a CS view by Conitzer and Sandholm (2002). Furthermore, for efficient macro-management it would satisfy 'moral hazard' and incentive based concerns, and in view of 'informational constraints', e.g. adverse selection, it may also be superior in performance since in a market based decentralized capitalistic system due to keen competition among operating managers - there will be more of higher type performing managers keeping truthful payoff-relevant information than in a comparative socialist planning system with plenty of lower type performing managers providing lower quality or less payoff relevant information.

A distributed algorithmic mechanism design (Feigenbaum et al, 2007) being computationally efficient in a large decentralized internet economy is a powerful paradigm to substantiate claims by Hayek (1945) that an industrialized economy based on market principles has an overall better performance than socialist type economies of a similar nature and scale. It is a paradigm that even contemporary theorists of MDT seem to have partially missed (Myerson, 2008) and that puts historically the socialist planning debate in a new light which ironically, by some proposals, has been conducted on the basis of computational feasibility and superiority.

Such a Hayekian MDP also extends to a dynamic real economy which also invokes highly desirable properties of incentive structures (Myerson, 2008) and knowledge creation through hi-tech entrepreneurship. This suggests that an MDP of the Hayekian-Hurwicz type should be more likely to generate a long-run sustainable growth and development process with comparative greater welfare benefits than what any socialist type planning could achieve. This is in compliance with Hayekian development ideas as put forward recently by Easterly (2013).

The focus of this paper would be to explore growth and development generating structures and factors that are compatible with a Hayek-Hurwicz design scheme for the developing world.

INDUSTRIAL AND MACRO COMPETITION

The striking pattern that emerges in the innovative activities of firms is their rivalries for a technological leadership position in situations that are best described as races or hypercompetition (Harris & Vickers, 1987; Gottinger, 2006b). A race is an interactive pattern characterized by firms or nations constantly trying to get ahead of their rivals, or trying not to fall too far behind. In high-technology industries, where customers are willing to pay a premium for advanced technology, leadership translates into increasing returns in the market through positive network externalities. Abramovitz (1986), in explaining the catch-up hypothesis, lays stress on a country's social capability in terms of years of education as a proxy of technical competence and its institutions. Competing behaviour is also a dynamic story of how technology unfolds in an industry. In contrast to any existing way of looking at the evolution of technology, racing behaviour, though in character more 'a productivity race than a runner's race (Abramovitz & David, 1997), recognizes the fundamental importance of strategic interactions between competing firms. Thus firms take their rivals' actions into account when formulating their own decisions. The importance of this characterization is at least twofold. At one level, racing behaviour has implications for appreciating technology strategy at the level of the individual firm; at the other level, for understanding the impact of policies that aim to spur technological innovation in an industry or country.

On a national scale, simple catch-up hypotheses have put emphasis on the great potential of adopting unexploited technology in the early stage and the increase of self-limiting power in the later stage. However, the actual growth path of the technological trajectory of a specific economy may be overwhelmingly constrained by social capability. The capability endogenously changes as states of the economy and technology evolve. The success of economic growth due to diffusion of advanced technology or the possibility of leapfrogging is mainly attributable to how the social capability evolves. In other words, which effects become more influential: growing responsiveness to competition or growing obstacles to it on account of vested interests and established positions?

Observations on industrial patterns in Europe, the US or Asia point to which type of racing behaviour is prevalent in global high- technology industries. The pattern evolving from such conduct could be benchmarked against the frontier pursuit type of the global technological leaders. Another observation relates to policy inferences on market structure, entrepreneurship, innovation activity, industrial policy and regulatory frameworks in promoting and hindering industry frontier races in a global industrial context. Does lagging behind one's closest technological rivals' cause a firm to increase its innovative effort? The term 'race' suggests that no single firm would want to fall too far behind, and that everyone would like to get ahead. If a company tries to innovate more when it is behind than when it is ahead, then 'catch-up' behaviour will be the dominant effect. Once a firm gets far enough ahead of its rivals, then the latter will step up their efforts to get closer. The leading company will slow down its innovative efforts until its competitors have drawn uncomfortably close or have surpassed it. Of course, the process of getting closer to may be much easier than surpassing the rival This process repeats itself every time a firm gets far enough ahead of its rivals. Of course, catch-up may only consistently apply to the next rivals but will not impact the leader. This is called 'persistent leadership'. On a national level catchup processes like this may not lead to convergence.

An alternative behaviour pattern would correspond to a business increasing its innovative effort if it gets far enough ahead, thus making catch-up by the lagging companies increasingly difficult. For any of these businesses there appears to be a clear link to market and industry structure, as termed 'intensity of rivalry'.

We investigated two different kinds of races: one that is a frontier race between itself and the technological leader at any point in time ('frontier- sticking' behaviour), or it might try to actually usurp the position of the leader by 'leapfrogging' it. When there are disproportionately large payoffs to being in the technical lead (relative to the payoffs that a firm can realize if it is simply close enough to the technical frontier), then one would expect that leapfrogging behaviour would occur more frequently than frontier-sticking behaviour. Alternatively, racing toward the frontier creates the reputation of being an innovation leader hoping to maintain and increase market share in the future. All attempts to leapfrog the current technological leader might not be successful since many lagging firms might be attempting to leapfrog the leader simultaneously and the leader might be trying to get further ahead simultaneously. Correspondingly, one could distinguish between attempted leapfrogging and realized leapfrogging.

Among the key issues to be addressed is the apparent inability of technology-oriented corporations to maintain leadership in fields that they pioneered. There is a presumption that firms fail to remain competitive because of agency problems or other suboptimal managerial behaviour within these organizations. An alternative explanation is that technologically trailing firms, in symmetric competitive situations, will devote greater effort to innovation, so that a failure of technological leaders to maintain their position is an appropriate response to the competitive environment. In asymmetric situations, with entrants challenging incumbents, research does demonstrate that startup firms show a stronger endeavor to close up to or leapfrog the competitors. Such issues highlight the dynamics of the race within the given market structure in any of the areas concerned.

We observe two different kinds of market asymmetries with bearing on racing behaviour: risk-driven and resource-based. When the incumbents' profits are large enough and do not vary much with the product characteristics, the entrant is likely to choose the faster option in each stage as long as he has not fallen behind in the contest. In view of resource-based asymmetries, as a firm's stage resource endowment increases, it could use the additional resources to either choose more aggressive targets or to attempt to finish the stage sooner, or both. Previous work has suggested that a firm that surges ahead of its rival increases its investment in R&D and speeds up, while a lagging firm reduces its investment and slows down. Consequently, preceding effort suggests that the lead continues to increase. However, based on related work for the US and Japanese telecommunications industry when duopolistic and monopolistic competition and product system complexity for new products are accounted for, the speeding up of a leading firm occurs only under rare circumstances. For example, a company getting far enough ahead such that the (temporary) monopoly term dominates its payoff expression, will always choose the fast strategy, while a company that gets far enough behind will always choose the aggressive approach. Under these conditions, the lead is likely to continue to increase. If, on the other hand, both monopoly and duopoly profits increase substantially with increased aggressiveness then even large leads can vanish with significant probability.

Overall, this characterization highlights two forces that influence a firm's choices in the various stages: proximity to the finish line and distance between the firms. This probability of reaping monopoly profits is higher the farther ahead a firm is of its rival and even more so the closer the firm is to the finish line. If the lead company is far from the finish line, even a sizeable lead may not translate into the dominance of the monopoly profit term, since there is plenty of time for the lead situation to be reversed, and failure to finish first remains a probable outcome. In contrast, the probability that the lagging company will get to be a monopolist becomes smaller as it falls behind the leader. This raises the following question: what kind of actions cause a firm to get ahead? Intuitively, one would expect that a firm that is ahead of its rival at any time t, in the sense of having completed more stages by time t, is likely to have chosen the faster strategy more often. We will construct numerical estimates of the probability that a leading firm is more likely to have chosen a strategy faster to verify this intuition.

Moving away from the firm-led race patterns revolving in a particular industry to a clustering of racing on an industry level is putting industry in different geo-economics zones against each other and becoming dominant in strategic product/process technologies. Here racing patterns among industries in a relatively free-trade environment could lead to competitive advantages and more wealth creating and accumulating dominance in key product/process technologies in one region at the expense of others. There appears to be a link that individual races on the firm level induce similar races on the industry level and will be a contributing factor to the globalization of network industries.

Thus similar catch-up processes are taking place between leaders and followers within a group of industrialized countries in pursuit of higher levels of productivity. Supposing that the level of labour productivity were governed entirely by the level of technology embodied in capital stock, one may consider that the differentials in productivities among countries are caused by the 'technological age' of the stock relative to its 'chronological age'. The technological age of capital is the age of expertise at the time of investment plus years elapsing from that time. Since a leading state may be supposed to be furnished with the capital stock embodying, in each vintage, technology which was 'at the very frontier' at the time of investment, the technological age of the stock is, so to speak, the same as its chronological age.

While a leader is restricted in increasing its productivity by the advance of new technology, trailing countries have the potential to make a larger leap as they are provided with the privilege of exploiting the backlog in addition of the newly developed technology. Hence, followers being behind with a larger gap in technology will have a stronger potential for growth in productivity. The potential, however, will be reduced as the catch-up process goes on because the unexploited stock of technology becomes smaller and smaller. However, as new technologies arise and are rapidly adopted in a Schumpeterian process of 'creative destruction', their network effects induce rapid accelerating and cumulative growth potentials which are catalyzed through industry competition. In the absence of such a process we can explain the tendency to convergence of productivity levels of follower countries. Historically, however, it fails to answer alleged puzzles as to why a country, such as the United States, has preserved the standing of the technological leader for a long time since taking over leadership from Britain in around the end of the nineteenth century and why the shifts have taken place in the ranks of follower states in their relative levels of productivity (i.e. technological gaps between them and the leader). Abramovitz (1986) poses some extensions and qualifications on this simple catch-up hypothesis in an attempt to explain these facts. Among other factors than technological backwardness, he lays stress on a country's social capability in terms of years of education as a proxy of technical competence and its political, commercial, industrial, and financial institutions. To become effective social capability may also include or expand to 'deep craft', a 'set of knowings' on technological performance and industrial techniques (Arthur, 2009). The social capacity of a state may become stronger or weaker as technological gaps close or grow and thus Abramovitz argues that the actual catch-up process does not provide itself to simple formulation. This view has a common understanding to what another economist, Olson (1996), expresses to be 'public policies and institutions' as his explanation of the great differences in per capita income across countries, stating that any poorer states that implement relatively good economic policies and institutions enjoy rapid catch-up growth.

The suggestion should be taken seriously when we wish to understand the technological catching-up to American leadership by Japan, in particular during the post-war period, and explore the possibility of a shift in standing between these two countries. This consideration will directly bear on the future trend of the state of the art which exerts a crucial influence on the development of the world economy (Juma & Clark, 2002; Fagerberg & Godinho, 2004). These explanations notwithstanding, we venture as a major factor for divergent growth processes the level of intensity of the racing process within the most prevalent value-added industries with cross-sectional spillovers. These are the communications and information industries which have been shaped and led by leading American firms and where the rewards benefited their industries and country. Although European and Japanese companies were part of the race they were left behind in core markets reaping lesser benefits. (Since ICT investment relative to GDP is only less than half in states such as Japan, Germany and France compared to the US, 2% vs. more than 4% in 1999, this does not bode well for a rapid catch-up in those countries and a fortiori, for the EU as a whole).

Steering or guiding the process of racing through the pursuit of industrial policies aiming to increase competitive advantage of respective industries, as having been practiced in Japan, would stimulate catch-up races but appears to be less effective in promoting frontier racing. Another profound reason lies in the phenomenon of network externalities affecting ICT industries. That is, racing ahead of rivals in respective industries may create external economies to the effect that such economies within dominant industries tend to improve their international market position and therefore pull ahead in competitiveness vis-à-vis their (trading) partners. As Krugman (1991) observed: 'It is probably true that external economies are a more important determinant of international trade in high technology sectors than elsewhere'. The point is that racing behaviour in leading high-growth network industries by generating frontier positions, create critical cluster and network externalities pipelining through other sectors of the economy and create competitive advantages elsewhere, as supported by the increasing returns debate (Arthur, 1996). In this sense we can speak of positive externalities endogenizing growth of these economies and contributing to competitive advantage. All these characteristics lay the foundations of the 'Network Economy'.

The Network Economy is formed through an ever-emerging and interacting set of increasing returns industries; it is about high-intensity, technology driven-racing, dynamic entrepreneurship, and focused risk-taking through (free) venture capital markets endogenized by societal and institutional support. With the exception of pockets of activity in some parts of Europe (the UK and Scandinavia), and in specific areas such as mobile communications, these ingredients for the Network Economy are only in the early stage of emerging in Continental Europe, and the political mindset in support of the Network Economy is anything but prevalent. As long as we do not see a significant shift toward movements in this direction, Europe will not see the full benefits of the Network Economy within a Global Economy.

Racing behaviour on technological positions among firms in high- technology industries, as exemplified by the globally operating telecommunications and computer industries, produce spillover benefits in terms of increasing returns and widespread productivity gains. Due to relentless competition among technological leaders the network effects result in significant advantages in the value added to this industry contributing to faster growth of GDP, and through a flexible labour market, also to employment growth. This constitutes a new paradigm in economic thinking through network economies and is a major gauge to compare the wealth-creating power of the US economy over the past decade against the European and advanced Asian economies. It is interesting to speculate on the implications of the way companies in major high-technology markets, such as telecommunications, split clearly into the two major technology races, with one group of firms clearly lagging the other.

The trajectories of technological evolution certainly seem to suggest that firms from one frontier cannot simply jump to another trajectory. Witness, in this regard, the gradual process necessary for a firm in the catch-up race to approach those in the frontier race. There appears to be a frontier 'lock-in', in that once a company is part of a race, the group of rivals within that same race are the ones whose actions influence that company's strategy the most. Advancing technological capability is a cumulative process. The ability to advance to a given level of technical capability appears to be a function of existing technical capability. Given this path dependence, the question remains: why do some firms apparently choose a path of technological evolution that is less rapid than others? Two sets of possible explanations could be derived from our case analysis, which need not be mutually exclusive. The first explanation lingers primarily on the expensive nature of R&D in industries like telecommunications and computers which rely on novel discovery for their advancement. Firms choosing the catch-up race will gain access to a particular technical level later than those choosing the frontier, but will do so at a lower cost.

TECHNOLOGICAL FRONTIERS

The evolution of a cross section of high technology industries reflects repetitive strategic interactions between companies in a continuous quest to dominate the industry or at least to improve its competitive position through company level and industry level technological evolution. We can observe several racing patterns across industries, each of which is the result of a subset of firms jockeying for a position either as a race leader or for a position near the leader constituting a leadership club. The identification and interpretation of the races relies on the fact that different firms take very different technological paths to target a superior performance level with the reward of increasing market shares, maintaining higher productivity and profitability. In a Schumpeterian framework such races cannot be interpreted in a free-riding situation where one firm expands resources in advancing the state of technology and the others follow closely behind. Such spillover interpretations are suspect when products are in the domain of high complexity, of high risk in succeeding, and different firms typically adopt different procedural and architectural approaches.

The logic underlying this evolution holds in any industry in which two broad sets of conditions are satisfied. First, it pays for a firm to have a technological lead over its rival; it also boosts its market image and enhances its reputational capital. Second, for various levels of technological complexity among the products introduced by various firms, technological complexity can be represented by a multi-criteria performance measure, that is, by a vector-valued distance measure. The collection of performance indicators, parameters, being connected with each other for individual companies form an envelope that shapes a 'technological frontier'. The technological frontier is in fact a reasonable indicator of the evolving state of knowledge (technical expertise) in the industry. At any point in time the industry technology frontier (ITF) indicates the degree of technical sophistication of the most advanced products carried by companies in that industry in view of comparable performance standards.

Firm level technology frontiers (FTF) are constructed analogously and indicate, at any point in time, the extent of technical sophistication achieved by the firm until that point in time. The evolution of company and industry level frontiers is highly interactive. Groups of company frontiers are seen to co-evolve in a manner that suggests that the respective firms are racing to catch up with, and get ahead of each other.

A data set could focus on a given set of products (systems) by major European, American or Asian enterprises in those industries for a sufficiently representative period of market evolution. In principle, we can identify at least two races in progress in the industries throughout a given period of duration. One comprises the world frontier race in each of those industries, the other, for example, the European frontier race which technically would constitute a subfrontier to the worldwide race. The aggregate technology frontier of the firms in a particular race (that is, ITF) is constructed in a manner similar to the individual FTFs. Essentially, the maximal envelope of the FTFs in a particular race constitutes the ITF for that race. The ITF indicates, as a function of calendar time, the best achievable performance by any firm in the race at a given date.

A statistical profiling of technological evolution and innovation relates to competitive racing among rival companies. Among the (non-exclusive) performance criteria to be assessed are: (1) frequency of frontier pushing; (2) technological domination period; (3) innovations vs. imitations in the race; (4) innovation frequency when behind or ahead; (5) nature of jumps, leapfrogging or frontier-sticking; (6) inter-jump times and jump sizes; (7) race closeness measures; (8) inter-frontier distance; (9) market leading through 'market making' innovations; and (10) leadership in 'innovation markets'.

A race may or may not have different firms in the leadership position at different times. It may be a tighter race at some times than at others, and in general, may exhibit a variety of forms of interesting behaviour. While analysis of racing behaviour is left to various interpretations, it is appropriate to ask why the firms are motivated to keep on racing at all. As access to superior technology expands the scope of opportunities available to the firms, the technology can be applied in a range of markets. However, leading edge technology is acquired at a cost. It seems unlikely that all the companies would find it profitable to compete to be at the leading edge all the time. Also not every firm has access to equal capabilities in leveraging a given level of technological resources. Firms may, for example, be expected to differ in their access to complementary assets that allows them to appropriately reap the benefits from their innovation. It is reasonable to assume that whatever the level of competence of a company in exploiting its resources it will be better off the more advanced the technology. Based on this procedure an analysis will show how dynamic competition evolved in the past.

Unlike other (statistical) indicators (such as patent statistics) referring to the degree of competitiveness among industries, regions and countries concerned, the proposed measures cover behavioral dynamic movements in respective industries, and therefore are able to lend intrinsic predictive value to crucial economic variables relating to economic growth and wealth creation. The results are likely to provide strategic support for industrial and technology policy in a regional or national context and will enable policy makers to identify strengths and weaknesses of relevant players and their environments in those markets. While this process looks like a micro representation of dynamic technological evolution driving companies and industries into leadership positions, we may construe an analogous process that drives a region or a nation into advancement on a macro scale in order to achieve a higher level pecking order among its peers. This may allow using the micro foundations of racing as a basis for identifying clubs of nations or regions among them to achieve higher levels and rates of growth.

Catch-up or Leapfrogging

It was Schumpeter (1947) who observed that it is the expectation of supernormal profits from a temporary monopoly position following an innovation that is the chief driver of R & D investment. Along this line, the simplest technology race model can be explained as follows: A number of firms invest in R&D. Their investment results in an innovation with the time spent in R&D subject to some varying level of uncertainty. However, a greater investment reduces the expected time to completion of R&D. The model investigates how many firms will choose to enter such a contest, and how much they will invest. However, despite some extensive theoretical examination of technological races there have been very few empirical studies on this subject (Lerner, 1997) and virtually none in the context of major global industries, and on a comparative basis.

Technological frontiers at the firm and industry race levels offer a powerful tool through which to view evolving technologies within an industry. By providing a benchmarking roadmap that shows where an individual firm is relative to the other firms in the industry, they highlight the importance of strategic interactions in the firm's technology decisions. From the interactive process of racing could emerge various behavioural patterns. Does lagging behind one's closest technological rivals cause a firm to increase its innovative effort? The term 'race' suggests that no single company would want to fall too far behind, and that everyone would like to get ahead. If a firm tries to innovate more when it is behind than when it is ahead, then 'catch-up' behaviour will be the dominant effect. Once a firm gets ahead of its rivals noticeably, then rivals will step up their efforts to catch up. The leader will slow down its innovative efforts until its rivals have drawn uncomfortably close or have surpassed it. This process repeats itself every time a company gets far enough ahead of its rivals. An alternative behaviour pattern would correspond to a firm increasing its innovative effort if it gets far enough ahead, thus making catch-up by the lagging firms increasingly difficult. This looks like the 'Intel Model' where only the paranoid survives (Grove, 1992). For any of these forms there appears to be a clear link to market and industry structure, as termed 'intensity of rivalry' by Kamien and Schwarz (1982).

We group two different kinds of races: one that is a frontier race among leaders and would-be leaders (first league) and another that is a catch-up race among laggards and imitators (second league). Though both leagues may play their own game, in a free market contest, it would be possible that a member of the second league may penetrate into the first, as one in the first league may fall back into the second. Another aspect of innovation speed has been addressed by Kessler and Bierly (2002). As a general rule they found that the speed to racing ahead may be less significant the more "radical" (drastic) the innovation appears to be and the more likely it leads to a dominant design. These two forms have been applied empirically to the development of the early Japanese computer industry (Gottinger, 2006a), that is, a frontier racing model regarding the struggle for technological leadership in the global industry between IBM and 'Japan Inc.' guided by MITI (now METI), and a catch-up racing model relating to competition among the leading Japanese mainframe manufacturers as laggards.

It is also interesting to distinguish between two sub-categories of catch-up behaviour. A lagging firm might simply try to close the gap between itself and the technological leader at any point in time ('frontier-sticking' behaviour), or it might try to actually usurp the position of the leader by 'leapfrogging' it. When there are disproportionately large payoffs to being in the technical lead (relative to the payoffs that a firm can realize if it is simply close enough to the technical frontier), then one would expect that leapfrogging behaviour would occur more frequently than frontier-sticking behaviour (Owen & Ulph, 1994). Alternatively, racing toward the frontier creates the 'reputation' of being an innovation leader facilitating to maintain and increase market share in the future (Albach, 1997). All attempts to leapfrog the current technological leader might not be successful since many lagging firms might be attempting to leapfrog the leader simultaneously and the leader might be trying to get further ahead simultaneously. Correspondingly, one should distinguish between attempted leapfrogging and realized leapfrogging. This phenomenon (though dependent on industry structure) appears as the predominant behaviour pattern in the US and Japan frontier races (Brezis et al, 1991). Albach (1993) cites studies for Germany that show otherwise.

Leapfrogging behaviour influenced by the expected size of payoffs as suggested by Owen and Ulph (1994) might be revised in compliance with the characteristics of industrial structure of the local (regional) markets, the amount of R&D efforts for leapfrogging and the extent of globalization of the industry. Even in the case where the payoffs of being in the technological lead are expected to be disproportionately large, the lagging companies might be satisfied to remain close enough to the leader so as to gain or maintain a share in the local market. This could occur when the amount of R&D efforts (expenditures) required for leapfrogging would be too large for a lagging firm to be viable in the industry and when the local market has not been open enough for global competition: the local market might be protected for the lagging local companies under the auspices of measures of regulation by the government (e.g. government purchasing, controls on foreign capital) and the conditions preferable for these firms (e.g. language, marketing practices).

When the industrial structure is composed of multi-product companies, as for example it used to be in the Japanese computer industry, sub-frontier firms may derive spill over benefits in developing new products in other technologically related fields (e.g. communications equipment, consumer electronic products). These companies may prefer an R&D strategy just to keep up with the technological frontier level (catch-up) through realizing a greater profit stream over a whole range of products.

What are the implications of the way firms split cleanly into the two technology races, with one group clearly lagging the other technologically? The trajectories of technological evolution certainly seem to suggest that firms from one frontier cannot simply jump to another trajectory. Witness, in this regards the gradual process necessary for the companies in the Japanese frontier to catch up with those at the global frontier. There appears to be a front line 'lock-in' in that once a firm is part of a race, the group of rivals within that same race are the ones whose actions influence the firm's strategy the most.

Advancing technological capability is a cumulative process. The ability to advance to a given level of technical capability appears to be a function of existing technical potential. Given this 'path dependence', the question remains: why do some firms apparently choose a path of technological evolution that is less rapid than others are? We propose two sets of possible explanations, which need not to be mutually exclusive. The first explanation hinges primarily on the expensive nature of R & D in industries like the computer industry, which rely on novel scientific discovery for their advancement. Firms choosing the subfrontier will gain access to a particular technical level later than those choosing the frontier, but will do so at a lower cost. Expending fewer resources on R & D ensures a slower rate of technical evolution. The second explanation relates mainly to technological spillovers. Following the success of the frontier firms in achieving a certain performance level, these become known to the subfrontier firms. In fact, leading edge research in the computer industry is usually reported in patent applications and scientific journals and is widely disseminated throughout the industry. The hypothesis is that partial spillover of knowledge occurs to the subfrontier firms, whose task is then simplified to some extent. Notice that the subfrontier firms still need to race to be technological leaders, as evidenced by the analysis above. This implies that the spillovers are nowhere near perfect. Company specific learning is still the norm. However, it is possible that knowing something about what research avenues have proved successful (for the frontier firms) could greatly ease the task for the firms that follow and try to match the technical level of the frontier company.

Statistical Metrics of Industrial Racing Patterns

Statistically descriptive measures of racing behaviour can be established that reflect the richness of the dynamics of economic growth among competing nations. The point of departure for a statistical analysis of industrial racing patterns is the aggregate technological frontier represented by the national production function as a reasonable indicator of the evolving state of knowledge (technical expertise) in a nation or region which is the weighted aggregate of all industries or activities that themselves are represented by industry technology frontier (ITF). Firm level technology frontiers (FTF) are constructed analogously and indicate, at any point in time, the weighted contribution of that firm to the industry on standard industry classification.

In this context we define ‘race’ as a continual contest for technological superiority among nations or regions with key industries. Under this conceptualisation a race is characterised by a number of countries whose ITF’s remain ‘close’ together over a period (T) of, say, 25 to 50 years. The distinctive element is that countries engaging in a competition have ITF’s substantially closer together than those of any company not in the race. A statistical analysis should reflect that a race, as defined, may or may not have different countries in the leadership position at different times. It may be a tighter contest at some times than at others, and in general, may exhibit a variety of forms of industrial behaviour. We look for clusters of firms who’s ITFs remain close enough throughout the duration (formal measures of closeness are defined and measured). We identify races to take place at any level of industrial performance between the very top and the very bottom throughout 50 years duration that is racing from the bottom to racing to the top.

One comprises the world frontier race in each of those industries, the other a subfrontier race (say, North America, Europe, East Asia, China, India, Latin America, Africa) which technically would constitute a subfrontier to the world, allowing under the best of circumstances for the subfrontier to be the frontier. Since the level and breadth of industrial activity is reflected as an indicator for economic welfare, racing to the top would go parallel with economic growth and welfare enhancing, whereas racing from the bottom would correspond to poverty reduction and avoiding stationary (under)development traps.

Characterization of Statistical Indicators of Industrial Racing

While a variety of situations are possible, the extremes are the following: (a) one country may push the frontier at all times, with the others following closely behind, (b) some countries share more or less equally in the task of advancing the most value generating industry technology frontiers (ITFs). Depending on the situation the most value generating industries may be high technology based increasing returns or network industries that are able to induce complementary emerging industries with high potentials. Extreme situation (a) corresponds to the existence of a unique technological leader for a particular race, and a number of quick followers. Situation (b), on the other hand, corresponds to the existence of multiple technological leaders.

Assessment of Frontier Pushing: .The relevant statistics for the races relate to counting the times the ITFs are pushed forward by countries or regions at large within a global or regional frontier. Frontier pushing can be triggered through industrial policy by governments or well fostered entrepreneurship in an advanced capitalistic system

Domination Period Statistics: Accepting the view that a country/region has greater potential to earn income and build wealth from its technological position if it is ahead of its race suggests that it would be interesting to examine the duration of time for which a country can expect to remain ahead once it finds itself pushing its ITF. We statistically define the 'domination period' to be the duration of time for which a country leads its particular race. It is interesting to note that the mean domination period is virtually indistinguishable for the three races, and lies between three and four years. A difference of means test cannot reject the hypothesis that the mean years of domination tend to cluster but hardly converge. So countries in each of the races can expect to remain ahead approximately in proportion to their technological capability and more than the amount of time after they have propelled themselves to the front of their respective races. However, the domination period tends to be a more uncertain quantity in the world frontier race, to a lesser degree in the EU frontier race than in any smaller regional races (as evidenced by the lower domination period standard deviation).

*Catch-up Statistic***s**: If key industries of a country push to innovate more when they are behind than when they are ahead, then 'catch- up' behaviour will be the dominant effect. For each country/region, these statistics compare the fraction of the total innovations carried out by industries in that country (i.e. the fraction of the total number of times that their ITFs advance) when it was engaging in its race when lagging, with the fraction of times that the country actually led its race. In the absence of catch-up behaviour, or behaviour leading to a country increasingly dominating its rivals, we would expect to see no difference in these fractions. Then the fraction of time that a country is ahead of its race could be an unbiased estimator of the fraction of innovations in its key industries that it engages in when it is ahead. Relevant data, however, suggest that this is usually not the case. They appear to show that the fraction of times a state leads its race at any development level in a group or club is larger than the fraction of innovations that occur when the country is ahead, i.e. more innovations occur when the country is lagging than would be expected in the absence of catch-up or increasing dominance behaviour. A major exception would arise if the country would act like an 'Intel Economy', where unchallenged leadership in key industries creates incentives to increase the lead to its rivals. Catch-up behaviour is supported by additional observations, as derivable from convergence and conditional convergence in the economic growth process that countries make larger jumps (i.e. the ITFs advance more) when they are behind than when they are leading the rac**e**

*Leapfrogging Statistics***:** From this, the distinction emerges between two kinds of catch-up. A lagging country might simply try to close the gap between itself and the technological leader at any point in time (frontier-sticking behaviour), or it might try to actually usurp the position of the leader by 'leapfrogging' it. When there are disproportional larger incomes per head when being in the technical lead (relative to a situation that a country can realize if it is simply close enough to the technological frontier), then one would expect that leapfrogging behaviour would make it a more attractive incentive than frontier-sticking behaviour.

All attempts to leapfrog the current technological leader might not be successful since many lagging firms/industries might be attempting to leapfrog the leader simultaneously. Correspondingly, we observe both the attempted leapfroggings and the realized leapfroggings. It appears likely that the leapfrogging phenomenon would be more predominant in the premier league than in following up leagues.

Interfrontier Distance: How long does 'knowledge' take to spillover from frontier to subfrontier industries? This requires investigating "interfrontier distance". One measure of how much subfrontier industries' technology lags the frontier industries' technology could be graphed as "subfrontier lag" in terms of calendar time. At each point in time, this is simply the absolute difference in the subfrontier performance and the frontier performance time. The graph would clearly indicate that this measure has been declining or increasing more or less monotonically over the past 50 years to the extent that the subfrontier industries have been able/unable to catch up with the frontier industries. A complementary measure would be to assess the difficulty of bridging the lag. That is, how much longer does it take the subfrontier to reach a certain level of technical achievement after the frontier has reached that level? Thus it might very well turn out that the interfrontier distance may be decreasing though the difficulty in bridging the gap is increasing.

Race Closeness Measure (RCM): None of the previous analyses tell us how close any of the overall races are over a period of time. The races are all distant/close by construction, however, some might be closer than others, We define 'a measure of closeness' of a race (RCM) at a particular time as follows:

$$RCM (t) = \Sigma_0^N [F_i (t) - F_j (t)]^2 / N (t) \quad (1)$$

where F_i (t) is country's i ITF at time t, F_j(t) is country's j comparable ITF at time t = max [ITF(t)] for each i, j and N(t) is the number of active key value-generating industries at time t.

The measure (Equation 1) thus constructed has a lowest value of 0, which corresponds to a 'dead heat' race. Higher values of the measure correspond to races that are less close. Unlike the earlier characteristics (domination period length, innovation when ahead versus when behind, leapfrogging versus frontier-sticking) which investigate the behaviour of a particular feature of the race and of a particular industry in relation to the race frontier, the RCM is more of an aggregate statistic of how close the various racing parties are at a point in time. The closeness measure is simply an indication of parity, and not one that says anything per se about the evolution of the technological frontier. To see this, note that if none of the frontiers were evolving, the closeness measure would be 0, as it would be if all the frontiers were advancing in perfect lock-step with one another.

TABLE 1. ITF SHIFTS ACROSS AGGREGATED INDUSTRIES

Aggregate Industries 1980-	ITF (max = 100)	2010	GDP (%)
US	80	85	70
EU	60	75	60
China	15	60	50
USSR	30	35	40
India	25	40	30
Brazil	20	30	25
Japan	70	70	65

We talk about value-added increasing returns industries over a period of 30 years. The industries comprise ICT, Consumer Electronics, Chemicals and Materials, Automobiles, Pharma/Biotech, Machine Tools, Medical Instruments, Aerospace/Defense, Energy Technologies, and HT Transportation Systems. Industry sectors can be assigned to various countries/regions such as US, EU, China, Russia, India, Brazil, Japan (Table 1). We benchmark the industry technology frontiers (ITFs) accordingly, that is, highest 'state of knowledge' at time t is 100 pc. The countries' rank to the max ITFs is assessed as the share of the max ITF. The assessment intervals are spaced in five year intervals starting in 1980 until 2010.

Efficiency

Let's explore the inefficiency of the follower nations; i.e., the negative effect on the potential technology gap stemming from inefficient social and institutional factors. A good example of cross industrial inefficiencies over a historically representative period (1810-2000) is Russia that was hardly advancing economically against underdeveloped benchmark countries and falling behind leading economies, reinforced through the bolshevik revolution and its underperforming economic mechanism design (Gaidar, 2012). Increasing efficiencies deblock catch-up in lagging countries (Juma & Clark, 2002). Efficiency is found by dividing a nation's estimated fixed effect by the regional adoption rate. As defined here, it is quite robust to different estimations and samples. The relative efficiencies of the nations within regions appear to conform to common beliefs. For example, in Europe, the Netherlands, Belgium and Switzerland are the most efficient while Turkey, Portugal and Greece are the least efficient. In East Asia, Hong Kong is the most efficient while Indonesia and Thailand are the least efficient. Finally, in Latin America, Mexico and Argentina are at the top and Honduras and Bolivia at the bottom. Another way to discuss the findings is to consider the time required to catch-up. Previously, Parente and Prescott (2004) showed that countries with lower levels of relative efficiency will adopt modern technologies at much later dates. Conversely, one could argue that if those countries adopt modern technologies concurrently with their low level of relative efficiency then their rates of growth would stay at a subpar level of their potential.

One major source of efficiency generation for a country, according to Parente and Prescott (2004), is belonging to a 'free trade club' that improves efficiency through greater industrial competition. We calculate the required time period until the nations reach their frontier when only the catch-up term and inefficiency are allowed to vary across regions and countries. Two frontiers are considered: nations' inefficiency frontier and the leader nation's frontier. The latter requires that the inefficiency levels fade away in time which we assume occurs at the rate of ρ. The European countries, with the exception of Turkey, all seem to have reached their inefficiency reduced frontier. The same is true for most of the East Asian countries. Thus, these nations will not catch-up with the US without higher accumulation rates or improved efficiency. For Latin America, most countries are still catching-up with their inefficiency frontier, so that if accumulation rates were the same catch-up would still take place through diffusion of disembodied technology. Of course, if inefficiency levels remain then a follower could never completely catch-up with the leader by taking advantage of the technology gap alone. As an illustrative example, for the required time to catch-up with the leader if inefficiency levels were improving at the rate ρ much of Europe and Latin America could then approach the frontier faster than East Asia on account of East Asia's lower rate of technology adoption. This begs the question of what determines these. (in)efficiencies?

It is reasonable to expect a tradeoff between a general technology level (GTL) of a nation's leading industries and its institutional efficiencies (IE). Thus, using an aggregate score, (GTL, IE) , say, a country may be in the top rank of GTL but weak on IE which may be surpassed in growth by one which is lower in GTL rank but strong on IE.

CONCLUSION AND FURTHER DISCUSSION

Economic growth over the long-run can only be achieved in the course of a real, sustainable value-creating process through industrial performance and open markets in which technology and innovation are the key facilitators. Nations with their industries engage in rival contests in what we term industrial races within a given international trade regime. This reflects a micro-economic based behavioral focus on economic growth (positive or negative). It builds a deeper foundation to explanations of economic growth than conventional macro-economic texts . It also uncovers the true sources of growth as a tool for growth diagnostics (Rodrik, 2007) allowing to embrace other observations on urban growth and non primarily economic factors. In an influential paper in Foreign Affairs entitled 'Can India overtake China' Huang and Khanna (2003) first looked at macro-economic factors, which favor China. They then considered micro-economic structures and behaviors such as competent indigenous entrepreneurship, a sound capital market, an independent legal system, property rights and a grass roots approach to development. The latter all favor India in the long run, say over the next fifty years.

In a widely covered empirical investigation on global growth patterns we concur with Easterly and Levins' (2002) finding that it is not factor accumulation, per se, but total factor productivity that explains cross-country differences in the level of GDP growth rates. This total productivity in turn is derived from technology (innovation) transfer and diffusion, its' supporting institutional characteristics and cultural dependence. Of course, on a deeper level, considerations of merely formal institutions may not suffice for explanations but instead forms of economic mechanism design may be called for that effectively deal with (enforce rules on) 'moral hazard' and 'adverse selection' issues (Myerson, 2006). Economic growth in a decentralized system would be fully supported by a a Hayek-Hurwicz mechanism design.

Observations on firm-led racing patterns emerging in oligopolistic market structures of particular high tech industries, and the clustering of racing on an industry level are putting companies in different geo-economic zones against each other, becoming dominant in strategic product/process technologies. Here racing patterns among industries in a relatively free trade environment could lead to competitive advantages and more wealth creating and accumulating dominance in key product / process technologies in one region at the expense of others. The question is whether individual contests on a firm level induce similar effects on an industry level and if so, what controlling effects may be rendered by regional or multilateral policies on regulatory, trade and investment matters? The point is that racing behaviour in leading high technology industries by generating frontier positions create cluster and network externalities pipelining through other sectors of the economy and creating competitive advantages elsewhere, as supported by the 'increasing returns' debate. In this sense we can speak of positive externalities endogenizing growth of these economies and contributing to competitive advantage.

We are about to show in the upcoming chapters how technological racing, rivalry and competition instigates a process of innovation, industrial and market evolution and how it extends to larger entities than firms and industries to regions and national economies or economy networks. It will show what drives economic growth and globalization, which industries are most significantly affected and how technological racing results in value generation in increasing returns and network industries. Furthermore, we consider how the emergence of selective managerial strategies is most likely to carry success in the pursuit of corporate and industrial policies.

Welfare enhancing technology racing as a constituent element of the capitalist process reinforced by globalization provides social benefits far exceeding the costs. Even more important, any alternative path, other than the competitive, would likely be inferior given the costs in that it would generate a less valued and less welfare producing technology portfolio. That is, even if the competitive process is wasteful, (for example, in parallel or correlated technology development) its unique high value innovation outcome far exceeds the benefits of any alternative path. There is historical, observational and analytical evidence given in Gottinger and Goosen (2012).

On a national scale simple catch-up hypotheses have put emphasis on the great potential of adopting unexploited technology in the early stage and the increase of self-limiting power in the later stage. However, an actual growth path of technological trajectory of a specific economy may overwhelmingly be constrained by social capability. The capability also endogenously changes as states of the economy and technology evolve. The success of economic growth due to diffusion of advanced technology or the possibility of leapfrogging is mainly attributable to how the social capability evolves (i.e., which effects become more influential: growing responsiveness to competition or growing obstacles to it on account of vested interests and established positions). Another observation relates to policy inferences on market structure, entrepreneurship, innovation activity, industrial policy and regulatory frameworks in promoting and hindering industry frontier races in a global industrial context. Does lagging behind one's closest technological rivals cause an industry to increase its innovative effort?

On an industry level, among the key issues to be addressed is the apparent inability of technology oriented corporations to maintain leadership in fields that they pioneered. There is a presumption that firms fail to remain competitive because of agency problems or other suboptimal managerial behaviour within these organizations. An alternative explanation is that technologically trailing firms, in symmetric competitive situations, will devote greater effort to innovation, so that a failure of technological leaders to maintain their position is an appropriate response to the competitive environment. In asymmetric situations, with entrants challenging incumbents, research does demonstrate that start-up firms show a stronger endeavour to close up to or leapfrog the competitors. Such issues highlight the dynamics of the race within the given market structure in any of the areas concerned.

Catch-up processes are taking place between leaders and followers within a group of industrialized countries in pursuit of higher levels of productivity and economic growth. Supposing that the level of labour productivity were governed entirely by the level of technology embodied in capital stock, one may consider that the differentials in productivities among countries are caused by the 'technological age' of the stock used by a country relative to its 'chronological age'. The technological age of capital is a period of technology at the time of investment plus years elapsing from that time. Since a leading country may be supposed to be furnished with the capital stock embodying, in each vintage, technology which was 'at the very frontier' at the time of investment, 'the technological age of the stock is, so to speak, the same as its chronological age'. While a leader is restricted in increasing its productivity by the advance of new technology, trailing countries 'have the potential to make a larger leap' as they are provided with the privilege of exploiting the backlog in addition of the newly developed technology. Hence, followers being behind with a larger gap in technology will have a stronger potential for growth in productivity. The potential, however, will be reduced as the catch-up process goes on because the unexploited stock of technology becomes smaller and smaller. However, as new technologies arise and are rapidly adopted in a Schumpeterian process of 'creative destruction', their network effects induce rapid accelerating and cumulative growth potentials being catalyzed through industry racing.

In the absence of such a process, we can explain the tendency to convergence of productivity levels of follower countries. Historically, it fails to answer alleged puzzles of why a country, such as the United States, has preserved the standing of the technological leader for a long time since taking over leadership from Britain in around the end of the nineteenth century and why the shifts have taken place in the ranks of follower countries in their relative levels of productivity (i.e. technological gaps between them and the leader). Abramovitz (1986) poses some extensions and qualifications on this simple catch-up hypothesis in the attempt to explain these facts. Among other factors than technological backwardness, he lays stress on a country's 'social capability' (i.e. years of education as a proxy of technical competence and its political, commercial, industrial, and financial institutions). The social capability of a country may become stronger or weaker as technological gaps close and thus, he states, the actual catch-up process does not lend itself to simple formulation. This view has a common understanding to what another economist, Olson (1996), expresses to be public policies and institutions as his explanation of the great differences in per capita income across countries, stating that any poorer countries that adopt relatively good economic policies and institutions enjoy rapid catch-up growth. The suggestion should be taken seriously when we wish to understand the technological catching-up to American leadership by Japan, in particular, during the post-war period and explore the possibility of a shift in standing between these two countries. This consideration will directly bear on the future trend of the state of the art, which exerts a crucial influence on the development of the world economy.

These explanations notwithstanding, we venture as a major factor for divergent growth processes the level of intensity of the racing process within the most prevalent value-added industries with cross sectional spillovers. These are the communications and information industries, which have been shaped and led by leading American firms and where the rewards benefited their industries and country. Though European and Japanese companies were part of the race they were left behind in core markets reaping lesser benefits. The IT investment relative to GDP, for example, used to be only less than half in countries such as Japan, Germany and France compared to the US. This does not bode well for a rapid catch-up in those countries. Steering or guiding the process of racing through the pursuit of industrial policies aiming to increase competitive advantage of respective industries, as having been practised in Japan, would stimulate catch-up races but appears to be less effective in promoting frontier racing. Another profound reason lies in the phenomenon of network externalities affecting IT industries. That is, racing ahead of rivals in respective industries may create external economies to the effect that such economies within dominant industries tend to improve their international market position and therefore pull ahead in competitiveness vis-a-vis their (trading) partners.

The point is that racing behaviour in leading high growth network industries by generating frontier positions create critical cluster and network externalities pipelining through other sectors of the economy and creating competitive advantages elsewhere, as supported by the increasing returns debate (Arthur, 1996). In this sense we can speak of positive externalities endogenizing growth of these economies and contributing to competitive advantage.

All these characteristics lay the foundations of the 'Network Economy'. The latter is formed through an ever emerging and interacting set of increasing returns industries, it is about high-intensity, technology driven racing, dynamic entrepreneurship, focussed risk-taking through (free) venture capital markets endogenized by societal and institutional support.

Racing behaviour on technological positions among firms in high technology industries, as exemplified by the globally operating telecommunications, and computer industries, produce spillover benefits in terms of increasing returns and widespread productivity gains. Due to relentless competition among technological leaders the network effects lead to significant advantages in the value added to this industry, contributing to faster growth of GDP, and through a flexible labour market, also to employment growth. This constitutes a new paradigm in economic thinking through network economies and is a major gauge to compare the wealth creating power of the US economy against the European and advanced Asian economies.

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