# The Co-evolution of Technology and Institutions: Lessons from Past Industrial Revolutions*

**Judit Kapás**
Associate Professor
Department of Economics
University of Debrecen
4028 Debrecen, 26 Kassai street, Hungary
Tel: +36-52-416-580, Fax: +36-52-419-728
e-mail: judit.kapas@econ.unideb.hu

*Paper for the EBHA 2008 Conference "Transactions and Interactions – The Flow of Goods, Services and Information", August 21-23, 2008, Bergen, Norway*

## Abstract

Evolutionary approaches are flourishing in explaining industrial revolutions, based on the view that the development of technology can be best understood as an evolutionary process (e.g., Basalla 1988). However, this view is further developed by scholars such as Langlois (1999), Pelikan (2003) or Mokyr (2002) who argue that technology co-evolves with institutions. By augmenting Pelikan's (2003) framework, in this paper I will develop a general model of the co-evolution of technology and institutions. Then through the examples of the British and the Second Industrial Revolution, I will use this theoretical model as an ideal type to establish the particular features of these historical events. The significance of the historical analysis of the co-evolution of technology and institutions is twofold. First, it may provide us with a more precise understanding of the British and Second Industrial Revolution. Second, the lessons drawn from past industrial revolutions may give us guidelines to better understand the relationship between today's ICT revolution, considered the third industrial revolution (Freeman and Louça 2001, Mokyr 1997).

**Keywords:** industrial revolutions, technological change, institutions, evolution

* This paper has benefited from the support of the National Office for Research and Technology (Jedlik Ányos Research Program, contract no: OM-00019/2007), the Hungarian Scientific Research Fund (contract no: 67713) and the János Bolyai Scholarship of the Hungarian Academy of Sciences.

## 1. Introduction

Economic historians have always investigated both the British Industrial Revolution (BIR) and the Second Industrial Revolution (SIR). Books and articles on the topic are numberless. Recently however, besides economic historians, scholars in growth theory and institutional economics are developing an interest in industrial revolutions as well. This newly emerged interest can be traced back to an increased focus on economic development and institutions that foster it in general and particularly in today's ICT revolution. The "style" of the analysis of industrial revolutions by these scholars differs from purely historical analyses: formal models, comparative analysis and econometric techniques are all used. These new research lines complement those of economic historians by shedding light on many new aspects of industrial revolutions.

Evolutionary approaches are equally flourishing in explaining industrial revolutions, based on the view that the development of technology can be best understood as an evolutionary process (e.g., Basalla 1988). However, the view that technology co-evolves with institutions (e.g., Langlois 1999, Pelikan 2003, Mokyr 2002b), which is a very natural insight among evolutionary economists, is becoming more and more solid even within a wider circle of economists (e.g., Helpman 1998). The prefix "co" is used in the sense that technology and institutions are evolving together, that is, two evolving phenomena interact causally with one another.[1]

A basic general model of the co-evolution of technology and institutions is developed by Pelikan (2003), but its major shortcoming is reverse causality; accordingly, this model cannot explain how an industrial revolution begins. Therefore, by augmenting Pelikan's (2003) framework, I will develop a general model of the co-evolution of technology and institutions in which I identify the causal link between the two units. Then through the examples of the British and the Second Industrial Revolution, I use this theoretical model as an ideal type to establish the particular features of these historical events.

The significance of the historical analysis of the co-evolution of technology and institutions is twofold. First, it may provide us with a more precise understanding of the British and Second Industrial Revolution. Second, the lessons drawn from past industrial revolutions may give us guidelines to better understand the relationship between today's ICT revolution, considered the third industrial revolution (Freeman and Louça 2001, Mokyr 1997,

[1] "Two evolving populations coevolve if and only if they both have a significant causal impact on each other's ability to persist" (Murmann 2003:22).

Mokyr 2002a, Lucas 2002) and institutional changes, which can help design policies and institutions to foster economic development.

The paper is organized as follows. Section 2 briefly shows Pelikan's (2003) model of the co-evolution of technology and institutions, and based on a criticism of this theory, it also argues for a reliance on the concept of social technology rather than institutions and for differentiating between macro- and microinventions within technology. Based on these distinctions, Section 3 develops a general model of a co-evolution of physical and social technology. Sections 4 and 5 analyses the co-evolution of social and physical technology during the BIR and the SIR, respectively, through the lens of the general model. Section 6 concludes.

## 2. Two kinds of technological advance and the hierarchy of institutions

When developing a general framework for an understanding of the co-evolution of technology and institutions Pelikan's (2003) model seems to be a good starting point.[2] His idea is that technologies and institutions must continually adapt to and depend on each other, i.e., the interplay works in both directions, from technology to institutions and from institutions to technology. In order to take both directions into account he develops a theoretical model with feedback loops, and in order to explain the interplay between technology and institutions he proposes to differentiate between two characteristics of institutions. On the one hand, there is a certain variety of technological changes that the prevailing institutions can absorb without themselves having to change. This is called institutions' innovation absorptivity. On the other hand, there is a certain variety of technological changes that the prevailing institutions allow and make likely to be generated. This is referred to as institutions' innovation potential. According to Pelikan, institutions and technologies generally co-evolve along the following lines. The innovation potential of the prevailing institutions may allow some technological changes which exceed the institutions' innovation absorptivity.[3] Once such a change is produced, this will create a pressure for an institutional change. The story will be repeated when the new institutions became established. As Pelikan (2003) argues, here we have in fact

[2] Note however that although Nelson (e.g., Nelson 1994, 2001, 2002, Nelson and Sampat 2001, Nelson, Peterhansl and Sampat 2004) has to be considered the most agonistic proponent of the view that institutions and technology co-evolve, he has not developed a "model" of the co-evolution.
[3] It is worth noting that Pelikan does not provide an explanation for how and why technological changes come to occur.

two evolutionary processes forming a co-evolutionary process, in which technological changes alternate with institutional changes.

Clearly, in this co-evolutionary process there are feedback loops between technological and institutional changes. However, the major problem here is that there is a circularity of causation: technological changes cause institutional changes which, in their turn, entail further technological changes. This problem becomes more serious if we take into account the fact that some technological change can be absorbed by institutions; that is not all technological change provokes institutional changes. And on the other hand, there is no doubt that it is not all but only certain institutional change that affects technology. Accordingly, the crucial question in an understanding of the co-evolution is which institutions (if not all) and which kinds of technological change affect each other, and in which way. Moreover, the most important question is what drives the whole co-evolutionary process. These problems can be surmounted by reconsidering Pelikan's model, based on two kinds of distinction: between types of technological changes and types of institutions. My argument is that a distinction between macroinventions and microinventions as proposed by Mokyr (1990) may be very useful in providing a more comprehensive view of the co-evolution of technology and institutions. As far as institutions are concerned, I argue for taking into account the hierarchy of institutions as proposed by Williamson (2000), a schema which calls for the interrelationship between institutions at various levels. In what follows I will highlight how these two distinctions help improve an understanding of the co-evolutionary process.

Mokyr (1990) proposes to call major technological advances macroinventions, which create essentially new techniques and tend to be abrupt and discontinuous. They represent a break compared to the previous techniques. As Mokyr (1999) proposes the idea of macroinventions is akin to the notion of speciation in biology: speciation is the emergence of a new category of life that is distinct from everything that existed before. By analogy, macroinventions are inventions that start the emergence of a new "technological species". Macroinventions are at the core of the forces behind long-term growth and structural changes (Perez 2004). They are usually followed by a large number of microinventions that improve and refine them or make them workable without changing the context of the macroinventions.[4] Microinventions result, for instance, in better quality or cost reduction. As Crafts (1995) points out microinventions involve learning by doing and learning by using.

[4] As Mokyr (1991) argues, without improvements most major inventions would have remained in the domain of curiosa, but without breakthroughs; with only local improvements today we would still be riding perfectly designed horse-and-buggies.

The reason for differentiating between macro- and microinventions is that they are driven by different forces. Since microinventions are the results of a conscious search for improvements in macroinventions, they can be conceptualized as economic forces that are driven, at least partly, by the law of demand and supply (Mokyr 1990). However, “[m]acroinventions … do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous variables. Many of them resulted from strokes of genius, luck, or serendipity” (Mokyr 1990:13). Usually macroinventions emerge in clusters in which one macroinvention can stimulate others and they are followed by numerous microinventions, creating an industrial revolution.[5]

Macroinventions are usually responsible for the emergence of a new technological paradigm[6], while microinventions stay within the same technological paradigm and represent small incremental steps in technical change. At this point Pelikan’s (2003) model can be augmented: since macroinventions, by definition, cannot be absorbed by the prevailing institutions, sooner or later they provoke *significant* changes in institutions. Surely, each new techno-economic paradigm initiated by macroinventions requires a matching with transformations at the institutional level. The new technologies cannot thrive in the environment of the preceding paradigm, a gradually worsening mismatch occurs, in which the greater and greater disruption gradually makes institutions more and more counterproductive. This mismatch sooner or later leads to a fundamental restructuring of the socio-institutional framework (Perez 1983, 2004, Freeman and Louça 2001). However, an important question is which institutions will change and how.

In this context, the hierarchy of institutions proposed by Williamson (2000) seems to be a very fruitful way to analyze institutional changes. Williamson’s idea is that various institutions are related to and depend on each other, where the direction and the concrete form of the dependence are determined by a hierarchy of institutions. He refers to this hierarchical schema in terms of levels of social analysis (see Figure 1). In fact, in this schema we should focus our attention on levels 1 to 3, since level 4 is concerned with standard market adjustments in prices and quantities. That is, institutions appear in levels 1 to 3.

The first level is related to embeddedness, where customs, norms, religions, and traditions play the major role, which are informal institutions. At this level the social changes take place

[5] The “technological definition of the industrial revolution is a clustering of macroinventions leading to an acceleration in microinventions” Mokyr (1993:22).

[6] The concept was developed in Perez (1983, 1985) and Freeman (1991). Each particular historical form of a paradigm results in a substantial change in the relative cost structure and it involves profound changes in the relative importance of the various branches of the economy.

very slowly (100-1000 years), consequently most economists regard them as external and unalterable conditions. At the second level we have the formal "rules of the game" (North 1990), i.e., constitutions, political institutions, laws, courts, institutions of enforcement, property rights representing the institutional environment. In addition, the monetary and financial system, the rules of migration of labor forces, international trade and capital flows, etc. can be found at this level, too. Here the frequency of change of the institutions is shorter than at level 1, but longer than that of the usual economic analysis (10-100 year period). At the third level we have the governance structures (Williamson 1991), namely firms, markets and hybrids forms that are changing within 1-10 year periods. Here questions arise related to the contractual relations, organizational boundaries, corporate governance and finance, that is, the play of the game.

As explained by Williamson (2000) particular levels are not independent of each other; rather, each level poses a constraint on institutional change at the level below. For instance when analyzing political institutions (level 2) we take the norms and beliefs as given (level 1). This kind of constraint is represented by bold arrows. However, Williamson (2000) also emphasizes that there exist feedback mechanisms between the levels, represented by broken arrows. However he argues that these effects are negligible.

In fact, what we have here is a hierarchy of institutions, which suggests that (1) there are three categories of institutions, namely informal institutions, formal institutions and organizations (governance structures), and (2) they are intertwined: partly shaped, partly constrained by each other. The advantage of this structure for an understanding of the co-evolution of technology and institutions will become quite clear in the next section, but here I would simply like to emphasize its usefulness from another viewpoint. In the literature there is no agreement on what an institution is.[7] Relying on the Williamsonian framework allows us to "equate" the term "institution" with "social technology", which makes it possible to avoid the definitional problem. Yet, what Nelson and Sampat (2001) and Nelson (2002) mean by social technology covers the institutions at levels 1 to 3. In this way, the concept of social technology is broad enough to make it possible to analyze the effects even between institutions.

To put it clearly, social technology involves the institutional environment, usually defined as determining the rules of the game (North 1990), and organizations (governance structures in terms of Williamson (1991) which are determined by the rules of the game together with

[7] For the multitude of definitions see among others North (1990), Hodgson (2006), Aoki (2007), Greif (2005).

deeply embedded norms and rules.[8] Clearly, this is a broad concept encompassing both ways of organizing activities within organizations, and ways of organizing transactions across organizational borders, which involves patterned human interactions. Put differently, Nelson includes under the social technology umbrella both behaviors associated with getting things done within organizations, and actions to get things done involving two or more separate individuals. The social technology concept is meant to encompass those aspects of goal-oriented ways of doing things, where behavior of agents is tailored to or intended to influence the expected actions of other agents. Nelson (2002) also argues that social technologies are to seen not so much as constraints on behavior, but rather as defining the effective way to do something and involving kinds of division of labor and modes of coordination.

Clearly, the concept of social technology is in full harmony with that of the hierarchy of institutions since some institutions provide a background context within which others operate. Just to give an example, institutions at level 1 in the Williamsonian schema (see Figure 1) provide a context for formal institutions at level 2, while they together are elements of social technology.

In addition, relying on the notion of social technology makes it very logical to distinguish it from physical technologies as suggested in Nelson and Sampat (2001). Physical technology is something that is traditionally understood as technology by scholars of economic growth, that is, production technology. Technological advances as used above, of course, referred to the physical technology.

## 3. The model of the co-evolution of social and physical technology

On the basis of the concepts of macro- and microinventions and that of social technology as a hierarchy of institutions it becomes possible to further develop Pelikan's (2003) framework. Two things are important in this. First, as already mentioned above, we should break the circularity of causation and should identify the driving force in the co-evolutionary process. Second, we should take into account not only those effects that operate between the two systems, i.e., physical technology and social technology, but also those that work within each system between its particular elements. In other words, on the one hand, the issue of how macro- and microinventions affect each other, and on the other hand, that of how informal and formal institutions and firms (governance structures) interact should also be incorporated into

[8] Note that North et al. (2006), following North (1990), continue to sharply distinguish organizations from institutions, arguing that as opposed to institutions, organizations are concrete and can act and make choices.

the analysis of the feedbacks between the physical and social technology. We must analyze the effects in two directions: from physical technology to social technology and in the opposite direction. The model is shown in Figure 2.

As proposed above, advances in physical technology are classified into either macroinventions or microinventions, and social technology includes the three levels of institutions, namely informal institutions, institutional environment and governance structures (or more narrowly organizations).

Micro- and macroinventions differ from one other in terms of what kind of changes they induce in social technology. Since microinventions do not exceed the social technology's innovation absorptivity, they will not provoke major changes in social technology; instead, they may lead to a fine-tuning of various elements of social technology (arrow 7 and 8). For instance improvement of particular machines used by firms may require a reorganization of the production system[9], which is to be considered a fine-tuning in a given form of organization. Microinventions may induce an improvement in formal institutions supporting innovation such as patent law, R&D-based tax reductions, etc. However, microinventions are not able to affect norms, rules, that is, institutions at the level of embeddedness.

As opposed to that, macroinventions by exceeding the social technology's innovation absorptivity bring about radically new social technology at levels 2 and 3 which has not existed before, for instance new laws or governmental and regulatory institutions, or new firm organization (arrow 1 and 2). However, it is very unlikely that informal institutions (level of embeddedness) could change due to macroinventions.

The model shown in Figure 2, highlights the effects between elements of the physical technology, too. The effects between macroinventions and microinventions are relatively easy to explore based on Mokyr's (1990) theory: macroinventions, by definition, determine what the microinventions aim to improve, but they cannot determine the possible outcomes of these improvements (arrow 3). Just recall Mokyr's "perfectly designed horse-and-buggies" (see footnote 4). Macroinventions usually require complementary innovations. However, microinventions may have only little or no impact on macroinventions (arrow 9).[10]

This being said, let me turn to the question of what kinds of effects work within social technology between its particular elements. Here institutions at higher levels, as explained

[9] Good example is the JIT system.
[10] This impact differs to a significant extent across the two industrial revolutions. This issue will be discussed in more detail later.

above, constrain institutional changes at lower levels.[11] That is, informal institutions largely determine the formal rules of the game (arrow 13), and accordingly how the players (firms) play the game (North 1990) (arrow 14). As suggested by the Williamsonian framework (Williamson 2000), the interrelationship between level 2 and 3 is more apparent than those between level 1 and the other two levels (arrow 16 and 17). Particularly, the institutional environment and governance structures (firm organization) must be in harmony in the sense that they must mutually support each other's effective operation. This harmony is disturbed, for instance, when firms have no option but to use excess resources to counterbalance the negative effects arising from the institutional environment (for instance from taxation). The impact the institutional environment may have on firms, however is stronger than the reverse effect: firms usually adopt the kind of internal organization that corresponds to the prevailing institutions (arrow 4) and firms themselves may have a weak effect on institutions (arrow 11). Nevertheless, this effect is not negligible because firms are able to „enforce" new rules (laws).

Let me consider now the effects from social technology to physical technology. Generally speaking, social technology affects the effectiveness of an economy in generating new technology. There are numerous mechanisms for this. Informal institutions and the broad institutional environment should be one that favors entrepreneurship (Boettke and Coyne 2003, Nelson 2008), which is essential for engaging in innovation (arrow 12). These institutions provide incentives for the actors to improve products and processes (microinventions) within the prevailing technological paradigm because, as noted above, microinventions being largely determined by economic forces may be stimulated via the right institutions such as the rule of law, secure private property, and enforcement of contracts, also by informal institutions such as the propensity to take risk (arrow 6 and 15). These are considered institutional preconditions for the functioning of the market.[12] But institutions do not affect only the generation of microinventions, but also the economy's ability to employ and diffuse these advances. To summarize, formal institutions affect the likelihood of the generation of microinventions and their use and diffusion. Organizations are of course crucial for microinventions: the internal structure of firms, the incentive system, etc. should provide an appropriate "climate" for innovation (arrow 10).

As far as macroinventions are concerned, the impact of institutions on these is rather weak, if it exists at all. As I have already mentioned, macroinventions arise partly by chance,

[11] The highest level is level 1. See Figure 1.

[12] Many scholars (e.g., Boettke and Coyne 2003, Acemoglu et al. 2005) argue that institutions are of primary importance for economic growth.

or at least as a result of exogenous factors. Accordingly, while admitting that informal institutions and the institutional environment may partly influence macroinventions by assuring a stimulating overall environment (arrow 12 and 5), which is, however, of primary importance for encouraging microinventions, macroinventions to a large extent are not endogenous in an economy, unlike microinventions.[13] Being partly exogenous, macroinventions have the capacity to start and keep moving the whole co-evolutionary process, i.e., they are the driving force in the co-evolution of physical and social technology. Accordingly, they are capable to bring about significantly new social technologies: new laws and governmental organizations (arrow 1) and new type of firm organization (arrow 2).

Note also that here we have broken out of the circularity of causation: macroinventions being partly determined by forces that are not generated by the system itself are responsible for the process being an evolutionary one in which new developments are likely to occur partly by chance. This may lead to mutations and temporary stabilization through a process of trial and error.

In order to have a complete model of the co-evolution of physical and social technology, note also that endogenous effects are at work both within the social technology and microinventions. These effects are largely based on complementarities that exist both between institutions and technological advances.

To sum it up, the driving force in the co-evolution of technology and institutions is macroinventions, because they are to a large extent exogenous in an economic system, and being so they can bring radical changes into the system. Once such a change has occurred, particular elements of social technology and microinventions change too, and due to numerous kinds of feedbacks a co-evolutionary process is set in motion. Of course, the concrete forms and the strength of the effects presented in Figure 2 differed largely across past industrial revolutions. In what follows, relying on the above general model, I will analyze in detail how social and physical technology co-evolved during the First and the Second Industrial Revolution. As an example I will take one country in each case. The choice for Britain as regards the First (British) Industrial Revolution is self-evident since the industrial revolution had its roots and blossomed fully in Britain, while continental Europe was a generation behind. The choice of the U.S. needs an explanation since the Second Industrial Revolution was not as concentrated as the first one; Europe (primarily Germany) and the U.S.

[13] This view is in fact in accordance with Schumpeterian Growth Theory. See Aghion (2004).

were equally pioneering. However, the U.S. became the technological leader and beyond the technological advances, institutional changes were more apparent in the U.S. than in Europe.

## 4. The co-evolution during the British Industrial Revolution

The period 1760-1850, known as the BIR had enormous long-run impact on Western Europe: it prepared the ground for the economic transformation that made the difference between the West and the Rest of the World (Mokyr 2005a).[14] The essence of the Industrial Revolution was technical. The technological advances occurred mostly in the following four areas: energy (water power, steam engine), metallurgy (iron making), cotton (cotton spinning, mechanical weaving) and divers industries and services (canals and road building).[15] The main technological features were a new infrastructure (railways), a new source of power (steam engine), new machine tools (Freeman and Louça 2001).

It is very common to divide the BIR into two periods (e.g., Freeman and Louça 2001, Lipsey et al. 2005). The first period was based on water-power mechanization, the second on steam-power mechanization, both sharing the key inputs of coal and iron. More particularly, in the second phase railways gave an impetus to qualitative and structural change throughout the economy and it had an extraordinary strong impact on social and economic development by widening the market for scale and specialization. While in the early phase living standards were more or less stationary, in the latter ("Solow"-phase) rapid technological change largely translated into higher living standards (Mokyr ant Voth 2007).

### 4.1. The effects of social technology on physical technology

The general model of the co-evolution of social and physical technology suggests that an analysis of how technological and institutional developments occur in a mutual reinforcement must start with analyzing, in the first place, those changes – partly arising from outside the economy – which were capable of setting in motion the co-evolutionary process. As argued above, it is macroinventions that are subject to the greatest extent to exogenous factors.[16] It is

[14] As argued my many (e.g., Mokyr 2005a, Lucas 2002), the major novelty brought about by the BIR was sustained growth. Growth before 1750 was, if not totally absent, different in nature from what was to occur in the 19th century. For more details see also Mokyr and Voth (2007).
[15] For an in-depth account of the technical advances, see (Mokyr 1990).
[16] Mokyr's macroinventions are in fact General Purpose Technologies (GPTs), as is also suggested by Lipsey et al. (2005). In today's economics of technological change the term GPT is becoming more and more frequently used. For the economic theory on GPTs see for instance Helpman (1998) and for a detailed overview of the

worth premising that the BIR shows significant differences as compared to the SIR in terms of what gave the co-evolutionary process the initial boost: here partly exogenous macroinventions played this role.[17]

GPTs of the BIR were the steam engine, mechanization[18], railway, iron steamship and the factory system (Lipsey et al. 2005). To a non-negligible extent these were due to talented inventors whose activities cannot be regarded as consequences only of the prevailing social, economic and demographic factors, that is, the inventions were the results of individual genius, rather than the outcome of a conscious social process (Freeman and Louça 2001). Put differently, macroinventions arose partly from outside the economy; British inventors were on numerous occasions simply lucky (Mokyr 1990) and macroinventions came simply "out of the blue". This is not to say that endogenous factors, such as institutions could not play a role; on the contrary (arrow 5 and 12). The uniqueness of Britain was precisely its extremely favorable institutional background for technological advances, which constituted Britain's advantage over the Continent when it comes to the "why in Britain?" question. In fact in Britain there was a congruence of favorable developments in all subsystems of the society and their positive mutual interconnection (Freeman and Louça 2001). In this sense the BIR was not a sudden event; instead, it was a contingent culmination of evolutionary paths that had been in place for centuries (Lipsey et al. 2005:258).[19]

So, macroinventions could not have come partly "out of the blue" if institutional background had not supported that. The latest research of Mokyr (2008a, 2008b) sheds particularly light on the overwhelming role of informal institutions (level 1 in Figure 1), where Britain's configuration was unique. According to him, at the level of embededdness, "cultural beliefs" created an environment in which inventors and entrepreneurs could operate. This is about a recognition of the importance of accepted codes of behavior, patterns of beliefs, trust, etc., that is, informal institutions that channel creativity into productive activities. In fact, what was unique in Britain was the growth of a set of these social norms

attributes of GPTs see Lipsey et al. (2005). Note that the view that GPTs arise mostly exogenously is very common in this literature. In what follows I will use the terms macroinventions and GPTs interchangeably.

[17] Note, however, that the difference between the two industrial revolutions in this respect can be attributed to the fact that the BIR had no precedent while the SIR in fact was a continuation of the BIR. See the next section.

[18] Mechanization was about using machines to what was formally done by human hands and human brains.

[19] In fact, as far as the theories explaining the timing and location of the Industrial Revolution are concerned, it is possible to distinguish two kinds of explanations. One (e.g., Jones 2001, Crafts 1977) sees the evolution of the Western countries as a highly unlikely event, the result of a fortunate concatenation of circumstances. In this respect, it differs dramatically from the unified growth theory (e.g., Galor and Weil 2000) where the seeds of economic development of the West were sown centuries before, and once they are there, growth is unavoidable. This latter can be paralleled with Landes (1994) who argues that both the Industrial Revolution and Britain's role in it were determined by that country's starting conditions.

beyond the rule of law and explicit penalties for opportunistic behavior. The development of such behavioral rules can be to a large extent attributable to the Enlightenment which made productive activity as such more attractive relative to rent-seeking.[20]

It may come as a surprise, but formal law enforcement was a last resort in Britain; markets functioned well because of the above-mentioned informal rules (Mokyr 2008b). The key to successful economic exchanges was not necessarily an impartial and efficient third-party enforcement, but precisely the existence of a level of trust or other self-enforcing institutions that supported free-market activities. Within a circle of commerce, finance and manufacturing trust relations and private settlement of disputes prevailed over third party enforcement. Most business was conducted on informal codes and relied on reputation; voluntary compliance, respect for property (private-order institutions) was important in Britain. These norms involved a variety of devices associated with "gentlemanly".[21] The idea of "gentleman" has acquired a meaning of behavioral codes that signaled that a person was trustworthy. This behavior made it possible to overcome the kind of free riding and opportunistic behavior that seem to require coercion by formal state institutions.[22] Briefly, informal rules were even more important than formal rules. What mattered was that within merchant and artisan classes there existed a level of trust that made it possible to transact with non-kin.[23] Thus it can be argued that such informal institutions not only supported markets, but also helped Britain take the technological lead.

Having said that, the question of how the middle classes gained ground vis-à-vis aristocrats still remains. In an innovative paper, Doepke and Zilibotti (2007) argue that the rise of a bourgeois elite in industrializing Britain may be regarded as a surprise. Before the transformation got under way, aristocrats had all the odds stacked in their favor – available funds, political connections, access to education. Despite this fact only few members of the old political elite actually got rich in manufacturing after 1750. Doepke and Zilibotti argue that this is because the middle classes had accumulated a larger stock of "patience capital", that is, a host of cultural practices and norms that make the delay of immediate gratification

[20] Mokyr (2005b, 2006) provides a detailed analysis of the role of the Enlightenment in sustained economic growth.

[21] Note, however, that these norms applied only to "middle class" that emerged before 1760 and included intelligent and well-educated people.

[22] As shown by Mokyr (2008a) a primary example of operation of gentlemanly codes was 18th century credit market in Britain. Credit markets depended on a set of self-enforcing codes frames by norms of gentlemanly conduct. This credit market was primarily enforced by reputational mechanisms; accordingly commercial disputes rarely came to courts and were often settled through private arbitration.

[23] What also mattered from this point of view was the fact that the British nation witnessed a blossoming of voluntary organizations (e.g., clubs) that created linkages supporting market activity. This was a kind of social network. For a detailed overview see Mokyr (2008a, 2008b).

accepted and expected. Through centuries, the middle class built up both financial capital and valuable cultural traits. As the new technologies of the Industrial Revolution suddenly offered greater returns to patience, the groups best-placed to exploit them were not the elite but the middle classes. Those people who acquired "patience capital" which was the kind of culture that played a central role in the subsequent development of capitalist industrialism became key figures in the British society.

In a nutshell, the effect of informal institutions on macroinventions (arrow 12) and microinventions (arrow 15) was especially strong and unique, which in the spirit of Mokyr (2008a, 2008b) can be seen as the determinant factor in the "why in Britain". As opposed to that, the impact of formal institutions on macroinventions, such as property rights, political institutions and government regulation was rather weak (arrow 5), which is not what one could think at first glance.

For instance North and Weingast (1989) argue that the political history of England before the BIR reflects two propositions: (1) the establishment of secure and stable property rights for private persons is a necessary and sufficient condition for economic growth, (2) the establishment of such rights depended on the creation of the representative democracy. Thus they believe that there was an inanimate relationship between the Glorious Revolution and the BIR in the sense that the Glorious Revolution has created preconditions for the BIR. This view is strongly contested by Clark (1996) and Mokyr (2006) who believe that the traditional emphasis on formal rules has been over-emphasized, and the enforcement of property rights by the state was less crucial than the Northian interpretation has suggested (see above).

After having a closer look at the history, it becomes clear that secure private property rights existed in England almost as early as 1600, or probably earlier. Nothing special happened in 1688 from this point of view. This suggests that secure property rights may be necessary conditions for growth, but they are not sufficient, and an adequate explanation for the BIR requires factors other than the emergence of stable private property rights. In addition, Clark (1996) in his empirical analysis finds that the Glorious Revolution seems to have no effect on rates of return in the English economy between 1660 and 1730. That is, financial revolution started before the BIR[24]; data show that capital assets were traded in an integrated market even before the BIR.[25]

[24] The Bank of England was established in 1694 as the principal lender to the government.
[25] Clark (1996) finds that rates of return on capital fell in the 100 years prior to the BIR, which in such a way shows no connection with political events.

In sum, the private economy after 1540 was largely insulated from political events (Clark 1996). So the view that Britain's advantage in leading the Industrial Revolution was due to its efficient enforcement of property rights after 1688 needs to be revisited.

However, some political institutions such as Parliament seem to have crucial importance in inducing favorable changes both in technology and institutions.The Parliament was a meta-institution that has the legitimacy to change other institutions. As explained by Mokyr (2008b) Britain was almost unique in Europe to have developed the Parliament after 1650, which has acquired a position of legitimacy and power. Mokyr and Voth (2007) emphasize another aspect of the British political constellation which seems to be central, namely that *de iure* and *de facto* power coincided to a great extent: both were in the hands of Parliament. Bearing in mind the model of Acemoglu et al. (2005) explaining how institutions affect economic performance, the significance of the above is hardly questionable. In addition, due to the control of the Parliament, the state was not predatory, instead was constrained from doing so. The importance of this fact is that profits the technological breakthroughs generated for entrepreneurs were not expropriated by the state, which is somewhat related to the issue of government regulation, too.

Regulatory institutions were also favorable to industrialists, the British government was not interventionalist unlike many other governments in the Continent. This behavior of the government rested probably on the notion of free trade, an idea which was introduced by Adam Smith's book: profit-seeking activities were seen as promoting social welfare.

All this means that the formal institutions were also favorable for inventors and entrepreneurs, but secure property rights and the rule of law in themselves were not sufficient to induce major technological changes. They were rather important for developing such other institutions that proved themselves crucial for inducing microinventions (arrow 6).

Among these institutions intellectual property rights are traditionally thought of as being extremely important (e.g., North and Thomas 1973)[26]. Dutton (1984) was the first to consider in a systematic way the connection between the patent system and inventive activities. He argued that a group of "quasi professional inventors" emerged during the BIR who took their profits through the sale or licensing their intellectual property rights. Sullivan (1989) confirms

[26] „Innovation will be encouraged by modifying the institutional environment, so that the private rate of return approaches the social rate of return. Prizes and awards provide incentives for specific inventions, but do not provide a legal basis for ownership of intellectual property. The development of patent laws provides such protection. … [B]y 1700 ... England had begun to protect private property in knowledge with its patent law. The stage was now set for the industrial revolution" (North and Thomas 1973:155-156).

this view by showing the existence of a structural break in 1757 in the time series of total British patents: after 1757 there was acceleration in the pace of invention.

However, MacLoad's (1988) evaluation of the British patent system is much more cautious[27], in addition Mokyr (2008a) stresses that the idea that technological progress depended on inventors' incentives through patent system is dubious on both historical and theoretical reasons. First of all, the British patent system was created in 1624, that is, long before the BIR. To a large degree, patent institutions in Britain offered rather limited incentives to investors (Khan and Sokoloff 2004).[28] In addition, Britain's advantage over the neighbors was only limited in this respect since many European countries adopted a patent law similar to Britain's. On the other hand, the technology in England developed rather along a system of open science or collective invention[29] (Allen 1983) before the BIR, akin to modern open-source technology (Nuvolari 2004). So, the above arguments put serious doubt on the strategic importance of the patent system in advancing technology. Just to give one additional support for this claim, remember that the key-technologies that laid at the heart of the BIR, such as high pressure steam engines, steamboats, iron production techniques, etc. were also developed in a collective invention fashion, and consequently they never were patented.

More importantly, Britain created alternative organizations that encouraged innovation and the dissemination of knowledge beyond patent system. A notable example is the Royal Society of Arts, founded in 1754, which explicitly aimed at disseminating existing technical knowledge, at augmenting it through an award program[30], encouraging networking, publication of periodicals. Another institution was the Royal Institution which was founded in 1799, devoted to research and charged with providing public lectures of scientific and technical issues. These private institutions together with Mechanics Institute have been adequate for creating a stimulating environment for most British inventors.

Although these institutions aimed at disseminating scientific ideas, a unique characteristic of the BIR was that before 1850 the contribution of formal science to technology remained

[27] She draws attention to the heterodox use of patents. The most typical case was where the patent was used for getting support of specific government concessions.
[28] The defects of the British patent institutions were the following (Khan and Sokoloff 2004): the interpretation of the "first and true inventor" included importers of inventions that had been created abroad, fees were extremely high, the system was too complicated, there was no examination. Patents laws were revised only in 1852, but the process continued to be discourage technological creativity.
[29] In collective invention settings, inventors freely release to one another pertinent technical information on the construction details and the performance of the technologies they have just introduced. This represents knowledge spillovers. As an example see Nuvolari's (2004) steam pumping engine case.
[30] Note that only inventions which had not been patented were eligible for the Society's prizes (Mokyr 2008a).

modest (Mokyr 2002a). Much of the technological progress came from the semi-formal and pragmatic knowledge generated by great engineers, or in other words, by a technological elite of inventors, engineers, mechanics and skilled craftsmen, whose dexterity and ingenuity was critical (Mokyr and Voth 2007). This seems to be true when thinking of the direct effect of the science. However, examples of the importance of science and mathematics to some of the inventions of the Industrial Revolution can certainly be amassed. It is equally true that many of the most prominent breakthroughs in manufacturing, especially in the mechanical processing of textiles were not based on science, and that in other areas of progress, such as steam power, progress occurred on the basis of trial and error, not a deep understanding of the underlying physical processes. As argued by Mokyr and Voth (2007) trial and error, serendipity, and sheer intuition never quite disappeared from the scene.[31]

But it is equally true that science affected technological advances not only directly, but through human capital. Those engaged in manufacturing in the 18th century required a passing familiarity with Newtonian mechanics, which required mathematical competences. In Britain mathematics was already widely thought in the 1720s. The degree to which science penetrated British society and was used by innovators and entrepreneurs separated England from all other European countries – only the Netherlands came close (Lipsey et al. 2005). What is more, the nineteenth century Britain was overeducated: the amount of human capital exceeded that which was needed by the demand for production (Mokyr and Voth 2007).

This explains Britain's comparative advantage in the skills and competence of her workmen. Britain imported many inventions that were further developed and utilized in Britain which were due to high-level British technical knowledge.[32] For instance in Britain technical training through master-apprentice relationships was at a relatively high level, favoring learning by doing and creating a favorable climate towards inventions and experimentations. Apprenticeship was ideal to transmit the kind of tacit artisanal knowledge that was essential to competence. In addition, at that time technical seminars and scientific associations were commonplace in England. The overall character of British science was oriented towards mechanics and experimentation rather than being of a deductive-

[31] In contrast, according to Lipsey et al. (2005), the development of science, mainly Newtonian mechanics was a necessary precondition for the BIR: "Indeed, it does not seem an overstatement to say that Newtonian mechanics provided the intellectual basis for the First Industrial Revolution, which in its two stages, was almost wholly mechanical" (Lipsey et al. 2005:241).

[32] In many cases the first successful applications of the new techniques appeared in Britain. Among these the most remarkable were gas-lighting, chlorine bleaching, the Jacquard loom and the Robert continuous paper-making machine. See Mokyr (2005a).

mathematical character, as for instance in France (Mokyr 1990). This made it much more appropriate for pioneering the industrial revolution.

### 4.2. The effects from physical technology to social technology: the rise of the factory

As far as the effects from physical technology to social technology are concerned, undoubtedly, the rise of the factory was the major novelty which, as an organizational GPT (Lipsey et al. 2005), had an enormous effect on the development of economies as a whole (arrow 2). But what was a factory? This question is crucial because the attributes of the factory must be clearly distinguished from its *distinctive* attribute. Of course, the factory shares many characteristics with other kinds of organization, but being interested in its uniqueness we have to determine that feature that exclusively characterizes it (as opposed to previous organizational forms). This requires an analysis of the emergence of the factory from the viewpoint of the theory of the firm.[33] The distinctive attribute of the factory vis-à-vis the putting out system was that it was a firm while the latter was a market-like organization based on market contracts. And as argued in the theory of the firm literature (e.g., Foss 2002, Kapás 2004) the distinctive feature of the firm is the predominance of authority among the coordinating devices used within the given organizational form. Accordingly, it is not large-scale production as such that was the essence of the factory, but rather firm-like monitoring.[34]

Although there are numerous explanations for the rise of the factory (for an overview see Mokyr 2002a), a closer look at these from a theory of the firm viewpoint suggests that in fact they all trace the factory back to the new technology (see Kapás 2008)[35]: the macroinventions of the BIR induced significant changes in the way the work was organized, which led to the rise and spread of the factory.[36]

[33] See Kapás (2008) for an argumentation on why the theory of the firm viewpoint must be added to the economic history viewpoint.
[34] To underpin this claim note that many entrepreneurs in the putting-out system worked with a large number of masters (Pollard 1965), and on the other hand, there were plants working only on small scale (Landes 1969). However, the nature of monitoring changed significantly in the factory (Langlois 1999): instead of monitoring the output, the capitalist monitored the production process itself, which means that a market-like monitoring was replaced by a firm-like monitoring. The latter involved a new kind of authority relationship between the capitalist and the workers (see Simon 1951).
[35] This implies that the team production argument à la Alchian and Demsetz (1972) comes to play only in the second place: the fact that the labor of individual workers became complementary inputs, implying that marginal products were costly to measure and consequently a monitor was appointed, is the result of the new technology and mechanization.
[36] Jones (1987) clearly shows that technological factors were primarily responsible for the adoption of the factory system in the silk industry, and the pace of the technological change appears to have been a major determinant of the speed with which factory production was adopted.

The significance of the rise of the factory can hardly be overstated: the capitalist firm as such was born to carry out production instead of households. Saying that production broke away from the household is equivalent to saying that an individual mode of production was replaced by a collectively organized mode, i.e., team production. Clearly, the factory was a new organizational form[37] that succeeded the putting-out system. Mokyr (2005a) is not the only economist to point out that the separation of the household and production is of extreme importance for modern growth. The "why" is brilliantly highlighted by North et al. (2006) who call for a recognition of the major role of organizations in economic development. They argue that organizations are the key to economic performance because it is organizations (and among them firms) that can voluntary bind to contractual relations which on the whole make market transactions.

In this spirit, it is easily understandable that the appearance of a well-structured organization for the pursuit of economic rent was of crucial importance. The rise of the factory was part of the process in which the British society transformed from a limited access order into an open access order, which, as argued by North et al. (2006), constitutes the "true" economic development: open access to entry into voluntary organizations is crucial in economic development.[38] The factory was such an organization: historical evidence shows that factories were founded by talented, risk-loving entrepreneurs, rather than by the members of the elite. Clearly, at that time there was an open access to form factories.

However, factories of the BIR were not perpetually lived organizations[39] because they were organized as individual proprietorship or partnership. In England there were only few corporations and these appeared mostly in public utilities: canals, railroads, water, and gas supply. It is beyond the scope of this paper to examine the causes, but two possible causes must be noted. First, by virtue of the Bubble Act of 1720 the creation of a joint-stock company with transferable shares was possible only with the consent of the state. Second,

[37] "Organizational forms are the rules about how individuals within an organization are supposed to interact and how the organization and its members are supposed to interact with people outside of the organization." (North et al. 2006:22).

[38] Recorded human history witnessed two kinds of social orders: limited access and open access orders (North et al. 2006). The limited access order, also called the natural state, emerged about 10.000 years ago and dominates even today. In this social order the political system manipulates the economic system to create rents for the elite so as to control violence and sustain order. Here the dominant coalition grants members privileges, creates rents through limiting access to valuable resources and organizations. The open access order appeared first about during the times of the BIR. It relies on competition and open access both in the political and economic systems to sustain order. The major feature of an open access order is that entry to form organizations is free and accordingly, by fostering competition, entry and mobility it leads to long-term economic development.

[39] A perpetually lived organization is an organization that lives beyond the life of its individual members.

obviously due to favorable informal institutions British entrepreneurs were willing to be associated with friends (Landes 1960).

Nevertheless, the factory spread gradually over a long transition period, but the spread was reinforced by the new wave of microinventions in the second phase of the BIR. As was made it clear in section 3, once macroinventions occur, they are intertwined with microinventions. Thus the 1820s witnessed another wave of inventions, which were not as spectacular and path-breaking as the classic inventions of the period 1750-1820. These were microinventions: improvements in high-pressure engine design, Stephenson's locomotive, etc. To a large extent these inventions were endogenous and the function of industrial needs (Mokyr 2002a), "[o]nce a major technology becomes established, however, its further evolution, which may stretch over centuries, becomes largely endogenous to the economic system (Lipsey et al. 2005:96). These microinventions were to a large extent induced by the factory itself. In this sense the spread of the factory became self-enforcing: the factory offered favorable organization for induced innovation (technical improvements within the factory) (arrow 10), which in its turn, stimulated the fine-tuning of the organization of the work within the factory (arrow 7).

To put it in a nutshell, the impact the macroinventions of the BIR had on the organization of production was extremely important and propagating. As opposed to this significant effect, technology had only minor effect on the institutional environment (arrow 8 and 1). Due to macro- and microinventions, particular institutions emerged to help the practical knowledge stemming from the inventions penetrate the academia: universities, polytechnic schools, research institutions, museums, agricultural research stations, and so forth. Technical subjects penetrated the school curriculum, professional and scientific journals appeared, and technical encyclopedias were published (Mokyr 2005a). The above institutional changes remained within the broad institutional setting that was already in place at least since the Glorious Revolution and can be characterized as open access order in terms of North et al. (2006).

To sum it up, by the end of the BIR the social and physical technology that prevailed were those of an open access order, in which development, due to competition and open access to form organizations, became sustainable. From that time onwards industrial revolutions became successive: the Second Industrial Revolution can be seen as the continuation of the

BIR (Freeman and Louça 2001); many inventions of the BIR were not realized until 1860, marking the beginning of the SIR.[40]

## 5. The co-evolution during the Second Industrial Revolution

The period 1870-1970 known as SIR was even far more wide-ranging than the BIR.[41] It is frequently divided into two periods (e.g., Freeman and Louça 2001). The first period (1860-1940) was characterized by the electrification of industry and transport, and the second one (1940-1970) by the motorization of transport and civil economy. Clearly, there is crucial difference between the BIR and the SIR as regards where the clustering of innovations had its roots. While, as was argued above, the BIR blossomed out from macroinventions, the SIR evolved from microinventions that targeted the improvements of the macroinventions of the BIR and coincided fortunately but accidentally with a new wave of macroinventions. The wave the inventions included those of Edison, Siemens, Westinghouse, Faraday, Maxwell, Diesel, Otto, and others.[42] GPTs of the SIR were electricity, motor vehicle, airplane, mass production and continuous process production (Lipsey et al. 2005) which came mostly after 1920. Chemicals and steel were two key products while electricity, oil and internal combustion engine were the new energy sources. By the 1880s new industries such as electricity, chemistry, ship-building, metallurgy, heavy engineering, large building construction, canning industry and armaments emerged. In the second phase automobiles and refineries became key industries. Clearly, contrary to the BIR where leading sectors were almost mechanical, the industrial development during the SIR was led by many non-mechanical sectors. But the new technologies transformed the production of many other industries, too. Indeed, almost every invention in one industry had an effect on many others. Briefly, the SIR brought modern industries into being and played a major role in the development of modern industrial capitalism.

### 5.1. The effect of physical technology on social technology: the rise of the M-form

[40] Similarly, today's ICT revolution is seen as the third industrial revolution (Freeman and Louça 2001, Lucas 2002).
[41] There is no consensus as regards until when the SIR lasted. For instance Mokyr (2002a) talks about the period 1870-1940. I follow Freeman and Louça (2001) who consider a longer period.
[42] Note that inventions such as anesthesia and sterilization were also important, as a result of which surgery underwent significant improvements. See Mokyr (1990, 2002a) for an overview of the inventions of the SIR.

In fact macroinventions of the previous industrial revolution such as railroad, telegraph[43] and ironmaking[44] experienced continuous improvement, which, in turn, led to a new industrial revolution. Accordingly, a demarcation line between the two industrial revolutions is difficult to determine, as the inventions of the SIR were embedded in those of the BIR. In this sense the SIR was the continuation of the BIR (Mokyr 1990). But what is of importance for my concern is the fact that the beginning of the SIR was marked by the further improvements in and the diffusion of railroad and telegraph. So, unlike the BIR, where initially macroinventions provoked changes in social technology, here microinventions in the above-mentioned fields had enormous impact on social technology by bringing about important innovations, among which the rise of a new firm organization, namely the multidivisional form (M-form), was the most significant (arrow 7). Nevertheless, as will become clear below, microinventions only gave the first impetus on the road to the rise of a new firm organization, and late comer macroinventions, most importantly the motor vehicle, reinforced this process (arrow 2).

The paradigm in which the factory was the dominant production structure was challenged in the 1860s, which brought about gradual changes in firm organization, culminating in the rise of the multiunit firm[45] by the 1920s. I will show below – based basically on Chandler's (1962, 1977, 1990) brilliant account of how the modern business enterprise has emerged – that the coming into being of the M-form as new social technology occurred in several phases in which physical and social technologies co-evolved.[46]

The premonitory sign of the coming of a new paradigm, as mentioned above, was the revolution in transportation and communication that gave the whole process the initial boost:

[43] The first commercial electrical telegraph was constructed by Sir Cooke and entered use on the Great Western Railway in Britain. An electrical telegraph was independently developed and patented in the U.S. in 1837 by Morse. The first successful submarine cable was laid by Thomas Crampton's Company between Dover and Calais in 1851 (Mokyr 2002a). However, long-distance telegraph required many subsequent microinventions. The first commercially successful transatlantic telegraph cable was successfully completed in 1866.

[44] The new technology was the Bessemer steelmaking process which was the first process for the mass production of steel from molten pig iron. Bessemer took out a patent on the process in 1855.

[45] The major characteristics of the M-form from are as follows (Chandler 1990, Rajan and Zingales 2000): It is (1) large enough to exploit potential economies of scale and scope in production and distribution, (2) physical capital-intensive, (3) integrated both forward and backward, (4) oligopolistic, and (5) run by professional managers. In such an enterprise each division could act as an independent business enterprise and deal with a conceptually different business, organized mainly along product, brand or geographic lines. The divisions are entrusted with making day-to-day operating decisions, while the corporate office is concerned with strategic decisions and can use incentives to favor divisions' operating behavior consistent with its objectives (Chandler 1962). The general manager is fully responsible for the activity of the division; while the activities of the lower-level managers are monitored and coordinated by middle-level ones.

[46] Note however that in Chandler's account an understanding of social technology as a creative force capable of inducing microinventions is missing: he saw social technology only as a response to technical changes (North and Wallis 1994).

the railroad had the first significant impact on U.S. business firms. Although railroad and telegraph networks were already in existence by the mid-1800s (see footnote 43) their full effects materialized only as they became cheaper and more widely diffused due to microinventions. As a result of various microinventions railroads became faster, safer and more comfortable. The steam locomotive provided fast, regular, safe and reliable transportation and also lowered the unit cost of moving goods, which was essential to high-volume production and distribution (Chandler 1977). This had an impact on social technology, especially in three areas: (1) it brought about the first formal administrative structure with professional managers inside the rail companies, (2) it created a need for novel institutions such as the modern investment bank, accounting and statistical innovations, limited liability, etc. (arrow 8), and (3) it gave rise to mass distribution and mass production.

As far as the first impact is concerned, the complexity of the railroads' operations required professional managers who subdivided their operations into smaller groups and then appointed middle-managers to supervise and monitor the different functional activities: the movements of trains, the handling of traffic, the maintenance of motive power, equipment, and accounting (Chandler 1990). To operate these activities railroad managers devised a line-and-staff system; both departments and central offices were built up. So, the rail (and telegraph) companies were themselves the first modern business enterprises to appear.

Besides the transformation that took place inside the companies, new institutions were also needed. The railroad was the first modern high-fixed-cost business which required novel forms of financing (Chandler 1990). The capital requirement was very high, which led to the concentration of the national money market in New York City and the formation of exchanges. Besides modern financial institutions, because of the volume of transactions, accounting became more complex and required new standards and new techniques. Another new need was created for well-educated managers which, some decades later, brought the modern business school into being. Professional journals and business associations also started to come into being in these years.

The third impact was that the railroad and telegraph contributed to the development of mass distribution (Chandler 1977) because they permitted new speed and regularity in transportation and communication, and a dramatic decrease in transportation costs. This expanded the market in a way never seen before. There appeared the modern mass marketer (e.g., mass retailer, chain store) who purchased directly from the manufacturers and sold directly to the retailers and final consumers.

The new method of transportation made it possible to handle large flows of raw materials into and finished products out of the factory. The realization of this required the invention of new machinery and processes (Chandler 1977). These were important microinventions. The new technology went hand in hand with the emergence of mass production which in itself was a new GPT.

Mass production meant exploiting economies of scale and scope made possible by the new technology, which lowered production costs and increased productivity, and required at the same time heavy investment in production facilities large enough to exploit these potential economies (Chandler 1990). It called for further organizational innovations, i.e., new ways in which the movements and activities of workers and managers were coordinated and controlled (Chandler 1977), while it reduced the number of workers required to produce a specific unit of output. That is, mass production industries were those in which technological and organizational innovation created a high rate of throughput and permitted a small workforce to produce a massive output. The high-volume industries soon became capital-intensive, energy-intensive and manager-intensive. However, production cost savings of scale and scope economies could only be realized by incurring the increasing transaction costs necessary to run large firms (North and Wallis 1994): building up a hierarchy was the only way to capture lower production costs.[47]

The final phase in the emergence of the M-form consisted in the integration of the process of mass production with mass distribution within a single firm. The rationale for this was not only that a manufacturing firm no longer found it safe to rely on outside wholesalers or commission agents because the interests of these agents differed from those of the manufacturers (Chandler 1990), but more importantly, the divergence of interests incurred higher transaction costs. Another important source of higher transaction costs was a new asymmetric information problem the firms found themselves facing: as products became more sophisticated, consumers became less able to identify the quality of the products. One important solution to the "lemons" problem was for firms to use advertising and brand-names as a commitment not to cheat (Kim 2001), i.e., the integration of distribution, leading to multiunit firms.[48]

[47] The first true application of mass production technologies was by Henry Ford in Detroit, namely the moving assembly line in the automobile. The Fordism dominated the management philosophy for more than half a century. New machine tools, skilled workers, strict discipline and unions were important parts of the Fordism.

[48] As opposed to this kind of explanation, Lamoreaux, Raff and Temin (2003) have argued that we should understand changes in business organization as a response to changing transportation and information costs.

Some enterprises went further: besides handling their own marketing and manufacturing, they took over the production of their raw materials. This expanded vertical integration occurred in those firms whose raw materials came from a limited supply.[49] That is, firms set up their marketing organizations and controlled raw materials and transportation facilities. An advantage of the internalizing of these activities was a decrease in the total costs, i.e., in the sum of transaction and production costs (North and Wallis 1994).[50]

Similarly to the factory, the significance of the rise of the modern business enterprise can hardly be overstated. One underlying fact is that economic development is related to an important feature of the M-form, namely its being a corporation. The corporate form is one of the central institutions of modern economies, it became the symbol of modern industrial capitalism capable of continually innovating, and accordingly, developing. While the corporation form was not central in England, by the 1830s it became important in the U.S., reflecting the different attitude of Americans towards business incorporation. By the 1900s, the U.S. had in place the outlines of the modern corporation that dominate modern manufacturing and finance throughout the global economy in the 20th century. As shown by Wallis (2003), U.S. states played an extremely positive role in promoting corporations starting from the 1830s, which was a clear case of market-augmenting government[51].

The historical record indicates that large enterprises almost universally adopted the corporate form, and the vast majority of businesses choosing to incorporate during the late 19th century were small firms whose stock was closely held.[52] Corporation form has many advantages over sole proprietorship or partnership (see Lamoreaux 1998) that characterized factories during the BIR. For my concern the major advantage is that corporation is a kind of perpetually lived organization. Perpetually lived organizations are more powerful and can undertake a wider range of economic activities than non-perpetually lived ones, which is important for economic development (North et al. 2006), while the partnership form of organization typically had a short time horizon. Thus the modern joint-stock form took root in this period and grew significantly compared with other business forms. However, the

---

[49] For instance, Standard Oil moved into the production of crude oil in the late 1880s to gain an assured source of supply.

[50] Note that Chandler (1977, 1990) was concerned only with the production costs.

[51] Mancur Olson developed the term “market-augmenting government”, by which he meant a government that fosters markets by – as for instance was the case here – supporting various forms of business organizations.

[52] Note that during the early part of the 19th century, most businesses were organized as single proprietorships or partnerships. At that time the only way to form a corporation was to secure a special charter from a state legislature, but such charters were usually granted only to projects deemed to be in the public interest. However, by the 1870s the states gradually liberalized their policies on charters, and most had passed general incorporation laws that made the corporate form widely available (Lamoreaux 1998).

evolution toward the efficiencies represented by tradable shares took time to work its course. The creation of the modern stock exchange represented an important step in that.

As demonstrated above, due to particular historical facts the way physical technology affected social technology manifests certain particular characteristics as compared to its evolution during the BIR. The most significant differences lie, on the one hand, in the fact that the rise of the new firm organization (M-form) appeared in several well identifiable phases (see Chandler 2006) meaning that feedbacks mechanisms were more important than during the BIR. On the other hand, the first significant changes in firm organization resulted from microinventions (arrow 7) – unlike in the case of the factory – that were improvements of macroinventions of the previous period. Macroinventions (e.g., the motor vehicle) came only later, but they provoked further changes in firm organization (arrow 2).

However, the effect of the M-form on institutions was also strong: many new formal institutions were necessary (arrow 11). In this respect the SIR differed from the BIR, where this kind of effect hardly existed. First of all, since there was a strong tendency towards cartelization, vertical integration with raw material suppliers a new regulation was needed, including antitrust law. Second, following massive private and public investments and the development of the national money market and stock exchange new regulatory laws were required in this field, too. Third, as already argued, the coming into being of the M-form gave birth to professional management, which in turn depended on, and at the same time stimulated, the educational system. Giant firms were run by professional managers and used complex administrative structures, which provided a demand for managers. Accordingly, the birth of business schools was an adequate response. Furthermore, even the “style” of managing had also changed: scientific management (Taylorism) was based on the professionalization and specialization of the various functions of management and in some cases also design and development of personnel.

However, au fond, the cumulative effect of changes in physical technology was one which further reinforced the process that took place during the BIR: large scale plants were favored. With the M-form the “size” became even more important than with the factory, but the increased “size” also entailed several new features such as scientific management, standardized products for mass markets, vertical integration, research and development units within the firm, divisions with responsibility. In fact, due to the above changes, the capitalist firm as such had been improved in many respects compared with the factory.

### 5.2. The effects of social technology on physical technology

As argued above, although implicitly, the role of macroinventions was different compared with the BIR. First, in the beginning microinventions were more important, and second, in the period after 1920 macroinventions became again less important. During the periods where macroinventions were absent, a continuous flow of microinventions was the driving force behind economic growth. Since microinventions are "sensible" to institutions, favorable formal institutions and supporting organizations were needed to induce technological advances (microinventions). At that time technological development was accompanied by two major problems, namely uncertainty and appropriability (Wright 1999). Therefore in the U.S. institutions that emerged aimed at mitigating these problems (arrow 6). These institutions included patent, nonprofit research institutions, government procurement policy, private market power, first mover advantage. The last two are related to oligopolistic market structure which was the result of the emergence of giant firms. However, patent and research institutions need to be analyzed at a greater length in order to understand their effects on physical technology.

The role of the patent system changed significantly during the SIR. The first patent system working by what we might consider truly modern procedures was not the British, but the American, especially after the Patent reform of 1836 (Khan and Sokoloff 2001). But even before, by the 1810s, the U.S. surpassed Britain in patenting per capita, and it remained higher throughout the 19$^{th}$ century (Khan and Sokoloff 2001:238-239). This evidence, according to Khan and Sokoloff suggests that the rate of innovation was probably lower in early industrial Britain than in the United States.

The U.S. data indicates a general responsiveness "of inventive activity … to material incentives, as well as to the availability and security of property rights in technology" (Khan and Sokoloff 2001:240). The U.S. patent institutions provided broad access to economic opportunities in trade in new technological knowledge through setting low fees and establishing favorable administrative procedures for application. According to Khan and Sokoloff (2004), the U.S. deliberately created a patent system that allowed a much wider range of technologically creative individuals to obtain property rights to their inventions than did European patent institutions. Briefly, the U.S. patent system was highly beneficial to inventors, which stimulated "investments" in inventive activities.[53]

[53] See Khan and Sokoloff (2004) for details.

Furthermore, what was unique in the U.S. during the 19th century as compared to England during the BIR was the emergence of a solid market for technical innovations structured around the institution of the patent system (Lamoreaux and Sokoloff 1996, 1999a, 1999b). Through this well functioning "market for technology", individual inventors were able to sell to firms the new technical knowledge they had discovered. In the second half of the 19th century, the growth and consolidation of this market was also favored by the emergence of a specialized class of intermediaries (patent agents and solicitors) which were able to "match" buyers and sellers in this market for patent rights, thereby lowering transaction costs substantially (Lamoreaux and Sokoloff 2002). However, and even more importantly, the coupled development of the patent system and the market for technology determined a steady acceleration in the rate of innovation (microinventions). The market for technology supported the inventors who were primarily, at least during the period 1840-1920, individuals with technical backgrounds, strongly committed to inventive activities. Later, organized research groups gained ground vis-à-vis individual innovators, and besides patent institutions the newly emerged research labs had the greatest impact on technological advances.

Thus the rise of the R&D labs is related to a new feature of the innovations during the SIR, namely that they were less experimental and more related to science compared with those during the BIR. In fact, microinventions in this period were the results of directed and well-organized searches for new knowledge: institutionalized research has emerged with institutionalized innovations (arrow 6). This points to an important difference between the two industrial revolutions: the character of technological development (microinventions) was changed. As argued above, in the 18th century innovations were primarily based on empirical trial and error without strong scientific underpinnings. Although science (Newtonian mechanics) did assist technological developments, it was still possible for experienced craftsmen to invent significantly new technology on a strictly trial and error basis. All this changed when new technologies, including GPTs began to have a basis in pure science. This is to say that the SIR was heavily science-oriented (Lipsey et al. 2005). In some industries the techniques that came into being after 1870 were the result of applied science, but note also that luck and instinct was not entirely replaced (Mokyr 2002a).

That is, starting from the second half of the 19th century there has been a vast increase in the amount of resources allocated to scientific research. Governments begun to set up research labs, which engaged in everything from pure to highly applied research (Mokyr 2002a). Universities also engaged in research, and in addition, a close collaboration has been established between universities and industries. But firms also set up their own R&D

departments[54] and major corporations such as GE, Westinghouse, DuPont, Eastman Kodak and AT&T were the sponsors of major research laboratories (Wright 1999). In addition, technological progress, as argued by Wright (1999), in the U.S. was a network phenomenon, growing out of the actions of large numbers of interacting people which institutionalized research. So, this is the period when research and development in the modern sense begun. Furthermore, the change in underlying science shifted technology from its early 19th century demands for tangible capital and resources into more intangible forms of capital such as knowledge and advanced education. This reinforced the central role of universities and polytechnic schools that collaborated to create better and cheaper access to knowledge. In fact, during the SIR the useful knowledge[55] became increasingly accessible and universal (Mokyr 2002a).

In sum, technology coevolved with the new institutions of industrial capitalism, and what is more, technological development became more endogenous.[56] Starting from that time the R&D activity has to be taken as a sector in the economy, whose performance depends to a large extent on the resources devoted to it.

## 6. Conclusions

The scope and pace of the changes over the past two decades qualify this period as the Third Industrial Revolution (ICT revolution) (Freeman and Louça 2001, Mokyr 1997, Lucas 2002). There are parallels between modern and historical industrial revolutions. Just as macroinventions of the past were capable of inducing microinventions and changes in social technology, today's ICT revolution has the same effects. On the one hand, new industries are developing, such as internet technology, the information industry and biotechnology, and, on the other hand, traditional industries are changing in character. Moreover, the new information technology induces fundamental changes in production technology by requiring new machinery, new materials and new inputs. Of course, these new physical technologies cannot work well with the old social technologies: fundamental changes are needed inside the firm as well as in other elements of the social technology.

Amongst the changes in social technology the extension and globalization of markets are the most important: the fall in the cost of information gathering and the reduction in the

[54] As an example, DuPont launched an ambitious research agenda in basic science in the late 1920s.
[55] Useful knowledge is defined in terms of production technology. See Mokyr (2002a).
[56] "The industrialization process inevitably transforms science into a more and more endogenous activity by increasing its dependence upon technology (Rosenberg 1982:159)".

barriers to trade make markets larger and support more competition (hypercompetition). Another development concerns the globalized markets, i.e., financial markets: new institutions (new regulating institutions, new laws) are emerging.[57] Firms have to adapt to global capital markets, weakening regulations and the effectiveness of monetary policy at national levels (Freeman and Louça 2001). The new style of management is in contrast with Fordism in many respects. Networking both within firms and in the external relations of the firm is becoming extremely important. The "vanishing hand" of the market (Langlois 2003) characterizes today's economy in which the market as coordinating mechanism seems to have a comparative advantage over hierarchy. The ICT revolution has significantly changed the character of work: knowledge has become the crucial input, which requires new organizational forms that rely more on teams and projects, and use more flexible methods. Due to changes in competition in markets firms also induce their members to behave entrepreneurially, leading to modular structures which have less need for management. Internet technology also makes it possible to work in smaller units or even at home (Mokyr 1997), which erodes the traditional boundaries of the firm. In some respect firms are becoming virtual teams assembled on an ad hoc basis for specific projects.

The above short discussion aimed at highlighting the fact that social and physical technology continues to co-evolve as a continuation of previous industrial revolutions. However, as I argued before, although particular historical contexts exhibit particular features in the process of co-evolution, lessons can be drawn from past industrial revolutions which may give us guidelines to better understand the relationship between today's ICT revolution and institutional changes. These can help design policies and institutions to foster economic development. In what follows I will put forward four propositions based on the experience of how technology and institutions co-evolved in the past.[58]

1. Informal institutions were critical during the BIR, and their role has changed to a considerable extent since then. The BIR was the period when formal institutions and organizations characterizing an open access order came into being, and this process was largely determined by them. Clearly, here the Williamsonian theory holds. Since then they have hardly changed; instead, they have exhibited strong path-dependent features and inertia. However, once informal institutions of an open access order are in place, as was the case during the SIR and as is the case today in developed countries, social and physical technology

[57] For an overview of the new international financial institutions see Buiter and Lankes (2003).

[58] Note, however, that other lessons can also be drawn from past industrial revolutions, but from other viewpoints.

can co-evolve in such a way as to produce economic development. This is a bad news for developing countries where informal institutions are not those which characterize an open access order, and accordingly, development is lacking. In this context, development policy has only a very limited impact on the development of a particular developing country, which is in line with North et al. (2006).

2. Since industrial revolutions are successive, the BIR was unique in the sense that it put in motion the co-evolution of social and physical technology, and macroinventions played the determinant role in that. During the SIR the role of macroinventions became less significant in initiating industrial revolutions but remained crucial in keeping in movement the co-evolution. In this way microinventions may start a new beginning for the clustering of innovations, but late coming macroinventions are needed to assure that development does not stop as a result of the decreasing returns arising from microinventions. This suggests that the promotion of innovation (microinventions) by policy today is far more important than during the BIR, and in this respect the trend that started during the SIR seems to prevail: formal institutions stimulating innovation (R&D activities) need careful design to foster economic development. That is, changes in formal institutions are becoming less spontaneous and enforced, and more designed. In this sense the experiences from the SIR are more useful and appropriate for today than those of the BIR.

3. Today's changes in social technology, due to the increased importance of microinventions, are inclined to develop around changes in firm organization – the production process and formal institutions representing mainly fine-tuning – rather than bringing about radically new social technology.

4. Historical examples suggest that organizations, and amongst them firms, play a particularly important role. The factory and the M-form brought about by previous industrial revolutions were crucial in economic development[59]; both can be seen as organizational GPTs that emerged as a result of significantly new physical technology. This is to say that radical changes within firms can only be caused by macroinventions. The emerging new organizational form in today's economy, namely the project-based form, is also the result of toady's macroinventions. Based on history, formal institutions (labor market regulation, R&D supports, the educational system, etc.) need to be adjusted to the requirements of this new firm organization. Western Europe's lagging behind the U.S. in these fields is the result of Europe's poor quality institutions, as is also argued by Phepls (2003).

[59] On the primary role of firms in development see North et al. (2006)

## References


Acemoglu, D. – Johnson, S. – Robinson, J. (2005) Institutions as the Fundamental Cause of Long-Run Growth. In: Aghion, Ph. – Durlauf, S. N. (eds), Handbook of Economic Growth, Volume 1A. Amsterdam: North Holland, pp. 385-472.

Aghion, Ph. (2004) Growth and Development: A Schumpeterian Approach. Annals of Economics and Finance 5:1-25.

Alchian, A. A. – Demsetz, H. (1972) Production, Information Cost, and Economic Organization. American Economic Review 62. 5:777-795.

Allen, Robert C. (1983) Collective Invention. Journal of Economic Behavior and Organization 4:1-24.

Aoki, M. (2007) Endogenizing Institutions and Institutional Change. Journal of Institutional Economics 3. 1:1-31.

Basalla, G. (1988) The Evolution of Technology. Cambridge: Cambridge University Press.

Boettke, P. J. – Coyne, C. J. (2003) Entrepreneurship and Develpoment: Cause and Consequence. In: Koppl, R. (ed), Austrian Economics and Entrepreneurial Studies. Advances in Austrian Economics Volume 6. Oxford: Elsevier Science Ltd. pp. 67-88.

Buiter, W. – Lankes, H. P. (2003) International Financial Institutions – Adapting to a World of Private Capital Flows. In: Das, D. (ed), Perspectives in Global Finance. London and New York: Routledge.

Chandler, A. D. (1962) Strategy and Structure: Chapters in the History of the Industrial Entreprise. Cambridge: The MIT Press.

Chandler, A. D. (1977) The Visible Hand: the Managerial Revolution in American Business. Cambridge: Harvard University Press.

Chandler, A. D. (1990) Scale and Scope: The Dynamics of Industrial Capitalism. Cambridge: The MIT Press.

Chandler, A. D. (2006) How High Technology Industries Transformed Work and Life Worldwide from the 1880s to the 1990s. Capitalism and Society 1. 2:1-55.

Clark, G. (1996) The Political Foundations of Modern Economic Growth: England, 1540-1800. Journal of Interdisciplinary History 26. 4:563-588.

Crafts, N. F. R. (1977) Industrial Revolution in England and France: Some Thoughts on the Question 'Why Was England First'? Economic History Review 30:429-441.

Crafts, N. F. R. (1995) Exogenous or Endogenous Growth? The Industrial Revolution Reconsidered. Journal of Economic History 55. 4:745-772.

Doepke, M. – Zilibotti, F. (2007) Occupational Choice and the Spirit of Capitalism. NBER Working Paper. No. 12917.

Dutton, H. I. (1984) The Patent System and Inventive Activity During the Industrial Revolution, 1750-1852. Manchester: Manchester University Press.

Foss, N. J. (2002) ‘Coase vs Hayek’: Authority and Firm Boundaries in the Knowledge Economy. International Journal of the Economics of Business 9. 1:9-36.

Freeman, C. (1991) Innovation, Changes of Techno-Economic Paradigm and Biological Analogies in Economics. Revue économique 2:211-231.

Freeman, C. – Louça, F. (2001) As Time Goes By. From the Industrial Revolutions to the Information Revolution. Oxford: Oxford University Press.

Galor, O. – Weil, D. (2000) Population, Technology, and Growth. American Economic Review 90. 4:806-828.

Greif, A. (2005) Commitment, Coercion, and Markets: The Nature and Dynamics of Institutions Supporting Exchange. In: Ménard, C. – Shirley, M. (eds), Handbook of New Institutional Economics. Dordrecht: Springer. pp. 727-786.

Helpman, E. (1998) General Purpose Technologies and Economic Growth. Cambridge: The MIT Press.

Hodgson, G. M. (2006) What Are Institutions? Journal of Economic Issues XL. 1:1-26.

Jones Ch. (2001) Was an Industrial Revolution Inevitable? Economic Growth Over the Very Long Run. Advances in Macroeconomics 1. 2:1-42.

Jones, S. R. H. (1987) Technology, Transaction Costs, and the Transition to Factory Production in the British Silk Industry, 1700-1870. Journal of Economic History XLVII. 1:71-95.

Kapás, J. (2004) Mutant-Firms in the New Economy. Economie et institutions 5. 2:77-96.

Kapás, J. (2008) The Factory: An Explanation from the Viewpoint of the theory of the Firm (in Hungarian). Mimeo.

Khan, B. Z. – Sokoloff, K. L. (2001) The Early Development of Intellectual Property Institutions in the United States. Journal of Economic Perspectives 15:233-246.

Khan, B. Z. – Sokoloff, K. L. (2004) Institutions and Democratic Invention in 19th Century America: Evidence From “Great Inventors” 1790-1930. American Economic Review 94:395-401.

Kim, S. (2001) Markets and Multiunit Firms from an American Historical Perspective. NBER Working Paper No. 8232.

Lamoreaux, N. R. (1998) Partnership, Corporations, and the Theory of the Firm. American Economic Review 88. 2:66-71.

Lamoreaux, N. R. – Raff, D. M. G. – Temin, P. (2003) Beyond Markets and Hierachies: Toward a New Synthesis of American Business History. American Historical Review 108. 2:404-433.

Lamoreaux, N. R. – Sokoloff, K. L. (1996) Long Term Changes in the Organization of Inventive Activities. Proceedings of the National Academy of Sciences 93. November:12686-12692.

Lamoreaux, N. R. – Sokoloff, K. L. (1999a) Inventors, Firms, and the Market for Technology in the Late Nineteenth and Early Twentieth Centuries. In: Lamoreaux N. R. –Raff, D. M. G. – Temin, P. (eds), Learning by Doing in Markets, Firms and Countries. Chicago: University of Chicago Press. pp. 19-60.

Lamoreaux, N. R. – Sokoloff, K. L. (1999b) Inventive Activity and the Market for Technology in the United States, 1840-1920. NBER Working Paper No. 7107.

Lamoreaux, N. R. – Sokoloff, K. L (2002) Intermediaries in the US Market for Technology, 1870-1920. NBER Working Paper No. 9017.

Landes, D. S. (1960) The Structure of Enterprise in the Nineteenth Century. In: Landes, D. S. (eds), The Rise of Capitalism, New York: Macmillan. 1966. pp. 99-110.

Landes, D. S. (1969) The Unbound Prometheus: Technological and Industrial Development in Western Europe from 1750 to Presen. Cambridge: Cambridge Universirty Press. 2003.

Landes, D. S. (1994) What Room for Accident in History?: Explaining Big Changes By Small Events. Economic History Review 47:637-656.

Langlois, R. N. (1999) The Co-evolution of Technology and Organization in the Transition to Factory. In: Robertson, P. L. (ed), Authority and Control in Modern Industry. London: Routledge. pp. 45-72.

Langlois, R. N. (2003) The Vanishing Hand: the Changing Dynamics of Industrial Capitalism. Industrial and Corporate Change 12. 2:351-385.

Lipsey, R. – Carlaw, K. I. – Bekar C. T. (2005) Economic Transformations: General Purpose Technologies and Long-term Economic Growth. Oxford: Oxford University Press.

Lucas, R. E. (2002) The Industrial Revolution: Past and Future. In: Lucas, R. E. (ed), Lectures on Economic Growth. Cambridge: Harvard University Press.

MacLeod, C. (1988) Inventing the Industrial Revolution. The English Patent System, 1660-1800. Cambridge: Cambridge University Press.

Mokyr, J. (1990) The Lever of Riches: Technological Creativity and Economic Progres., New

York, London: Oxford University Press.
Mokyr, J. (1991) Evolutionary Biology, Technological Change and Economic History. Bulletin of Economic Research 43. 2:127-149.
Mokyr, J. (1993) Introduction: The New Economic History and the Industrial Revolution. In: Mokyr, J. (ed), The British Industrial Revolution: An Economic Perspective. Oxford: Westview Press.
Mokyr, J. (1997) Are We Living in the Middle of an Industrial Revolution? Federal Reserve Bank of Kansas City Economic Review Second Quarter:31-43.
Mokyr, J. (1999) Invention and Rebellion: Why Do Innovations Occur at All? An Evolutionary Approach. In: Brezis, E. – Temin, P. (eds), Minorities and Economic Growth. Amsterdam: Elsevier Publishers. pp. 179-203.
Mokyr, J. (2002a) The Gifts of Athena. Historical Origins of the Knowledge Economy. Princeton University Press. First paperback, 2005.
Mokyr, J. (2002b) Thinking about Technology and Institutions. Paper for the Macalester College International Roundtable 'Prometheus's Bequest: Technology and Change' October 10-12, 2002.
Mokyr, J. (2005a) Long-term Economic Growth and the History of Technology. In: Aghion, Ph. – Durlauf, S. N. (eds), Handbook of Economic Growth. Amsterdam: North Holland. pp. 1113-1180.
Mokyr, J. (2005b) The Intellectual Origins of Modern Economic Growth. Journal of Economic History 65. 2:285-351.
Mokyr, J. (2006) The Great Synergy: the European Enlightenment as a Factor in Modern Economic Growth. In: Dolfsma, W. – Soete, L. (eds), Understanding the Dynamics of a Knowledge Economy. Cheltenham: Edward Elgar. pp. 7-41.
Mokyr, J. (2008a) Entrepreneurship and the Industrial Revolution in Britain: In: Baumol, W. – Landes, D. S. – Mokyr, J. (eds), Entrepreneurship in History. Princeton: Princeton University Press.
Mokyr, J. (2008b) The Institutional Origins of the Industrial Revolution. In: Helpman, E. (ed), Institutions and Economic Performance. Cambridge: Harvard University Press. (forthcoming)
Mokyr, J. – Voth. H.-J. (2007) Understanding Growth in Europe, 1700-1870: Theory and Evidence. Available: http://www.degit.ifw-kiel.de/papers/degit_11/C011_002.pdf
Murmann, J. P. (2003) Knowledge and Competitive Advantage. The Coevolution of Firms, Technology, and National Institutions. Cambridge: Cambridge University Press.

Nelson, R. R. (1994) The Co-evolution of Technology, Industrial Structure, and Supporting Institutions. Industrial and Corporate Change 3:47-63.

Nelson, R. R. (2001) The Coevolution of Technology and Institutions as the Driver of Economic Growth. In: Foster, J. – Metcalfe, J. F. (eds), Frontiers of Evolutionary Economics: Competition, Self-organization, and Innovation Policy. Cheltenham: Edward Elgar. pp. 19-30.

Nelson, R. R. (2002) Bringing Institutions into Evolutionary Growth Theory. Journal of Evolutionary Economics 12:17-28.

Nelson, R. R. (2008) What Enables Rapid Economic Progress: What Are the Needed Institutions? Research Policy 37. 1:1-11.

Nelson, R. R. – Peterhansl, A. – Sampat, B. (2004) Why and How Innovations Get Adopted: A Tale of Four Models. Industrial and Corporate Change 13. 5:679-699.

Nelson, R. R. – Sampat, B. H. (2001) Making Sense of Institutions as Factor Shaping Economic Performace. Journal of Economic Behavior and Organization 44:31-54.

North, D. C. (1990) Institutions, Institutional Change, and Economic Performance. Cambridge: Cambridge University Press.

North D. C. – Weingast, B. R. (1989) Constitutions and Commitment: Evolution of Institutions Governing Public Choice in Seventeenth-Century England. Journal of Economic History XLIX. 4:803-32.

North, D. – Wallis, J. J. (1994) Integrating Institutional Change and Technical Change in Economic History: A Transaction Cost Approach. Journal of Institutional and Theoretical Economics 150. 4:609-624.

North, D. C. – Thomas, R. P. (1973) The Rise of the Western World. Cambridge: Cambridge University Press.

North, D. C. – Wallis, J. J. – Weingast, B. R. (2006) A Conceptual Framework for Understanding Recorded Human History. NBER Working Paper No. 12795.

Nuvolari, A. (2004) Collective Invention during the British Industrial Revolution: the Case of the Cornish Pumping Engine. Cambridge Journal of Economics 28:347-363.

Pelikan, P. (2003) Bringing Institutions into Evolutionary Economics: Another View with Links to Changes in Physical and Social Technologies. Journal of Evolutionary Economics 13:237-258.

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

Perez, C. (1985) Microelectronics, Long Waves and World Structural Change: New

Perspectives for Developing Countries. World Development 13. 3:441-463.

Perez, C. (2004) Technological Revolutions, Paradigm Shifts and Socio-Institutional Change. In: Reinert, E. (ed), Globalization, Economic Development and Inequality: An Alternative Perspective. Cheltenham: Edward Elgar. pp. 217-242.

Phelps, E. S. (2003) Economic Underperformance in Continental Europe: A Prospering Economy Runs on the Dynamism from its Economic Institutions. Lecture, Royal Institute for International Affairs, London, March 19.

Pollard, S. (1965) The Genesis of Modern Management. London: E. Arnold.

Rajan, R. – Zingales, L. (2000) The Governance of the New Enterprise. Megjelent: Vives, X. (ed), Corporate Governance. Cambridge: Cambridge University Press. pp. 201-227.

Rosenberg, N. (1982) Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press.

Simon, H. A. (1951) A Formal Theory of the Employment Relationship. Ecometrica 19. 3:293-305.

Sullivan, R. J. (1989) England's "Age of Invention": The Acceleration of Patents and Patentable Invention during the Industrial Revolution. Explorations in Economic History 26:424-452.

Wallis, J. J. (2003) Market-Augmenting Government? States and Corporation in the Nineteenth-Century America. In: Azfar, O. – Cadwell, C. A. (eds), Market-Augmenting Government. The Institutional Foundations for Prosperity. Ann Arbor: Michigan University Press. pp. 223-265.

Williamson, O. E. (1991) Comparative Economic Organization: The Analysis of Discrete Structural Alternatives. Administrative Science Quarterly 36:269-296.

Williamson, O. E. (2000) The New Institutional Economics: Taking Stock, Looking Ahead. Journal of Economic Literature XXXVIII. Sep:595-613.

Wright, G. (1999) Can a Nation Learn? American Technology as a Network Phenomenon. In: Lamoreaux N. R. – Raff D. M. G. – Temin P. (eds), Learning by Doing in Markets, Firms and Countries. Chicago: University of Chicago Press. pp. 295-332.

## Appendix

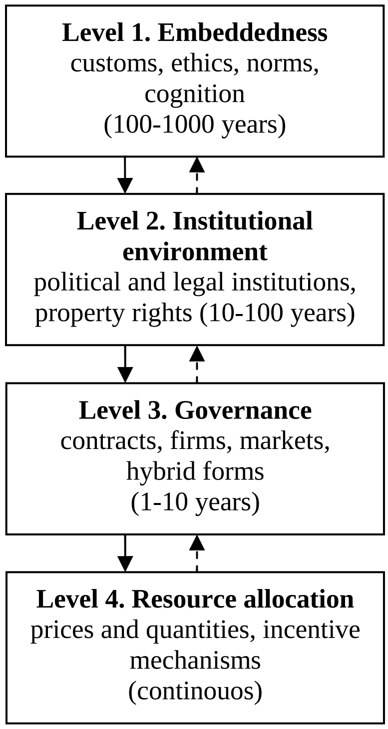


Figure 1. Levels of social analysis

Source: Williamson (2000:597)

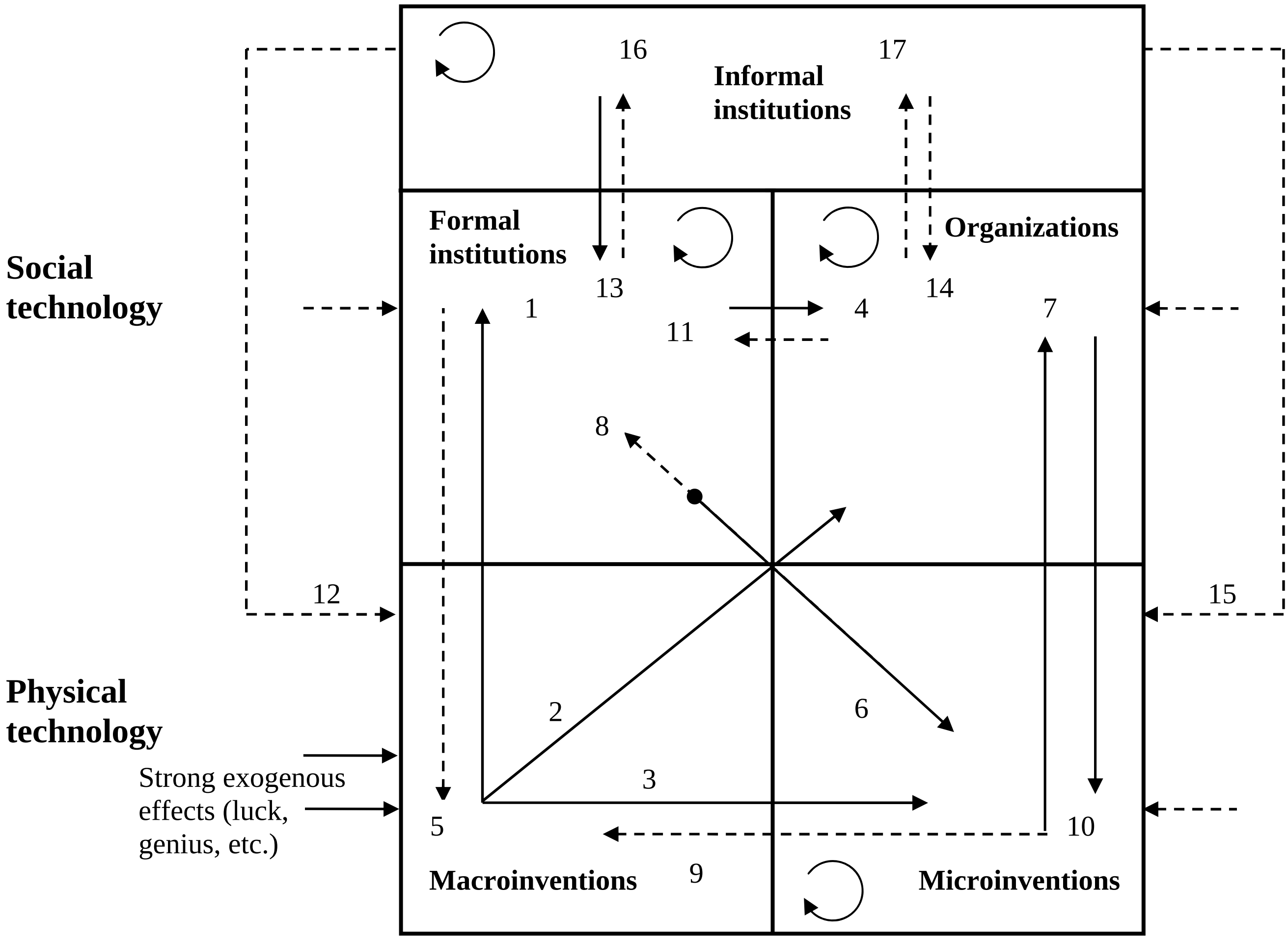


Figure 2. The model of the co-evolution of social and physical technology

endogenous effect, - - - -> weak effect, ——> strong effect

The signification of arrows:

1 – significantly new laws, new governmental, political and regulatory institutions
2 – significantly new firm organization
3 – determines what can be improved
4 – fine-tuning in a given type of firm organization
5 – very weak effect, if any (favorable overall environment)
6 – provides incentives to innovate (patent institutions, technological agencies, etc.)
7 – fine-tuning in a given type of firm organization
8 – fine-tuning: better (or new) new institutions supporting innovation (patent law, R&D-based tax reduction, governmental agencies, etc.)
9 – none (or very weak effect)
10 – provides incentives and environment to innovate (R&D department, royalty, etc.)
11 – fine-tuning: new or better regulations and laws
12 – provides an overall favorable environment
13 – determines the framework for formal (legal, political and economic) institutions
14 – provides an overall favorable environment for the operation of firms
15 – provides an overall favorable environment
16 – weak and uncertain effect
17 – none (or very weak effect)