Exploring the evolution of mass production (1765-2018) from the Deep Transitions perspective

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1. Introduction

The systemic perspective to socio-technical change, paying attention to the co-evolution of actors, technologies, institutions and their linkages, has become increasingly popular in recent decades. Recently two mature branches of literature on systems change – the Multi-level Perspective (MLP) on socio-technical transitions (Rip and Kemp, 1998; Geels, 2005; Grin et al., 2010) and the Techno-economic Paradigm (TEP) theory (Perez, 1983; Freeman and Louçã, 2001; Perez, 2002) – have been synthesized into the Deep Transitions framework (Schot and Kanger, 2018; Kanger and Schot, forthcoming). This framework aims to conceptualize the co-evolution of niches, single socio-technical systems, interconnected systems and the broader macro-level selection environment, called industrial modernity, over the past 250 years. The aspiration is to offer an explanation of socio-technical systems change that would be able to grasp very long term continuities in the process of industrial modernization, occasional major discontinuities (e.g. transitions and long waves) as well as the presence and scale-up of niches offering radical alternatives to incumbent systems.

Schot and Kanger (2018) developed an evolutionary institutionalist (Fürstenberg, 2016) model to explain how alternatives that begin in niches and are scaled up in single systems as transitions, further come to guide the evolution of multiple systems during successive long waves or Great Surges of Development (Perez, 2002), and eventually start to shape socio-technical landscape. Through this process long-term directionalities in the evolution of socio-technical systems, e.g. drive towards increasing mechanization or increasingly global value chains, are created, consolidated and maintained. This long-term process is called the First Deep Transition.

Although Schot and Kanger (2018) draw on the history of technology to illustrate their claims the framework has yet to be subjected to systematic empirical testing. This is the task undertaken in the current paper. The historical evolution of mass production in the Transatlantic area from 1765 to the present is chosen as the focal case. The case selection reflects the profound importance of mass production and its corollary, individualized mass consumption, for shaping modern industrial practices, lifestyles and expectations about

"normal" quality of life, but also its contribution to major environmental issues such as pollution, creation of waste, or resource depletion (Ponting, 1991; Stearns, 2013). A practical consideration concerns the abundance of prior literature on the history of mass production which enables to trace its development and its take-up in various socio-technical systems throughout the whole period of observation.

The Deep Transitions framework, as it stands today, also has a particular blindspot that it shares with its analytical building blocks, MLP and TEP. Namely, while it has provided a multi-level explanation of great surges of development it currently does not have an explanation for the evolution of formerly dominant solutions that cease to be the hotspot of innovative activities once one surge ends and another begins. This is also true for mass production that was dominant during the 4th surge (1908 to mid-1970s) but then gave way to the 5th surge, centred on Information and Communications Technologies (Perez, 2002). Hence this study will also trace the evolution of mass production from the 1970s to the present to further develop the Deep Transitions framework. The two main research questions of the paper are thus as follows:

1. How do the evolutionary dynamics described by the Deep Transitions framework match with the historical evolution of mass production between 1765-1970s?
2. What are the evolutionary dynamics of mass production after the 1970s and how do they relate to the Deep Transitions perspective?

The paper is structured as follows. Section 2 provides an outline of the basic propositions of the Deep Transitions framework. Section 3 describes the methodology of the study whereas section 4 presents an historical narrative of the evolution of mass production. Section 5 provides an assessment of the extent to which the findings match the Deep Transitions framework and further develops the theory. Section 6 concludes.

2. Theoretical framework

Interaction between rules and socio-technical systems is central to the Deep Transitions framework. Rules are seen as a genotype, a set of driving principles that manifest themselves as a phenotype, that is, a socio-technical system with certain characteristics in a certain locality at a certain point in time. However, ongoing technological experimentation with system elements or the build-up of new systems by different actors in niches might lead to the introduction of new rules or to the modification of existing ones: in other words, rules and socio-technical systems are seen as mutually constitutive.

The rules differ in terms of their scope and degree of systemicity: hence the four-fold distinction between rules, meta-rules, regimes and meta-regimes, manifested either in single systems or complexes of socio-technical systems. A Deep Transition can thus be viewed as a process whereby rules emerge, diffuse and become aligned, thereby providing single systems and interconnected complexes of systems with a specific long-lasting set of directions. Table 1 presents a summary of these concepts, including a formal definition and an empirical example.

Table 1. Rules and socio-technical systems.

Concept	General definition	Example
Rule	A humanly devised constraint that structures human action leading to a regular pattern of practice, present in a single socio-technical system	A drive to optimize fuel efficiency in the automobility system
Meta-rule	A single rule present in multiple socio-technical systems	Imperative to use fossil fuels (e.g. in agriculture, energy provision and mobility systems)
Regime	Relatively stable and aligned sets of rules directing the behaviour of actors along the trajectory of incremental innovation, present in a single socio-technical system	Mass production as defined in the US automobile industry at the beginning of the 20th century
Meta-regime	Rule-sets present in multiple socio-technical systems, coordinating their development and leading to a shared directionality	Global mass production in various systems (e.g. food, mobility, communications) after World War II, giving rise to throwaway consumer culture
Socio-technical system	Configuration of actors, technologies and institutions for fulfilling a certain societal function; manifestations (phenotype) of regimes	Systems of individual passenger transport with somewhat different national characteristics in post-war USA, Netherlands and Germany
Complexes of systems	Configurations of socio-technical systems, manifestations (phenotype) of meta-regimes	The virtuous cycle of expansion of the automobile system and the housing system in USA, starting from the interwar era

This vocabulary can be used to explain the Great Surges of Development. According to Perez (2002) these are clusters of technological innovations and associated best practices that tend to come in every 40-60 years (e.g. the Age of Steel, Electricity and Heavy Engineering from 1875, the Age of Oil, the Automobile and Mass Production from 1908 and the Age of Information and Telecommunications from 1971). Combining her description of the phases of each surge (which she calls irruption, frenzy, synergy and maturity, with a turning point in the middle) with the conceptual insights of the Multi-level Perspective (Geels, 2005; Grin et al 2010) Schot and Kanger (2018) developed eight propositions about Deep Transition dynamics:

1. Deep Transitions begin with the parallel emergence of new socio-technical systems and associated rules in separate niches, defined as spaces governed by specific selection criteria (e.g. military applications prioritizing performance over cost). In

some instances wider landscape pressures might destabilize dominant regimes, opening up a window of opportunity for niches. The niche rules might then become aligned into a new regime and break through, resulting in regime-shifts (transitions) in individual systems (Geels, 2005). All these niches and emerging regimes provide a raw material, an essential variety from which more expansive meta-regimes and eventually one dominant meta-regime will be constructed.

2. During the first phase of the surge (irruption), the emerging and incumbent rules come to compete against each other, resulting in further transitions or transition failures. Early interactions between some regimes might occur and some rules may turn into meta-rules as a result. However, overall these interactions as well as their outcomes remain *ad hoc*, non-standardized and accidental in nature: at this point no systemic connections between regimes and systems are created, and thus no clear directionality is established.
3. Towards the end of the irruption phase and the beginning of frenzy phase, many rules increasingly start to cross the boundaries of a single system. This now occurs on a much more systematic basis than before, possibly leading to partial alignment between different meta-rules. When this happens a clearer new directionality becomes visible, yet in this phase there will still be competing options (alternative directions of evolution) available.
4. Two mechanisms for achieving more coordination across the boundaries of single systems are structural and functional couplings (Konrad et al., 2008). Structural couplings refer to shared use of infrastructures, actors, and/or rules (e.g. both waste management and energy system using the same R&D facility). Functional couplings refer to input-output relations (e.g. waste management system providing an input to the energy system).
5. Additional mechanism, further facilitating and accelerating the creation of between-system links, is the aggregation and intermediation work of inter- and transnational organizations (Kaiser and Schot, 2014). These actors bring together experiences and ideas from different sectors, nurture mutual learning processes, help to establish networks between various stakeholders, and shape expectations about the future of the niches. Note that in contrast to the relatively uncoordinated interactions between systems during the early irruption phase the nature of the aggregation work is much more purposeful, geared towards homogenization and standardization.
6. The competition between meta-rules and the emergence of partially aligned rule-sets is finally resolved at the turning point. This point is reached by the combination of two types of crises – the bursting of a speculative bubble around new technologies (Perez, 2002) and the occurrence of an external shock, e.g. the role of World War II in accelerating mass production in USA (Gordon, 2016). These crises provide an impetus for powerful actors to tilt the playing field decisively towards a set of specific meta-rules and the alignment of these into a specific meta-regime driving out the competitors. Therefore, from this point onwards one can start talking about the existence of *the* dominant meta-regime providing directionality across many socio-technical systems.
7. During the synergy phase that follows, the dominant meta-regime starts to exert its

influence in three directions. In relation to niches it acts as a selection mechanism, favouring technologies compatible with its logic and rejecting non-compatible ones (Perez, 2011). It continues to diffuse from one system to another, leading to the increasing take-up of its principles in various sectors and thus to ever stronger couplings between different regimes. Finally, it starts to shape landscape dynamics through the feed-in mechanism (e.g. the transport regime, based on individual automobility, partially contributing to global greenhouse gas emissions).

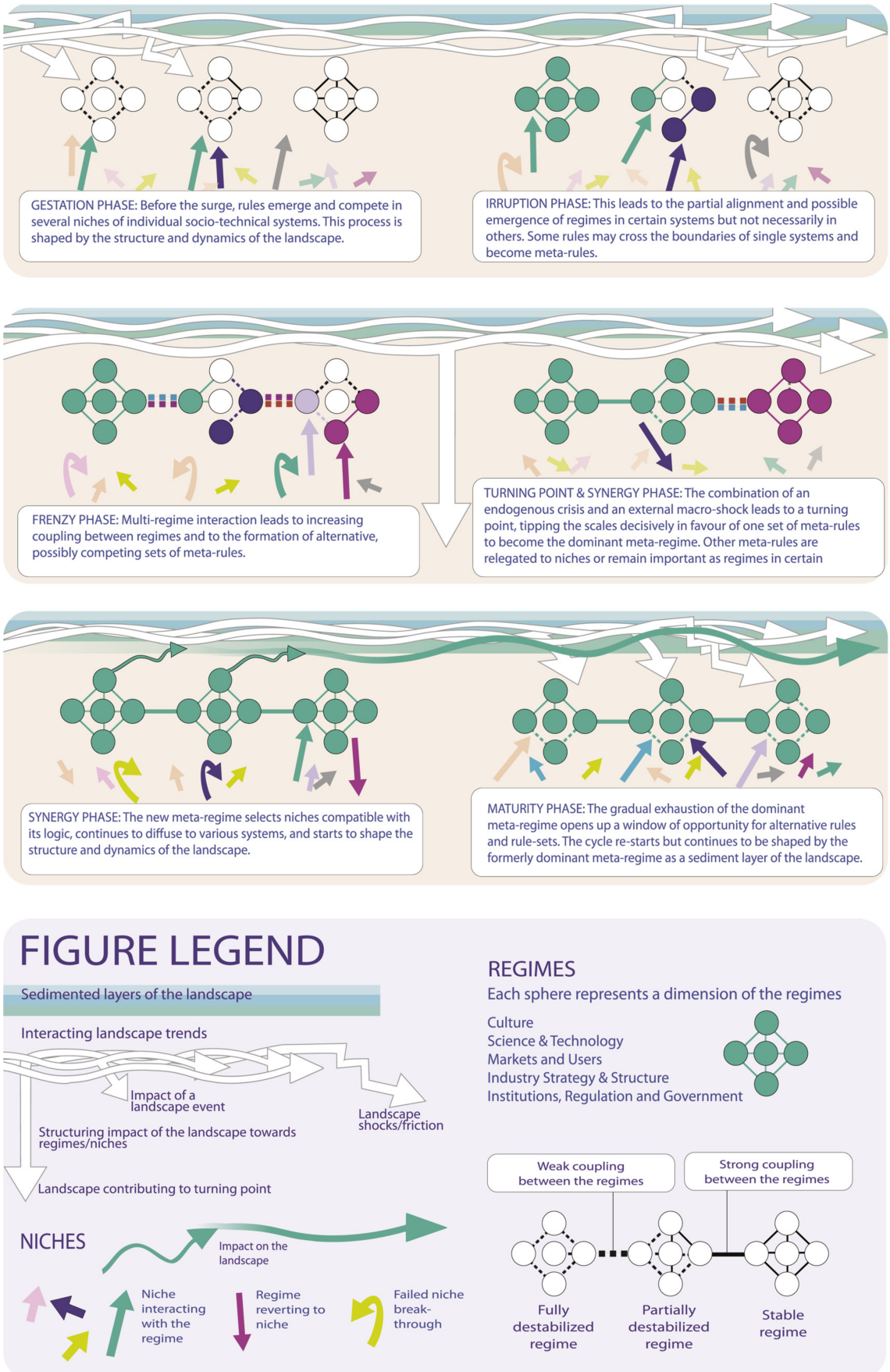
8. When the surge reaches its final phase (maturity), new problems start to appear which cannot be fully resolved within the confines of the dominant meta-regime. The scene is set then for yet another surge with new systems becoming the main loci of radical innovative activities. However, by now the manifestations of the previous surge have become firmly embedded in the socio-material fabric of society, expressed in infrastructures, spatial patterns of urbanization, and environmental changes (e.g. climate change). Through the sedimentation mechanism they have become another layer of socio-technical landscape that continues to structure further interactions between new niches, regimes and meta-regimes (e.g. the reliance of digital revolution on electricity networks, or the problems created by the transport regime prompting efforts in the field information and communication technologies to solve them).

The sequence of events is visualized on figure 1.

The problem with this conceptualization is that it stops at highlighting the impact of an existing surge on the new one (e.g. the impact of electrification on the emergence of mass production). However, it does not explain the evolution of the formerly dominant surge after it has ceased to be the hotspot of radical innovative activities. For example, it is not able to explain the evolution of mass production during the most recent surge centred on ICT-s. The current study thus aims to both test and develop the Deep Transitions framework, focusing on the following research questions:

1. How do the evolutionary dynamics described by the Deep Transitions framework match with the historical evolution of mass production between 1765-1970s?
2. What are the evolutionary dynamics of mass production after the 1970s and how do they relate to the Deep Transitions perspective?

Figure 1. A multi-level explanation of great surges of development (Schot and Kanger, 2018: 12).



3. Methodology

The study focuses on the historical evolution of mass production in the Transatlantic region from 1765 to the present. Mass production has been selected because of substantive and practical considerations. The former include the importance of mass production and mass consumption as fundamental elements of modern lifestyles but also its contribution to major environmental issues such as pollution, creation of waste, or resource depletion (Ponting, 1991; Stearns, 2013). The latter include the availability of a broad array of secondary literature since conducting historical work with primary sources on the scale required for testing such a framework would fall beyond the scope of the study. The focus is on the Transatlantic region as this enables to avoid the "methodological nationalism" implicit in MLP (where socio-technical systems are often nationally bounded) and TEP (with its focus on "leading countries" imitated by others). The Transatlantic focus enables to turn attention to the circulation of rules and technologies across national boundaries, observe local modifications and adaptations, and to avoid treating a specific national manifestation (e.g. the mobility system as defined in the interwar USA) as a "model" that other countries would sooner or later need to follow. The time frame of the study covers the pre-history of mass production, beginning with the emergence of the ideal of interchangeability in the French military to the present turning point/deployment phase of the ICT surge.

As a strategy of complexity reduction the study focuses on the genotype of mass production, that is, on the evolution of rules underlying mass production. This means that instead of the comparison of the observed features of the systems of mobility, food, agriculture etc. in different countries the study focuses on outlining the emergence, consolidation and transformation of different combinations of rules related to mass production that manifest themselves differently in particular locations. These rules can relate to different dimensions of mass production such as science/engineering, economy, policy, users or culture. Because of the feasibility considerations this study mainly focuses on the science/engineering and, to a lesser extent, on consumption. This omits many parallel developments occurring at the time that, in the long wave literature, are often treated in connected to the technical principles of mass production (e.g. new corporate models or the emergence of a social contract between employers, labour and the state within the framework of a nationally-bounded economy).

For the purposes of the study mass production is defined as the "large-scale volume production of goods aiming at capturing economies of scale". Note that this definition is very minimal and purposefully omits associating mass production with the employment of particular technical solutions such as special-purpose machinery. The reason for this is, as will be shown below, the principles underlying mass production have changed over time and thus roughly the functional equivalents can be delivered through various configurations (e.g. present-day robots being much more flexible than the single-purposed machinery used by Ford).

The analysis was conducted in the following steps:

1. Assembling a list of historical accounts of mass production attempting to include experiences from various countries of the Transatlantic region (as the histories are

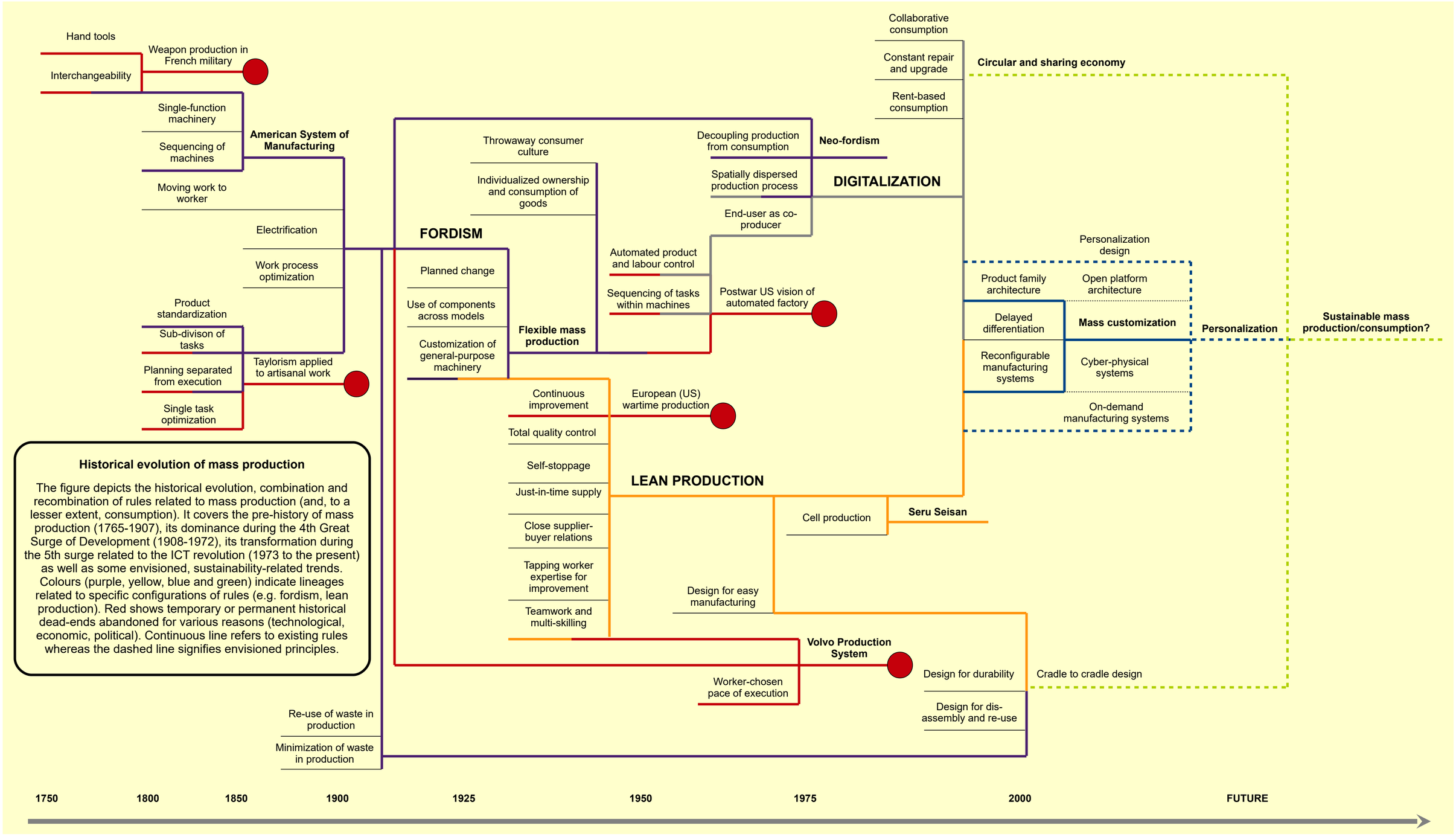
commonly written from the national perspective).

2. Working through the literature to create a) a genotype, i.e. a list of recurrent rules underlying mass production (e.g. "electrification" as one of the foundations of modern mass production); b) a list of recurrent technological solutions for which no underlying rule could be easily found (e.g. time and motion studies).
3. Trying to minimize the latter list through further reading of the literature either by allocating the solution to an already existing rule (e.g. treating time and motion studies as embedding the principle of sub-division of tasks) or adding a new rules to account for the technological solution.
4. On the basis of the list a preliminary genealogy of rules was constructed. This showed the emergence of different rules at different times, their combination into different configurations (e.g. mass production as practised by Ford or General Motors), and the historical dead-ends (imagined or experimental practices that were eventually abandoned, at least for the time being).
5. The genealogy and the emerging interpretations were also discussed with three historians of technology with expertise in mass and/or specialty production in the Transatlantic region to detect possible omissions, correct some misinterpretations and to improve the genealogy.
6. The resulting genealogy was then matched to the propositions of Deep Transitions, assessing the extent to which the framework would be able to explain observed developments, the extent to which the findings deviated from the expectations of the framework, and to further develop the original framework.

4. Case study: The historical evolution of mass production 1760-2017

The following narrative presents the historical evolution of mass production. The narrative is divided into gestation (1760-1907), the 4th surge (installation phase 1908-1938, turning point 1939-1945, deployment phase 1946-1972) and the 5th surge (installation phase 1973-2000, turning point from 2001 with the possibly emerging deployment phase at present). The narrative is organized according to three categories: "rules" describes new relevant rules and combinations of rules that were pioneered at each phase, "diffusion and directionalities" discusses various attempts to apply the ideas of mass production in different geographical areas and socio-technical systems, and "contestation" describes salient problems, conflicts and struggles within mass production, and between mass production and its potential alternatives. The genealogy of mass production is presented on figure 1.

Figure 2. The genealogy of mass production



Historical evolution of mass production

The figure depicts the historical evolution, combination and recombination of rules related to mass production (and, to a lesser extent, consumption). It covers the pre-history of mass production (1765-1907), its dominance during the 4th Great Surge of Development (1908-1972), its transformation during the 5th surge related to the ICT revolution (1973 to the present) as well as some envisioned, sustainability-related trends. Colours (purple, yellow, blue and green) indicate lineages related to specific configurations of rules (e.g. fordism, lean production). Red shows temporary or permanent historical dead-ends abandoned for various reasons (technological, economic, political). Continuous line refers to existing rules whereas the dashed line signifies envisioned principles.

4.1 Gestation (1760-1907)

Rules. The elements of what came to be known as mass production had been experimented with in very different areas of application for almost 150 years before they were combined into the regime of mass production. The rules underpinning mass production included the following:

1. Interchangeability: the ideal was envisioned in armsmaking for the French military (Hounshell, 1985) and proof of principle was demonstrated with hand tools by the beginning of the 19th century. The strive toward interchangeability was eventually abandoned in France for political reasons (Alder, 1997) but transferred to the USA by politicians (Thomas Jefferson), French military experts and books (Hounshell, 1985).
2. Single-function machinery: special-purpose equipment to perform one function only came to be systematically practised in US state armories (Harpers Ferry, Springfield) in the first half of the 19th century (Smith, 1977; Hounshell, 1985).
3. Sequencing of machines: building on British example of wooden blockmaking (from the 1790s) Thomas Blanchard developed the idea of sequencing of machines according to the work process from 1818 to the mid-1820s (Smith, 1977; Hounshell, 1985).
4. Moving work to worker: continuous movement and flow production was tried out in various applications such as flourmilling in Minnesota, bakeries (British Navy mass producing biscuits from 1804, automating the process by the 1830s), breweries, cigarette-making, canning, oil and chemical industries, foundries and bicycle production (runners delivering parts to stationary machinists) (Hounshell, 1985; Beniger, 1986). Important precedents include disassembly lines in meat-processing (origins in Cincinnati in the late 1860s, then Chicago in the early 1880s) and Edison's iron mining facility in Ogdenburg which was visited by Henry Ford (Nye, 2013).
5. Electrification: introduced from the 1880s, first as an add-on to the central steam engine but gradually moving toward unit drive (each machine having a separate electric motor). Before that the central power source largely dictated the placement of the machines and also limited the precision that could be achieved. Additional bonuses of electrification included improved lighting and ventilation (enabling increases in precision and working time but also better health for the workers) (Geels, 2006).
6. Work process optimization: systems management had its roots in the engineering developments toward the end of the 19th century and in the efficiency movement (Beniger, 1986; Biggs, 1995; Geels, 2006).
7. Product standardization: the idea to make one product only and minimize changes to its design to avoid expensive and time-consuming retooling (Nye, 2013).
8. Sub-division of tasks: first described by Adam Smith (1776) in the context of pin-making, increasing division of labour characterized a whole array of industries during the 19th century. It required the calculation of tasks for time allocation: time and motion studies were thus an essential part of Frederick Winslow Taylor's system of scientific management that started to develop around the 1880s (Beniger, 1986; Nye, 2013).
9. Planning separated from execution: clear separation between engineering, management and executive roles, also associated with Taylor's emerging thinking

(Beniger, 1986).

10. Standardization of work routines: replacing workers' rules of thumb with rules devised by experts. Note that this is distinct from optimizing a task/work process as it concerns standardizing the sequences of motions within a task rather than a set of tasks themselves. Again, scientific management is the best known advocate of this principle (Beniger, 1986; Van Elteren, 2017).

Diffusion and directionalities. The ideal of achieving interchangeability in weapon production started in the French military from 1765. Decades later the feasibility of this idea was demonstrated with hand tools but this combination turned out to be a dead-end after experiments with new modes of weapon production were terminated in France for political reasons (Alder, 1997). After that the centre of gravity gradually shifted to the USA. Here the principle of interchangeability was combined with single-function machinery and sequencing of machines in US state armories. These three principles formed the core of the American System of Production crystallized by mid-19th century after which European observers started to take note of the advances in US production (Hounshell, 1985). With subsequent refinements (e.g. sheet steel stamping in bicycle industry) the American System was mediated to automobile industry in the second half of the 19th century through various industries such as private armsmaking, clockmacking, sewing machines, typewriters and bicycles. Interchangeability and standardized parts were first introduced to the automobility industry by Henry Leland (Cadillac) in 1908. In terms of the origins of niches there is no clear pattern: armsmaking, mobility, food, energy and chemical production all seemed to contribute to the rules eventually associated with mass production.

Contestation. During this period various rules were experimented with and occasionally combined (e.g. state armories, Taylor's scientific management) with high degree of uncertainty around specific solutions, e.g. suitable methods for cost accounting in firms (Scranton, 1997). However, for various reasons in no industry or sector were all of them brought together (Hounshell, 1985; Nye, 2013). Throughout the period the mode of flexible specialty production remained a largely dominant part of the ecosystem of production in the Transatlantic region. The main observable features of specialty production include the following (based on Scranton, 1997):

1. Use of skilled workers;
2. Use of customizable general-purpose machinery;
3. Custom or batch production, competing on novelty or quality (not price);
4. Interpersonal and cooperative (vs. bureaucratic) relations between owners/partners and clients/rival firms/workers;
5. Paternal (vs. adversarial or manipulative) management style;
6. Formation of collective institutions on a regional or metropolitan scale to address common problems and to coordinate prices (vs. internalizing different activities in different departments of a managerial corporation);
7. Small- or medium-sized enterprises clustering in certain districts to enable synergies;
8. Pursuing systematization of working practices but not the standardization of components or products (flexibility and innovation valued over speed and volume of

production);
9. Tapping workers' knowledge for improvement of production;
10. Often defending high tariffs (believed to be coupled to high wages, expanding consumption and business prosperity) and resisting any federal interventions or labour unionization;
11. Following the strategy of quick adaptation to environmental fluctuations (vs. attempting to shape the environment itself).

4.2 4th surge: irruption (1908-1919)

Rules. The decade from 1906-1915, especially the last three years in Highland Park factory, were characterized by a wave of experimentation by Henry Ford and his engineers (Hounshell, 1985). This led to drawing together the principles of interchangeability, single-function machinery, sequencing of machines, moving work to worker, electrification, work process optimization, product standardization, sub-division of tasks, planning separated from execution and standardization of work routines into the regime of mass production for car production. As there were no prior precedents this experimentation was almost unavoidable although once crystallized the version of mass production as defined by Ford became more rigid over time. Pioneering a low-cost car for the masses and capturing the economies of scale, Ford also had a significant first-mover advantage, resulting in continuous demand and low inventories. However, both continuous improvement and minimization of stocks were side-effects rather than systematic parts of the early version of mass production. From the economic side, Ford's introduction of the 5-dollar day in 1914, although eventually largely a failed experiment (Hounshell, 1985; Flink, 1990), foreshadowed the emergence of consumer society, tying efficient mass production to high wages and hence increasing the purchasing power of a broad array of consumers.

Another stream of rules concerned waste. The principles of waste minimization and re-use of waste in production (e.g. sawdust for electricity generation) were often noted by contemporary observers as significant features of Ford's factories (see Tolliday, 1998, vol. 1). However, these rules were mainly directed to optimizing the production process: the later rise of consumer society, increasing demand and the profusion of goods amply compensated for efficiency gains in production. Hence the initial “sustainability” promise of Ford's production became increasingly muted until mass production was equated with wastefulness (see 4.6).

Diffusion and directionalities. Ford's Highland Park factory, pioneering a moving assembly line, quickly became a widely publicized international phenomenon, drawing visitors from different countries (e.g. Germany and UK). World War I can be considered a giant learning experience for Europeans in employing both the techniques of mass production (e.g. Citroen producing artillery shells during WWI) as well as the outcomes of these techniques (e.g. enabling many men to get first-hand experience with driving which promoted the principle of individualized automobility) (Mom, 2015). Furthermore, sending men and horses on the front facilitated the mechanization of agriculture. However, not all attempts to extend mass production were successful, e.g. Ford's failure to deliver submarine patrol boats as quickly as anticipated (Hounshell, 1985b).

The mobility system was an initial source of the mass production regime, serving as an inspiration for automotive engineers in the Transatlantic area. In terms of diffusion between systems the introduction of the Fordson tractor (1917) demonstrated the promise of mass production for agriculture, i.e. agricultural vehicles and the application of fossil fuels being combined into the mechanization of agriculture. War can also be considered as a direct stimulus to establish links between the socio-technical systems of mobility and defence: here the use of automobiles for transport (Mom, 2015) can be considered a functional coupling between two systems.

Contestation. In terms of offering solutions for volume production Ford's and Taylor's approaches can be considered as competing alternatives. Whereas both involved a minute division of tasks, separation of planning from execution and replacing workers' rules of thumb with expert rules, scientific management largely took the work task as given and tried to optimize it, whereas Ford and his engineers aimed to optimize the work process as a whole (which might have led to the elimination of a certain task altogether or delegating it to a machine). The supremacy of Ford's approach was clearly demonstrated early on: in 1914 Ford's production exceeded that of the Packard factory, organized by Taylor's principles, by 30 times (Nye, 2013: 250). Taylor's "one best way" of doing things turned out to be a historical dead end as it was too rigid for flexible production and too focused on task optimization to achieve real productivity gains similar to mass production. *"Until Ford, complete saturation of the world market by a single product had remained a theoretical concept"* (Hounshell, 1985: 186).

The societal response to mass production reflected a high degree of uncertainty about its merits. For example, in USA Ford's decision to double the wages was considered dubious by businessmen but praised by the socialists. In Germany labour unions, not manufacturers, initially welcomed the approach and demand its adoption (Nye, 2013).

Despite much public enthusiasm about Ford's system, a system of specialty production continued to thrive. In USA specialty production contributed roughly about one third of the value added in 1909, remaining viable in many domains such as machinery and machine tools, furniture, stylized textiles, printing and publishing, apparel, and jewelry (Scranton, 1997). In some cases quickly changing consumer demand made the adoption of mass production techniques non-viable (jewelry, furniture), in some cases specialty producers began to establish symbiotic relationships with mass producers (e.g. building specialized single-purpose machinery for early automobile manufacturers). Occasionally different strategies were even pursued in a same organization (e.g. Allis-Chalmers having separate lines for tractors and heavy electrical equipment) (ibid.).

However, the situation began to change from 1913 as the combined effects of president Wilson public policy, wartime requirements, postwar inflation, and the depression around 1920-1921 altered the environment for specialty production. Scranton (1997) argues that the period between 1913-1922 was characterized by high degree of uncertainty, series of federal

interventions, and fierce labour and market conflicts that surpassed anything that had been happening during the past 50 years. This resulted in various adaptive responses, e.g. toolmakers devising new technical designs and collective strategies to confront the challenges, jewelry trades entering a sectoral crisis, and furniture firms allying in a trade association resisting federal interventions during the 1920s.

4.3 4th surge: frenzy (1920-1938)

Rules. Ford had changed the context in which other car-makers were operating. It continued on the path of mass production, focused on reaping economies of scale from producing mainly one model (Model T), albeit with incremental improvements over time. The need to stay competitive led General Motors to pursue the strategy of creative imitation, resulting in the emergence of "flexible mass production" (Hounshell, 1985). This included introducing the strategy of planned change, using similar components across different models and customization of general-purpose machinery (but also other innovations in marketing, demand management and corporate structure). As planned change often referred to cosmetic variety and stylistic changes, not a massive overhaul of existing production, flexible mass production can be considered an extension of Ford's practices rather than an entirely new branch. The stimulation of greater variety by GM (different cars for different customer segments) created a need to deal with fluctuating demand: for this reason Tolliday and Zeitlin (1986) call GM's approach a controlled variety. In parallel, the increasing availability of mass produced consumer durables (refrigerators, radios, toasters etc.) started to stimulate the emergence of consumerism, centred around the individual ownership and consumption of goods.

Diffusion and directionalities. During this period the regime of mass production was experimented with in a number of areas in the Transatlantic region with varying success. Ford's plants in USA continued to draw visitors from home and abroad but knowledge was also transferred by Ford and General Motors establishing plants in Europe. In France the reception was fairly warm with the automobile industry adopting the assembly line in the 1920s (e.g. Citroen, 1919; Berliet, 1920; Renault, 1922; Peugeot, 1929) (Nye, 2013). Adoption of Fordism and Taylorism was initially most enthusiastic in Soviet Union, followed by increasing scepticism and turn toward domestic manufacturing from the 1930s. The Soviet emphasis was first and foremost on machinery and autocratic taylorist methods of workforce control, less on techniques of industrial management (considered suspicious for ideological reasons). The transfer of mass production techniques to the USSR, however, led to the endemic problems related to lack of qualified workforce, inexperienced users and lack of mechanics (Bailes, 1981; Nye, 2013). The Soviet Union can also be credited for devising an original solution to the dilemma between stimulating variety and benefiting from economies of scale encountered by Ford and GM: homogenizing (or curtailing) supply so economies of scale could be achieved by the production of as few models as possible. Hence instead of developing mass production to match it to the dynamic nature of capitalism the Soviet powers chose to shape the supply-and-demand environment in a manner that would fit the Fordist version of mass production the best.

In other countries the reception of mass production was more hesitant. In Germany the

industrial establishment largely resisted the full-scale adoption of American techniques until the Nazi rule and its vision of mass motorization. However, Nazis focused overly on the production side and consumer-oriented rhetoric but largely neglected the demand-side preconditions of consumer society. The combination of low wages, rising oil prices and relatively high cost of the car meant that not many Germans could actually afford the car. Nazis prioritized autarky and armament in practice because victory in war was supposed to lead to cheap labour and unlimited resources) (König, 2004). In the UK adoption was slow throughout the interwar period even in Ford's own branch plants because of different work cultures and attempts to transfer the American approach without any modifications to local conditions. Local manufacturers did adopt some methods for improving quality and throughput but resisted absolute standardization and quantity production, continuing to rely on skilled workers and remaining less capital-intensive than their American counterparts (Nye, 2013).

The diffusion of mass production to Europe can then be described as selective adoption and modification to suit it to local conditions. Radical political forces were initially the most receptive but business conservatives started to embrace it towards the 1930s when mass production was dissociated from utopian connections (e.g. the initial utopian promises of mass production to erase class differences) (Maier, 1970). In general, however, small market size, greater variety in preferences and other factors were widely considered as arguments against a full-scale adoption of American techniques. For example, as Europeans did not believe in the possibility of mass markets they did not adopt the American examples of combining mass production with high-wage and low-price policies in the interwar era (Nye, 2013).

In terms of application areas the period was characterized by the take-up of the techniques of mass production in the realm of consumer goods (e.g. radios, washing machines, refrigerators, vacuum cleaners, toasters, tires, electric irons and other household appliances) (Nye, 2013). Adoption of the logic of mass production continued in the food systems with the mechanization of agriculture in various countries or applications in food processing, e.g. fruit canning, candy industry, baking). At the beginning of 1930s Ford himself was advocating a full-scale transfer of mass production techniques to agriculture (e.g. the use of mechanization, soil study, fertilization and crop selection) but also machinery and chemical industry as a solution to the Great Depression. Mass produced vehicles started to make their impact felt on the food system in two ways: directly, through the use of mechanized and fossil-fuel based agricultural vehicles, and indirectly, through cutting the costs of transportation, making it more flexible and hence increasing markets for agricultural products. Combined with other emergent rules specific to the food system such as chemicalization (e.g. the use of nitrogen fertilizers and pesticides) and selection of plants and animals suitable for standardized production the food system began to transform into the regime of intensive agriculture (Mazoyer and Roudart, 2006).

There is also evidence of specialty producers in USA selectively adopting some principles from mass production that fit them, e.g. limited standardization of parts and interchangeability

within firms, or using progressive assembly methods despite low volumes of production (machine tool building) (Scranton, 1997). Nevertheless, the preference for variety and flexibility in a number of sectors limited the overall adoption process.

The attempts to extend mass production to other areas of application often turned out to be problematic, however. For example, in the mobility system the automotive dealers largely resisted Ford's attempts from the 1910s to introduce routinized work procedures, division of labour, specialized machinery and progressive layout of equipment (McIntyre, 2000). In fact, in many cases failure seems to have originated from attempts to directly imitate the practices of the automotive industry, e.g. attempts to produce houses on the assembly line (in Europe and in USA), or engineering societies trying to extend mass production to the areas of woodworking and furniture industry on the grounds of increased efficiency (Hounshell, 1985; Hughes, 1985).

From the 1920s mass production became an increasingly *"powerful general concept. It quickly shed its technical and precise meaning and started to move toward an abstract ideal of standardization, mechanization and repetitive production, allied to implications of order, rationality and universality"* (Tolliday, 1998: xvii). Examples of this process include: a) mass production language used in other socio-technical systems that were, strictly speaking, not employing the regime of mass production as defined in the mobility system (e.g. to explain economies of scale in energy production) (Hounshell, 1985); b) loose analogues employed in education (the assembly-line language appearing in influential educational texts); c) machine aesthetic influencing industrial designers and artists (e.g. Gropius, Le Corbusier, futurists, Soviet avant-garde etc.) (Nye, 2013); d) mass production being relegated to the status of a general philosophy of the era, e.g. Freeman and Louçã (2001: 292) quoting the Hoover report from 1929: *"We now apply to many kinds of services the philosophy of large-scale production. We integrated these services and organized them and we have developed the new philosophy to such a degree in recent years that we now have what might be termed 'mass services'."*). Tolliday (1998: xvii) suggests that through these acts an idea and image of Fordism was built up that, combined with technological novelty and commercial calculations, helped to diffuse Ford's methods. In other words, it was rather the abstract "generalized fordism" rather than the specific set of techniques that often connected different systems and served as an inspiration for further activities.

Contestation. Some regional differences in the reception of mass production can be noted. In USA the euphoria about the possibilities of mass production (e.g. associating it with the promises of erasing class distinctions, enabling increased leisure, permanently high wages, employment for everyone and high levels of consumption) during the 1920s gave way to increasing public scepticism and contestation from the 1930s. Mass production was now associated with fears of technological unemployment and insecure, monotonous, unhealthy and inhumane working conditions (repetitiveness, de-skilling and speed-up of the assembly line as common worries). This was reflected in an increase in labour strikes, formation of unions and eventually striking deals between unions and automobile manufacturers, a process completed in the postwar era (Tolliday, 1998; Nye, 2013).

In Europe, on the other hand, the rhetorical celebration of mass production was accompanied by many concerns from the outset. It was often claimed that mass production is specific to USA and cannot be repeated in Europe (having smaller market size, diversified consumer preferences, lower incomes etc.). Furthermore, Europe also had a strong tradition quality production by skilled workers and the adoption of mass production techniques was perceived to undermine this (e.g. Germany, UK, especially in the 1920s). Finally, deep worries were expressed about the supposed societal impact of mass production, e.g. associating it with the homogenization of products as well as consumers, leading to the homogenization of personality and culture (Nye, 2013).

Another friction point concerned relation between mass and specialty production. In USA, the maturation of mass production went hand in hand with the emergence of decades of crisis and decay for American specialty production (although still contributing around one third to the value added in 1923) (Scranton, 1997). The emergence of mass production as the "one best way", ideology of management as a scientific practice and accounting as a financial tool overlooked the different technical and market-related characteristics of specialty producers. The increasingly prevalent rhetoric of "simplification" (advocated by president Hoover, engineering societies and managers) associated diversity with inefficiency and waste in industry. Moreover, attempts of the Federal Trade Commission and Department of Justice to counter attempts at regulating competition through price coordination and exclusive sales agreements effectively forced specialty production to compete on price, losing one of their distinctive features (ibid.). The combined effect of these changes thus led to the gradual waning of specialty production from the 1920s although it remained part of the overall ecosystem of production.

4.3 4th surge: turning point (1939-1945)[1]

War requirements greatly increased the need for standardized production of machines and goods (e.g. uniforms, tanks, food). For example, the US government spent $315.8 billion in contracts, particularly with automobile and aircraft manufacturers (Nye, 2013) and by the end of the war aviation industry was the largest employer with 2 million workers (Best, 2017). WWII considerably increased the need for airplanes far beyond what had been produced in the civil sector so far. Hence the logic of mass production was extended from automobile to airplane (and to ship) production. Government procurement, investments in factory equipment and other subsidies provided to private producers as well as the forced savings of a substantial amount of soldiers (Gordon, 2016) jointly contributed to the consolidation of a postwar society based on mass production and mass consumption. Similarly to the previous war WWII served as a learning experience for European countries, e.g. British manufacturing Jeeps from American-supplied parts (Nye, 2013).

1 Note that Perez (2002) dates the turning point as 1929-1933 for Europe and 1929-1943 for USA which creates inconsistencies as the beginning of the synergy phase is dated 1943. A quicker resolution of the turning point in Europe does not make much sense considering that the take-up of mass production was lower in Europe and the transfer of American expertise to Europe was strongly accelerated after WWII. For this reason the current study treats WWII as the turning point for the dominance of (traditional version of) mass production.

On the other hand, wartime requirements also led to a number of experiments such as facilitating the diffusion of statistical quality control that had been slowly developing before the war. Moreover, the attempts of Germans, British and Americans to seek a trade-off between quantity and quality of airplanes led to differing experiments with continuous improvement and just-in-time strategy (Zeitlin, 1995). Germans were also experimenting with flexibility in uniform production (combining the use of female prisoners with no special skills or training needed, state-of-the-art sewing machines and electric motors) (Nye, 2013). However, these experiments did not spill over to the civil sector after the war when both USA and Europe reverted to more traditional techniques of mass production (see below). Best (2017) also argues that the creation of the Office of Scientific Research and Development in USA marked the emergence of the combination of government sponsored mission-oriented scientific and technological research with technology-driven, engineering-intensive enterprises. This combination was also at work in the creation of postwar ICT industry (cutting-edge R&D coupled with mass production techniques).

4.4 4th surge: synergy (1946-1959)

Rules. According to Piketty's analysis (2014) WWII acted as a shock that enabled substantial redistribution of societal wealth and hence the reduction of inequality. It was during the long boom of the postwar period that the constellation of technological, economic and regulatory rules – mass production, mass consumption, horizontally-integrated and multi-divisional big firms, unionization, and a social contract between employers, labour and the state within the framework of a nationally-bounded economy – came to characterize many economies in the Transatlantic area (Perez, 2002). From the consumption side the increasing availability of a variety of goods for lower prices was crystallized as a staple of consumer expectations, leading to the gradual emergence of a throwaway culture, treating consumerism as a form of democracy and consumption as an individual choice (Cross, 2000). Once again, however, important regional exceptions remained: for example, in Soviet Union the techniques of mass production were employed to a great extent but the prioritization of the military-industrial complex and limited supply of consumer durables (Kornai, 1992) meant that self-repair of consumer items remained a characteristic feature of Soviet everyday life.

Beginning from the late 1940s Toyota began to develop an alternative to American way of mass production by trying to achieve economies of scale in the context of relative lack of capital, smaller volumes of production, and higher variety of models. This was based on studies – in may cases reinterpretation and/or re-discovery – of prewar and wartime American and European production techniques but also drawing on Japanese own industrial experience. The prime difference in Toyota's approach was an emphasis on minimizing error rather than speeding throughput. Hence the institutionalization of many practices that had been pioneered in USA and Europe (or Japan) but not taken there, e.g. strive toward continuous improvement (Ford's initial experiments), total quality control using statistical methods (USA in WWII), tapping worker expertise for improvement (early Ford), just-in-time supply (supply chain of US supermarkets), possibility to stop the assembly line upon the detection of error (Toyota's automatic looms in the pre-war era) or making different models on a single line (pioneered by US Hotpoint for refrigerators and the US Marmon Motor Car Company in 1929) (Nye, 2013).

Additional principles included teamwork, job rotation and multi-skilling workers and establishing close relations between suppliers and buyers (Monden 1981a, b; Ohno, 1982; Shimokawa, 1993).

In parallel the experience with growing labour unrest in USA had prompted a managerial vision of a fully automated factory (computer-controlled assembly line staffed with robots), enabling to replace not only semi-skilled blue-collar workers but also skilled blue-collar and white-collar workers. Some influential experts (e.g. Norbert Wiener) already envisioned this to become a reality by the 1960s: however, technical difficulties considerably delayed actual implementation (Nye, 2013). Combining flexible mass production with the rules of sequencing tasks within machines (i.e. making machines more and more flexible) and automated product and labour control thus turned out to be a dead-end, at least in the short-term. Hence while Americans focused on capital-intensive solutions for developing mass production and achieved little success, Japanese (especially Toyota's) labour-intensive niche achieved much more in terms of improved performance.

Diffusion and directionalities. Leaving aside the experimental niches the dominant theme of this phase was the take-up of US practices of mass production in Western European countries (e.g. UK, Federal Republic of Germany, France) and (at least initially) in the majority of Japanese enterprises. Mass production techniques, corporate organization structures, management styles, American-style distribution channels, advertising, and consumer goods flooded Europe and Japan through various channels of influence such as the Marshall Plan, the Productivity Mission, Fulbright Program and United States Information Agency. Whereas existing studies again stress selective adoption, modification of rules to suit local conditions, cross-fertilization (Zeitlin and Herrigel, 2000), and the prevalence of European traditions of material- and energy-saving, in many ways European countries started to become more similar to USA during this era (Schröter, 2007). This also meant the connection between mass production/consumption and environmental issues became increasingly visible. Soviet Union, on the other hand, continued on its established path of limiting consumption and placing emphasis on producer goods – however, because of increasingly inefficient production technology and lack of attention to the environment the energy and materials usage profile were quite similar to the West countries (Krausmann et al., 2016) whereas environmental problems were arguably even worse.

During this period mass production became thoroughly consolidated in the mobility systems of different Western countries, reflected in the rapid diffusion of private vehicles and corresponding spatial reorganization of cities. Another stronghold of mass production continued to be consumer durables. Mass production also seemed to gain a firmer foothold in other systems. Examples include the application of the principle of product standardization to food (e.g. breeding a tomato with a thick skin so that could be picked up with metal claws while green and then matured by the use of various chemicals; diffusion of fast food chains, breeding new types of chicken to accelerate meat production etc.). Some principles of mass production (e.g. standardized components, identical look, economies of scale, division of tasks) were applied to housing (Levittown) (Nye, 2013) although the adaptation was again

rather selective, e.g. the principle of moving work to worker on an assembly line had been abandoned.

Contestation. Synergy phase seems to have been the honeymoon period: mass production was propagated and framed as a basis for postwar reconstruction with rising productivity leading to higher living standards supposedly stopping the battle between capitalists and workers. European production techniques were increasingly perceived as "outmoded", being based on monopolized technical knowledge and over-charging for items produced in low volumes (Schröter, 2007). The prevailing view seemed to acknowledge some deficiencies in mass production but these were assumed to be temporary and hence mass production and its economic, regulatory and consumption-related corollaries were continuously associated with social progress throughout the Transatlantic area. On the other hand, at least in USA the 1950s were also characterized by the recurrent fear of near-future technological unemployment because of the anticipated effect of automation. Monotony of assembly-line work, speed-up, overtime and health also remain important issues with labour turnover increasing into the 1960s (Nye, 2013).

4.5 4th surge: maturity (1960-1972)

Rules. During this period the excesses of the dominant version of mass production started to provoke responses from niches. For example, activists of the counterculture movement started to experiment with food cooperatives and small-scale enterprises under local ownership, emphasizing homemade goods, recycling, organic food, celebration of small-scale technologies, and DIY including furniture, food, energy, shelter etc. (Cross, 2000; Nye, 2013). The Japanese reinvention of mass production was gradually refined in parallel with the Toyota Production System being formally documented for the first time in the mid-1960s (Holweg, 2007). Meanwhile in USA the realization of full automation still turned out to be more problematic than initially anticipated: by mid-1970 the number of robots was still around 6,000 despite large investments in R&D (Nye, 2013: 157-161).

Diffusion and directionalities. In terms of diffusion this period seems to have been one of further consolidation of the traditional version of mass production. Despite increasing dissatisfaction with mass production its possible alternatives were still restricted to particular geographical, sectoral and technological niches.

Contestation. In addition to continuing labour problems there were two additional streams of contestation. The first case seems to reflect a cultural exchange in the Transatlantic area from the end of the 1950s: whereas mass production was taken up more and more in practice in Europe worries about its societal impacts (cultural homogenization, loss of individuality, creativity and spontaneity) now also surfaced in the USA, becoming "a litany" by the 1960s (Nye, 2008). By the end of the 1960s the contestation of mass production had gradually escalated into attack on industrial society and its values of efficiency, standardization and business-drivenness (Nye, 2013). A novel stream of contestation focused on the environmental impacts of mass production, attacking the throw-away culture of consumption and the contribution of this meta-regime to pollution, e.g. the environmental impact of

intensive agriculture (Carson, 1962) or questioning the long-term viability of economic growth based on the ever-increasing resource consumption (Meadows et al., 1972).

4.6 Crisis of the 4th surge, installation of the 5th one (1973-2000)

Rules. The oil crisis of 1973 signalled the maturation of the 4th surge, centred around mass production. In the conventional dating (Freeman and Louçã, 2001; Perez, 2002) the beginning of the 1970s signalled a shift to a new hotspot of activities, a 5th surge in the domain of information and telecommunications. With the accompanying acceleration in economic globalization the meta-regime of mass production was opened up to various alternatives. The responses, in order of increasing degree of novelty, included the following:

1. Optimization of traditional mass production (neofordism): neoliberal policies of liberalization, privatization and deregulation allowed Western manufacturers to move their production to countries with far cheaper labour. This move entailed complementing the traditional version of mass production with two additional principles: spatial dispersion of the production process (e.g. product design conducted in the developed country, assembly in the developing one) and decoupling of production from consumption (as the assemblers were not envisioned as the end-users of the product any more).
2. Attempts to borrow principles from traditional approaches to cope with the perceived limitations of traditional mass production (neocraftism): examples of this include Volvo's experiments in Sweden with stopping the assembly line and letting the workers choose their own pace of work. The resulting increase in labour costs was compensated by increase in worker satisfaction and decrease in labour turnover (Muffatto, 1999; Nye, 2013). Dock assembly techniques were also copied by the Germans in the 1970s during public debate on the humanization of work (Cooney, 2002). Advertised as an alternative to lean production (Berggren, 1993) experiments in Sweden were largely stopped in the early 1990s because of high labour costs. Nevertheless, this niche remains an historical alternative of disassociating mass production from low worker satisfaction, a problem encountered by the traditional version of mass production.
3. Internal transformation of mass production: the gradually modified and extended system of production principles, pioneered in Toyota, constituted a substantially modified version of mass production, later named lean production (Krafcik, 1988) (see 4.4 for the description of its characteristics). Its impacts on product quality, productivity and efficiency were such that it has been interpreted as a leap in the evolution of mass production (Nye, 2013).
4. Tapping the potential of the 5th surge (ICT revolution): the relation between ICT-s and mass production was reciprocal. On one hand many elements of the 5th surge (e.g. microprocessors, personal computers, printers, screens, hard drives, mobile phones, consumer electronics etc.) were mass produced in a rather conventional manner in the USA (and later in Japan). On the other hand, while the acceleration of the ICT revolution likely stimulated further attempts at factory automation actual progress continued to be piecemeal. By 1989 the Japanese had caught up with Americans in the use of automation in welding and painting, with Germany also making increasing

progress (Nye, 2013). From the end of the 1980s visions of a new hybrid mode of production, called mass customization, started to emerge. This approach reflected the desire to combine economies of scale and scope with the deployment of highly automated production technologies and flexible modes of production (Hudson, 1994; Hu, 2013).

5. Alternative pathways to mass production (appropriate technology, flexible specialization, post-fordism): an array of narratives underlined the rigidity of "fordist" mass production and its incompatibility with countries not able to afford capital-intensive solutions with accompanying expectations that mass production (often dubbed "fordism" would be soon surpassed with alternative modes of production such as post-fordism (Kumar, 2005), appropriate technology (Schumacher, 1973), or the historical return of flexible specialization (Piore and Sabel, 1984; Sabel and Zeitlin, 1985; 1997).

Diffusion and directionalities. In terms of changing geographies of innovation the "deindustrialization" of Western countries of the establishment of a New Industrial Division of Labour (Fröbel et al., 1980) constituted a major change in this period. Although the direct measurement of the diffusion of rules is difficult one might assume that when it comes to underpinning the production of goods the meta-regime of mass production actually strengthened its position worldwide during this period as it was taken up in ever new locations.

From the other end of the spectrum the radical transformation of mass production and its susbtitution with alternative modes largely failed to happen. Despite the popularity of some much-studied local examples (e.g. Silicon Valley, Emilia Romagna) beginning from the 1990s the supposed shift to post-fordism came to be increasingly criticized for being a normative ideal rather than an empirical reality (Gertler, 1988; Kumar, 2005; Lovering, 2009).

The most influential change proved to be lean production. From the 1970s more and more Japanese producers switched to this mode of production (Ohno, 1982) with early adopters following in Europe and USA during the irruption phase (1971-1987) of the 5th surge. From the late 1970s its diffusion was accelerated by the establishment Japanese transplants and joint ventures between Japanese and American/European companies demonstrating the applicability of lean production outside Japan. A crucial channel of influence, accelerating the diffusion of lean production in the Transatlantic region, was the International Motor Vehicle Program (1979) (Holweg, 2007). By the frenzy phase of the 5th surge (1988-2000) lean production had become a new production standard. Similarly to the traditional version of mass production the number and interrelatedness of rules, requiring changes in existing production practices and organizational arrangements, the adoption of lean production has taken decades to occur and has been marred with setbacks – only this time difficulties were experienced by European and American enterprises (Nye, 2013). However, although lean production does seem to have instituted substantial transformation in the production side of the meta-regime then in terms of the overall directionality little seems to have changed: the effect of lean production seems to be tweaking the mass production/consumption complex

towards increased flexibility and responsiveness to the consumer.

Lean production was quickly adopted in the computer industry (e.g. Dell's delivery system) but also for the production of vacuum valves, ice cream, forceps, engines, sanitary napkins, computer work stations, single-use cameras, radial tires, air-conditioning compressors, anti-lock braking systems, ethylene, yogurt, and vinyl ceiling panels (Nye, 2013). At the same time, there remains a great degree of difference and uncertainty about the extent to which other Japanese companies, other automobile producers or different manufacturers have adopted lean production: while evidence of full-scale adoption exists, the principles are often applied selectively (e.g. luxury automobile manufacturers, focusing on small-scale batch production), or even only rhetorically (Cooney, 2002). Similarly to the traditional version of mass production in the interwar era it seems that lean production has become a general buzzword, encountered in a wide variety of settings (including public and service sectors), and thereby leading to criticisms that it has lost its analytical edge (Arlbjørn and Freytag, 2013). However, the historical experience might view this as a form of rhetorical coupling: lean production as a mobilizing metaphor encouraging further experiments and adaptations.

Contestation. The reception of lean production followed a similar pattern to the debates around traditional mass production in the interwar era. On one hand, lean production was enthusiastically celebrated for its promises, e.g. to empower the worker and to enable to overcome the alienation associated with previous forms of mass production (Kenney and Florida, 1988). On the other hand, critics claimed that the approach was specific to the postwar Japanese context and could not be successfully transferred (Dohse et al., 1985). The success of Japanese transplants in Europe and USA proved this argument decisively wrong during the 1980s-1990s. Nevertheless, further experience demonstrated that the deliberative potential of lean production proved to be an exaggeration (see 4.7).

Overall, this period was notable for the fact that mass production was being contested more fundamentally and in a more diverse manner than in previous decades as the debate focused not only on quarrels within the framework of mass production but also whether it was a viable approach as a whole. Each choice brought corresponding counter-arguments: neo-fordism was contested on the grounds of loss of jobs to developing countries which, between 1988-2008, contributed to the rising real incomes of Asian middle class and Western entrepreneurs, whereas the incomes of the lower middle classes of developed countries remained virtually stagnant (Milanovic, 2016). The institutionalization of the environmental agenda and the mainstreaming of the green agenda posed more questions about the long-term viability of the meta-regime of mass production/mass consumption. Appropriate technology problematized the suitability of Western capital-intensive solutions for developing countries whereas the advocates of post-fordism saw an end to mass production and the return of the historical alternative of flexible specialization.

4.7 Turning point/deployment(?) of the 5th surge

Rules. The "double bubble" (dotcom boom of 2001 and the following global financial crisis) marked the turning point of the 5th surge (Perez, 2009) with the deployment phase possibly to

follow. By that time the fusing of two parallel streams developed in the postwar era, one signifying the internal transformation of the 4th surge (lean production) and another the maturation of the promises of the 5th surge (automation), has become an increasing reality. Indeed, by 2010 Japan had the highest number of multi-purpose robots (258,000), surpassing USA (168,000) and Germany (148,000). These were mainly used by the automobile industry and electronic companies but also by manufacturers of plastics, rubber, chemicals and food (Nye, 2013: 230-231).

From the 2000s mass customization, combining the principles of product family architecture, delayed differentiation and reconfigurable manufacturing systems, is gathering strength as a vision but also as a set of experiments (Fogliatto et al., 2012). A further extension, personalization, based on additional principles of on-demand manufacturing systems, cyber-physical systems, open platform architecture and personalization design, is envisioned to be a future development but it is unclear when it can be achieved in practice (Hu, 2013).

The environmental agenda, in turn, has brought increased attention the sustainability, ranging from incremental responses of "greening" from incumbent industries to calling for a renewal of mass production and mass consumption on an even more fundamental basis. However, there is a question about the extent to which the current meta-regime of mass production and consumption, embodying the values of constant acceleration of production and consumption and based on the assumption of virtually unlimited raw materials, can be re-directed onto the path of sustainability (Nye, 2013). This would entail a fundamental overhaul in many rules, e.g. the employment of cradle to grave design, collaborative consumption, constant repair and upgrade, rent-based consumption (Perez, 2015) and probably many more.

Diffusion and directionalities. The way in which the deployment phase eventually unfolds is unclear at the moment. It is possible to sketch three possibilities that differ in terms of their degree of transformative potential:

1. Business as usual: stabilization of market shares and the emergence of the structure of global oligopolies, accompanied by the slowing down of (radical) innovation, with the possible expansion of this structure to new industries (enabled by increased possibilities for capturing economies of scale). In many ways this pathway would be a repetition of the 4th surge but on the global, instead of national level. Would it help to address the challenge of environmental degradation? The answer is no, because it would effectively amount to extending the meta-regime of mass production/ consumption to new sectors and developing countries. Is it a realistic scenario? Yes, at least in the short term. In fact, in some areas there is indeed evidence of heavy global concentration, e.g. in the smartphone System on a Chip market six enterprises (Qualcomm, Apple, Mediatek, Samsung, HiSilicon, Spreadtrum) have virtually captured all the market share with the leader (Qualcomm) having more than 40% (Friedman, 29.12.2017).
2. Mass customization pathway: fusing the internally transformed mass (lean) production with the capabilities of ICT revolution to lead to a new hybrid form of production and consumption. Would it help to address the challenge of environmental degradation?

Not really, as it can be treated as yet another attempt to tailor the traditional version of mass production toward increasing flexibility and responsiveness to diversified consumer demand. Is it a realistic scenario? Perhaps in the medium term, in a decade or two. According to the literature experiments with mass customization have been undertaken since the early 2000s, including successful applications in food industry, electronics, large engineered products, mobile phones, personalized nutrition homebuilding and the production of foot orthoses (Fogliatto et al., 2012). On the other hand, the extension of mass customization, personalization, largely remains a vision (Hu, 2013).

3. Sustainable mass production pathway: fusing the internally transformed mass (lean) production with the capabilities of the ICT revolution and the principles of sustainable design, production, distribution, consumption and re-use. Would it help to address the challenge of environmental degradation? At best one can currently say that the potential is there but the rest is uncertain. Is it a realistic scenario? No, not in the short or medium term if the assessment is based on historical experience as outlined above. It took decades (1970s to 2000) to build up the 5th surge and to realize the vision of automation through digitalization, a process which is ongoing even now – and the difficulties with this were grossly underestimated in the 1950s. Hence it is reasonable to expect that the maturation and scale-up of sustainability niches would take at least a few decades to occur.

Contestation. The different streams of contestation again reflect the differing combinations of rules employed under the rubric of mass production. Worries about the loss of jobs in developed countries are now being mirrored in the developing countries where working conditions in various industries such as clothing, automobiles and electronics are often appalling by Western standards (e.g. compulsory overtime, low wages, unhealthy working environment, use of child labour, lack of unions, vulnerability for another round of offshoring) (Nye, 2013). In some ways the current situation in developed countries resembles the one in developed countries in the interwar era.

On the other hand, initial enthusiasm about the deliberative potential of lean production has been dampened by experience. Especially when combined with electronic surveillance and automated performance assessment worker experience with lean production often means layoffs, speed-up of work, elimination of small pauses and relief time, repetitive strain and adverse health effects (Nye, 2013). It therefore seems that lean production can still be associated with high degree of managerial control resulting in adverse effects quite similar to those of traditional mass production (Nye, 2013; Van Elteren, 2017). It has been even argued that *"flexible innovations represent a revision of production methods such that principles of scientific management not previously incorporated into Fordist regimes have assumed key positions in the post-Fordist era"* (Crowley et al., 2010: 423). Moreover, the transferability of lean production might also owe to the fact that it has been accompanied by broader contextual changes such as the significant decrease in the bargaining power of unions. Once again then, similarly to mass production, shaping both the mode of production as well as the environment into which it would fit could have well facilitated the "fitness" of lean production.

Age-old fears of technological unemployment also started to resurface in the 2010s (Brynjolfsson and McAfee, 2014; Frey and Osborne, 2017), this time related to ICT-s that are claimed to eliminate routine mental tasks (as opposed to earlier machines that eliminated routine physical tasks), leading to permanent loss of jobs. In parallel, the climate change agenda continues to be increasingly prevalent with corresponding expectations and likely an increasing political pressure that the meta-regime of mass production/consumption should be geared toward increased sustainability.

5. Analysis and discussion

5.1 Correspondence of the DT framework to the case study

We begin from relating the propositions of the Deep Transitions framework to the empirical observations of the case study, assessing the extent to which the two match. The results are found in table 2.

Table 2. Deep Transitions framework and the evolution of mass production [to be filled in!]

No	Proposition	Case of mass production	Match
1	Before the Great Surges of Development (GSoD) rules emerge and compete in several niches of individual socio-technical systems without much coordination	*Rules.* *Diffusion and directionalities.* *Contestation.*	
2	During irruption (1st phase of GSoD) the emerging and incumbent rules and regimes come to compete against each other in individual systems, resulting in transitions	*Rules.* *Diffusion and directionalities.* *Contestation.*	
3	During frenzy (2nd phase of GSoD), many rules increasingly start to cross the boundaries of a single system and partially align to each other, leading to the formation of alternative, possibly competing rule-sets	*Rules.* *Diffusion and directionalities.* *Contestation.*	
4	Two mechanisms for achieving more		

	coordination across the boundaries of a single system are structural and functional couplings	
5	Additional mechanism, further facilitating and accelerating the creation of between-system links, is the aggregation and intermediation work of inter- and transnational organizations	
6	Competition between meta-rules is finally resolved at the turning point of a GSoD, tipping the scales decisively in favour of one meta-regime that becomes dominant	*Rules.* *Diffusion and directionalities.* *Contestation.*
7	During synergy (3rd phase of GSoD) the dominant meta-regime selects niches compatible with its logic, diffuses to various systems and starts to shape the landscape	*Rules.* *Diffusion and directionalities.* *Contestation.*
8	During maturity (4th phase of GSoD) the dominant meta-regime loses its grip and the cycle re-starts with other niches, systems and rules becoming central to the new surge. The formerly dominant meta-regime shapes the new surge as part of the landscape through feed-in and sedimentation mechanisms	*Rules.* *Diffusion and directionalities.* *Contestation.*

As seen from the table the case also yields two vectors of influence between systems beyond functional and structural couplings: rhetorical couplings and the transfer and internalization of rules. The former seems to refer to the fact that in the installation phase (interwar era for traditional mass production, 1970s-1990s for lean production) the success of new meta-

regimes-in-the-making seems to have prompted over-generalizing in at least three senses: a) seeing the paradigmatic industry as a direct source of imitation (e.g. that the principles of automobile production can be applied virtually unchanged to housing); b) over-estimating the difficulties associated with transferring the principles, initially developed in one system, to another one (e.g. widespread expectations in the interwar era that mass production would be soon applied to furniture production); c) abstracting the industry-specific principles into an overarching philosophy or ethos (e.g. creating seemingly necessary connections between mass production and various other economic, political and cultural elements, such as the initial belief that mass production is necessarily related to high wages). Whereas features a) and b) seem to be recipes for setbacks and failures strategy c) seems to function as a rhetorical mobilizing device, guiding the vision of actors around the new meta-regime even when actual applications are scarce. This observation is well in line with the hype cycle theory (van Lente et al., 2013), transitions (Raven and Geels, 2010) and systems of innovation literature (Bergek et al., 2008) all of which stress the importance of visions for technological development.

The transfer and internalization of rules is a mechanism by which two systems come to employ similar principles. Example of this is the emergence of automobiles in the mobility system and tractors in the food system, both embodying the principles of mechanization, individual operation and the application of fossil fuels. Although initially there were attempts at direct transfer, such as farmers tailoring their Model T's for agricultural purposes (Kline and Pinch, 1996), tractors soon became a separate category of vehicles, part of the socio-technical system of food production[2].

Overall we conclude that the historical evolution of mass production matches the propositions of the DT framework on the aggregate level (Transatlantic region) fairly well. However, the findings also point to some limitations:

1. Also the case study provided some illustrations of transfer or rules more work is needed on the identification of structural and functional couplings. More attention should also be paid to the changing relation between mass and specialty production in the production ecosystem over the observation period. However, this might be difficult to achieve as systematic comparative treatments about the long-term evolution of specialty production are currently largely lacking.
2. In different ways the mass production seemed to be contested in every phase. This might reflect the need to make a clearer distinction between the actually experienced and anticipated effects of mass production. Especially the latter seem to be operating somewhat independently from the actual diffusion of mass production as well as the economic context. For example, the cultural critique of mass production promoting homogeneity of personality and culture was found in both interwar Europe with relatively little mass production and economic hardship and in postwar USA with high degree of mass production and affluence.
3. The findings also call for more caution in linking mass production as a set of engineering rules with “necessary” economic, political and cultural rules as these

2 Note that this does not exclude the existence of different types of couplings. When it comes to the provision of transport for agricultural products one can speak of a functional coupling between food and mobility systems.

connections might reflect a certain source bias. The current study was based on literature in English language, focusing largely on a limited set of economically and politically similar countries, largely neglecting the experience of different settings such as the USSR. As a result the connections between mass production and its economic, political, user-related and cultural correlates might appear closer than they actually are. Or to put it in another way: if the wider selection environments consist of market economy, democratic state and cultural individualization then meta-regime level correlates of mass production are likely to include some business strategies for balancing quantity production with diversified demand, some form of social contract between stakeholders as well as a long-term trend toward increasing fragmentation of consumer preferences.

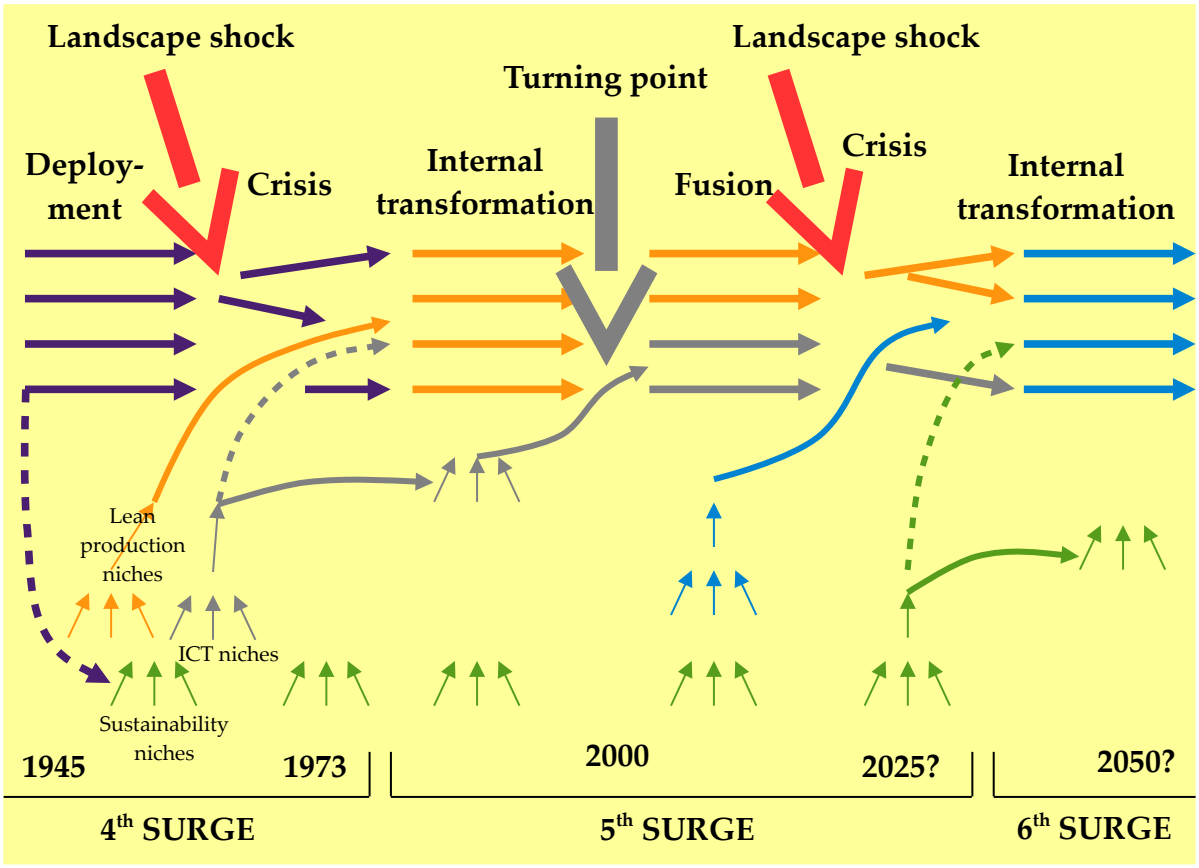
5.2 Dynamics of the formerly dominant surge during the next one

Tracing the history of mass production onward from the 1970s, during the ICT surge, also enables to formulate new insights on the interactions of surges. Based on our findings we formulate a specific pattern as a complement to the original DT framework:

1. Crises of existing surges lead to various responses that do not only involve investments in new domains underpinning a new surge but also attempts to transform the previously dominant meta-regime. These responses, many of which are pioneered in specific niches, include optimization (offshoring), selective adoption of new rules from the overall ecosystem of production (neocraftism), internal transformation (lean production), visions of a more fundamental transformation by the employment of technologies central to the new surge (ICT revolution), and visions about fundamental overhaul (flexible specialization, post-fordism, local production in self-sufficient communities).
2. Niches internal to the focal meta-regime are likely to be scaled up first, during the installation phase of the next surge because of the long-term learning curve required for the maturation of each new surge (20-30 duration of the installation phase). However, more radical niches (e.g. ICT-s, sustainable technologies) continue to develop and mature in parallel. In the case of mass production the severity of the crisis of mass production toward the end seemed to have been serious enough to lead to adopting a fairly radical internal fix to mass production – yet the overall directionality of mass production/consumption was not changed as a result.
3. The internally transformed formerly dominant meta-regime undergoes another transformation during the deployment phase of the next surge (e.g. the fusion of ICT revolution with lean production). This is likely to be paralleled about early niche-building and exaggerated visions about next-wave technologies (e.g. visions of fully automated factories in the postwar era, visions of sustainable mass production/ consumption from the early 20th century). However, the speed of change is likely to be over-estimated as the niches are not immediately scaled up after the maturation of the current surge but take another 20-30 years to mature.

This sequence of events is visualized on figure 3.

Figure 3. The crisis of a mature meta-regime and possible responses.



6. Conclusions

This study aimed to provide a tentative test to the emerging Deep Transitions framework. For this purpose it analysed the historical evolution of mass production from the mid-18th century to the present. The overall pattern of evolution as hypothesized by the framework was largely confirmed despite some limitations related to structural/functional couplings, the ecosystem of specialty production and the pervasiveness of contestation throughout the observation period. The findings yielded two new mechanisms, facilitating the emergence, consolidation and diffusion of meta-regimes: rhetorical couplings and transfer and internalization of rules. Finally, the DT framework was also extended by offering an explanation to the transformation of a mature meta-regime at the beginning of a new surge.

The immediate implication of the findings is that without important changes in the selection environment sustainable turn in the meta-regime of mass production/consumption will have to wait for decades, including the deployment phase of the current surge and the installation phase of the next one. Analogously to the visions of fully automated factories in the 1950s the current claims about the immediate feasibility of sustainable mass production should be taken with a grain of salt.

That being said, one should also be reminded that Deep Transitions are not only about

interactions between single and interconnected systems. The framework also argues that over time the meta-regimes of successive surges have built up a macro-level selection environment of industrial modernity, strongly shaping the directionality of a broad array of existing and new socio-technical systems (Kanger and Schot, forthcoming). The Second Deep Transition, then, would require a transformation in the fundamental features of industrial modernity itself. Whether this is already happening is an empirical question: however, over the past 50 years the changing rhetoric around the relation between humans and nature, the build-up of global institutions for tackling climate change as well as the abundance of niches pioneering sustainable solutions can be considered promising signs in this direction. In the context of a broader rupture the shift towards sustainable forms of mass production might be considerably accelerated.

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