Emergence, consolidation and dominance of meta-regimes: exploring the historical evolution of mass production (1765–1972) from the Deep Transitions perspective

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Emergence, Consolidation and Dominance of Meta-regimes: Exploring the Historical Evolution of Mass Production (1765-1972) from the Deep Transitions Perspective

Abstract
Grand environmental and societal challenges have drawn increasing attention to system innovation and socio-technical transitions. A recent Deep Transitions framework has provided a comprehensive theory of the co-evolutionary patterns of multiple socio-technical systems over the last 250 years. However, so far the framework has not been subjected to systematic empirical exploration. In this paper we address this gap by exploring the co-evolutionary model linking niche-level dynamics, transitions in single systems and 'great surges of development', as conceptualized by Schot and Kanger [1]. For this purpose, we conduct a case study on the historical evolution of mass production in the Transatlantic region from 1765 to 1972. Instead of focusing on dominant technologies or common practices the development of mass production is understood as the emergence of a meta-regime, i.e. a set of mutually aligned rules guiding production activities in multiple socio-technical systems. The results broadly confirm the overall model but also enable to extend the Deep Transitions framework by uncovering new mechanisms and patterns in the variation, diffusion and contestation of meta-regimes.

Keywords: deep transitions, socio-technical transitions, great surges of development, mass production, meta-regime

1. Introduction
The world is confronted by a socio-ecological emergency brought on by climate change, resource depletion and loss of biodiversity. Solving these crises requires rapid and deep decarbonization of a broad range of socio-technical systems including energy, housing, food, water and mobility. These challenges have drawn increasing attention to system innovation in the sustainability transitions field, including co-evolutionary dynamics extending beyond single systems. Although so far the stream of studies on multi-regime interaction has remained fairly small [2-6], lately the importance of the topic has been increasingly recognized in the Sustainability Transitions Research Network agenda as well as the debates around it. The need for 'zooming out' has been advocated [7, p. 6] in order to shift “emphasis away from within system dynamics that have received considerable attention to the interconnected and multi-scalar qualities of socio-technical systems that are less well understood” [8, p. 4].

A recently developed Deep Transitions (DT) framework [1,9] attempts to go beyond the analytical limitations of studies focused on single systems. Synthesizing insights from sustainability transitions studies, long wave theory and industrialization literature DT theorizes how interactions between socio-technical systems produce 40-60 year long 'great surges of development' [10] and how successive surges, in turn, accumulate into a set of principles driving every industrial society – an industrial modernity. The authors of the DT framework argue that the co-evolution of single systems, interconnected systems and industrial modernity – the First Deep Transition – has created a fundamentally unsustainable trajectory of environmental degradation while not being able to solve recurring problems of social inequality. Altering the situation requires a shift of comparable magnitude – the Second Deep Transition.

DT aspires to offer a comprehensive conceptual framework of the co-evolutionary patterns of multiple socio-technical systems over the last 250 years. However, beyond the provision of selected illustrative historical examples in the original outline, the framework has yet to be subjected to
systematic empirical assessment. In this paper we address this gap by exploring the co-evolutionary model outlined in Schot and Kanger [1] which links niche-level dynamics, transitions in single systems and great surges of development through the emergence, consolidation and alignment of rules. For this purpose, we conduct a historical case study of the development of mass production in the Transatlantic region from 1765 to 1972. The case of mass production has been chosen because of its centrality to the 4th long wave beginning at the early 20th century [10,11] making it both a 'most-likely' case for the DT framework and an influential case with considerable environmental impact. Our main research question is: how does the historical development of mass production correspond to the co-evolutionary patterns as proposed by the Deep Transitions framework?

Section 2 defines the central concepts of the framework – rules, meta-rules, regimes, meta-regimes – and outlines a model of the co-evolutionary dynamics of rules. Section 3 describes our methodological approach. Section 4 presents a stylized narrative of the historical evolution of mass production. Section 5 assesses the extent to which the observed dynamics match the theoretical expectations and situates our findings in broader literature on socio-technical change. Similarly to early case studies exemplifying the Multi-level Perspective on socio-technical transitions [12-15] we also use our results to modify and extend the DT framework. Section 6 concludes.

2. Deep Transitions framework

2.1. Basic concepts and phase-specific propositions

The DT framework [1] was developed to address two gaps in existing knowledge on multi-system co-evolution. First, to theorize how niche-regime dynamics and transitions in single systems [13,16] relate to long waves [10,11]. Second, to understand how successive long waves accumulate into major historical continuities characterizing the overall industrialization process [9].

DT focuses on rules – “humanly devised constraints that structure human action, leading to regular patterns of practice” [1, p. 1053] – as a central coordination mechanism. By being embedded in the very structure of socio-technical systems rules shape the behaviour of actors and provide systems with long-lasting directionality. Rules differ in terms of their scope and degree of alignment to other rules, resulting in a four-fold classification:

1. Rule is a single prescription for action present in a single system. For example, a principle 'design for modularity' has its origins in the American housing system around 1920s-1930s, where the use of modular components was seen as means to lower construction costs, reduce waste and increase efficiency [17].

2. Meta-rule is a single rule present in multiple systems. For example, Russell [17] describes how metaphors such as 'architecture', 'throughput' and 'modularity' started to appear in the vocabulary of American computer engineers in the 1950s. This indicates that the 'design for modularity' rule had crossed a boundary between housing and data processing systems.

3. Regime is a set of aligned rules present in a single system. For example, Zuboff [18] analyses how Google invented and perfected interrelated principles constituting what she calls 'surveillance capitalism'. This involved treating human experience as a free raw material, using this 'behavioural surplus' for the fabrication of prediction products and trading these predictions in behavioural futures markets [18, p. 8]. From the early 2000s this regime became paradigmatic in the communication system and was adopted by major players like Microsoft or Facebook.

4. Meta-regime is a rule-set present in multiple systems. For example, by treating user-generated data from self-driving vehicles as a commodity to be sold to advertisers [19,20] the regime of surveillance capitalism might be currently expanding from the communication system to the mobility system.
Drawing on these concepts, Schot and Kanger [1] connected processes on niche- and system-level as described by the Multi-level Perspective on socio-technical transitions [13,16], to successive 'great surges of development' as conceptualized by Carlota Perez. Perez [10] argues that since the late 18th century there have been five 40-60 year surges, each characterized by particular phases: 1) gestation (pre-surge period); 2) installation period (first half of the surge, lasting 20-30 years), further divided into irruption and frenzy phases; 3) turning point; 4) deployment period (second half of the surge, lasting 20-30 years), further divided into synergy and maturity phases. The model by Schot and Kanger [1] relates the emergence, consolidation and alignment of rules to different phases of each surge, resulting in a specific pattern:

1. A protracted gestation period is characterized by the emergence of new rules in separate niches, i.e. spaces governed by specific selection criteria such as military applications prioritizing performance over cost. In some niches some of these rules may be aligned to each other. In exceptional instances, exogenous macro-level 'landscape' pressures might destabilize dominant systems, opening up a window of opportunity for niches and resulting in regime-shifts, i.e. transitions in single systems [13].

2. Each surge starts with the irruption phase where emerging and incumbent rules come to compete against each other, resulting in further transitions or transition failures. Early interactions between some systems might occur and some rules may turn into meta-rules as a result. Overall these interactions as well as their outcomes remain ad hoc, non-standardized and accidental in nature: at this point no lasting connections between systems are created, and thus no clear directionality in multi-system co-evolution is established.

3. At the beginning of the frenzy phase, many rules increasingly start to cross the boundaries of a single system, generating widespread enthusiasm about the prospects of emerging rules and associated technological opportunities but also major concerns about their anticipated societal impacts. Partial alignment between different meta-rules starts to occur leading to the gradual emergence of structural and functional couplings between systems, e.g. different systems relying on the same infrastructure or forming input-output relations [22]. This process is further amplified by the purposeful aggregation work of transnational organizations aiming to homogenize and standardize within- and between-system practices. As a result, a clearer new directionality becomes visible, yet in this phase there will still be competing options (alternative directions of evolution) available.

4. The competition between meta-rules and their various combinations is resolved at the turning point. Major crises such as wars provide an impetus for the alignment of expectations, enabling powerful actors to tilt the playing field in favour of a particular rule-set. Therefore, from this point forward one can start talking about the existence of the dominant meta-regime providing directionality across many socio-technical systems.

5. During the synergy phase the dominant meta-regime acts as a selection mechanism, favouring niches compatible with its logic and rejecting non-compatible ones [23]. It continues to diffuse from one system to another, leading to the increasing take-up of its principles in various systems. Because of its expansive nature the meta-regime now also starts to shape landscape structure and dynamics.

6. In the maturity phase new problems start to appear which cannot be fully resolved within the confines of the dominant meta-regime. The scene is set for yet another surge with new niches and systems becoming the main loci of radical innovation. As the former meta-regime has now become part of the landscape, it continues to structure new niche-regime-meta-regime interactions. Figure 1 presents a visual summary of the model.

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1 These are: 1) The Industrial Revolution (1771); 2) Age of Steam and Railways (1829); 3) Age of Steel, Electricity and Heavy Engineering (1875); 4) Age of Oil, the Automobile and Mass Production (1908); 5) Age of Information and Telecommunications (1971, ongoing) [21].
Figure 1. A rule-based model of great surges of development [1, p. 1056].
2.2. Cross-phase trends in Deep Transitions

As the above model focuses on developments distinctive to each phase, it implies but does not really make explicit the accumulation of phase-specific developments into long-term outcomes. An alternative way to look at the process of meta-regime building would be to separate the overall co-evolutionary dynamics of rules into different sub-trends. Such an analytical exercise potentially enables to observe different patterns and mechanisms related to various dimensions of meta-regime evolution that might otherwise remain unnoticed. Although we recognize the difficulties with making clear-cut conceptual distinctions, we suggest that broadly speaking the co-evolutionary model of Schot and Kanger [1] can be seen as a result of three interacting sub-trends:

1. Variation: emergence of new rules or the alignment of existing rules into rule-sets (regimes/meta-regimes) with novel qualities. From the evolutionary perspective we expect gestation, irruption and frenzy phases to be dominated by high but gradually decreasing variety, reaching its low point during the synergy phase. This would reflect a move from radical to incremental innovation and the increasing alignment of rules leaving less possibilities for the emergence of major novelty. However, towards the end of the maturity phase we expect variety to increase again as the deepening crisis of the dominant meta-regime provides an opportunity for radical niches.

2. Diffusion: imitation and selective adoption of rules and rule-sets in different systems and various countries. Although we assume the process of diffusion to occur in a piecemeal manner involving various setbacks and failures, as an aggregate trend we expect the emerging meta-regime to spread to new systems and locations throughout the surge.

3. Contestation: debates, conflicts and struggles around emerging rules and rule-sets concerning their application, their changing relations with existing modes of production and their broader societal effects. Here the implied pattern is somewhat more complex. During irruption and frenzy phases we expect that the increasing public visibility of the emerging meta-regime and the attempts to apply it in different systems would prompt increasing societal contestation up to the turning point when large-scale conflicts are resolved. During the following phases we expect the dynamics to be reversed: low contestation during the synergy phase followed by renewed contestation during the maturity phase, reflecting a gradual shift from the dominance of the meta-regime to its crisis.

These phase-specific and cross-phase trends constitute a set of expectations against which empirical data on the historical development of mass production will be assessed. This will be done in sections 5.1 and 5.2 respectively.

3. Methodology

3.1. Case selection

The research is based on a single longitudinal case study design [24], adopting a 'most-likely' case selection strategy. The literature on case selection stresses the symmetrical strengths of 'most-likely' and 'least-likely' cases for assessing the validity of an existing theory. Whereas 'most-likely' cases cannot offer strong proof for a theory (as the case is expected to conform closely to theoretical propositions) they can strongly undermine it if the case does not fit the theory (because if the theory does not even explain the closest expected match it will probably perform even worse on less likely cases). Conversely, 'least-likely' cases can offer strong proof for a theory (demonstrating that the theory explains even less likely cases) but they cannot strongly undermine it if the case does not fit the theory (as the case is not expected to conform strongly to theoretical propositions in the first place) [25, p. 121]. Where multiple theories exist for explaining a given phenomenon, the strongest supporting evidence can be obtained by choosing a case least-likely for a given theory and most-likely for competing theories (all of which also make different predictions about the outcome of
interest). The strongest weakening evidence can be obtained by choosing a most-likely case for a given theory as well as all competing theories making similar predictions, and failing to find supporting evidence for it [25, p. 121].

Arguments like this [26-28] implicitly assume a rather mature field of research characterized by considerable knowledge base (established through numerous prior case studies) and the existence of a number of competing theories for a given phenomenon. Although this might be an accurate description of the authors' own disciplines (usually political science), neither assumption holds for the current framework which establishes a new phenomenon – Deep Transitions – through a synthesis of existing theories (Multi-level Perspective and Techno-economic Paradigms). In this way DT goes beyond MLP and TEP by design and cannot be argued to offer strictly competing explanations to either of the two frameworks. This is well evidenced by Geels's seminal analysis of the transformation of factory production from the MLP perspective [15]. Not only is the study geographically and temporally restricted (USA, 1850-1930), it also focuses on the breakthrough of mass production where impacts exceeding the mobility system and emerging connections with other systems are largely excluded. The most complete long-wave account of mass production [11, pp. 257-300], on the other hand, largely focuses on a few leading countries (primarily USA) during the 4th wave only, neglecting the role niche-system dynamics in generating the surge. In contrast, the use of the DT framework necessitates the observation of interactions between niche, regime, meta-regime and landscape dynamics over a much longer time-frame and broader geographical scope (see below).

We suggest that in the context of scarce knowledge of the focal phenomenon (Deep Transitions) and the lack of competing theories offering alternative explanations, a 'least-likely' case would constitute a far too strong first empirical test of the framework. A similar reasoning, although not explicitly spelled out as such, seems to have been pursued in seminal works on socio-technical transitions which initially focused on transport, sanitation and production [12-15]. It is very difficult to see what would have been gained if MLP had started out from a 'least-likely' case such as rock'n'roll instead [2]. Therefore, in our view a 'most-likely' case constitutes the best option for a first empirical test of a nascent theory.

Mass production was chosen as a case for three reasons. First, as the TEP framework considers mass production a central element of the 4th surge (1908-1972) it can be considered a 'most-likely' case for the DT framework. This means that we expect the evolution of mass production to mirror the conceptual model of Schot and Kanger [1]. A failure to detect a close match with the theoretical propositions, on the other hand, would cast serious doubt on the overall validity of the DT framework. Second, during the past century mass production has become increasingly central to modern lifestyles in developed and developing countries, thereby exacerbating environmental problems such as pollution, waste or resource depletion [29-31]. Because of its global impacts mass production constitutes an influential case the co-evolutionary dynamics of which are crucial to understand in its own right. Third, practical considerations such as the availability of a broad array of secondary historical literature on the topic also played a role in the case selection. Conducting in-depth qualitative work with primary sources on the scale required for exploring the DT framework would have simply fallen beyond the scope of the study.

The case is bounded as follows. Temporally, we focus on the events between 1765 and 1972. This covers the long gestation period of mass production (1765-1907), its installation during the 4th surge (including irruption, 1908-1919, and frenzy phases, 1920-1938), turning point (1939-1945) as well as the deployment period (including synergy, 1946-1959, and maturity phases, 1960-1972). Geographically, we focus on the Transatlantic region. This enables us to trace the varying origin and
circulation of rules across national boundaries, including their regional adaptations. Thematically, we focus primarily on the engineering-related dimension (production organization and labour control), largely excluding the dimensions of economy, policy, everyday life and culture. While the latter choice has been largely made for feasibility concerns we also recognize the resulting limitations of our study (see below).

3.2. Data and methods
Following an established tradition in transitions studies our research employs a stylized narrative explanation based on an interpretive analysis and synthesis of a broad range of secondary historical literature. As Geels and Schot argue, “the strength of a narrative is that it can capture complex interactions between agency and changing contexts, time, event sequences, making moves in games, and identities” [32, p. 97]. Although narrative-based approach is versatile, flexible and attentive to complexity, it has also been criticized for the subjectivity of researcher choices or difficulties with assessing the extent to which the results conform to expected patterns [33,34]. A similar sentiment is echoed in Nuvolari’s assessment of Freeman and Louçã (2001) as both “the most articulated treatment of this [long wave] approach” but also “highly impressionistic and descriptive” [35, pp. 34, 42]. Given our aim – to provide an early empirical assessment of a complex theoretical framework of broad scope – we argue that the strengths of a narrative-based approach outweigh its weaknesses. To address the shortcomings of the narrative approach we try to provide a clear assessment about the possible biases of our study (see below), to substantiate each statement on a general trend with empirical support (section 4) and to establish clear connections between empirical data and theoretical abstractions (section 5). Nevertheless we readily acknowledge that ultimately our selection, presentation and interpretation of data contains a certain degree of subjectivity.

Data collection and analysis was conducted in four stages, involving a great degree of iteration between different steps:

1. Beginning from authoritative works [36-38] and literature search from various databases we used a snowball sampling approach to assemble a corpus of secondary literature on the history of mass production. Given the analytical dimensions of interest (see section 2) and the case bounding (see above) we aimed at a systematic coverage.

2. Based on the literature we then constructed a genealogy of mass production, consisting of different rules, combinations of these rules (rule-sets) as well as several historical dead-ends (see figure 2). This stage involved interpretive work, whereby various technologies, practices and principles described in the sources were transformed into rules (see box 1). The emerging interpretations were discussed with two historians of technology with expertise in mass and specialty production to further improve the genealogy.

3. We then compiled a stylized narrative explanation of the development of the rules underlying mass production. Upon detecting gaps in the narrative, additional literature search was conducted to cover the missing dimensions and to update the genealogy.

4. In the final stage, we used the pattern-matching technique [24, pp. 224-225] to compare the patterns that emerged from the stylized empirical narrative with the expected ones derived from theory. In doing so we assessed overlaps and deviations and, where necessary, developed further conceptual extensions. The pattern analysis was twofold. First, the phase-specific patterns of every period were matched to the six propositions (gestation, irruption, frenzy, turning point, synergy, maturity) described in subsection 2.1. The results of this exercise are presented in subsection 5.1. Second, the cross-phase patterns evident throughout the periods were matched to the three overall trends (variation, diffusion, contestation) described in subsection 2.2. These results are presented in subsection 5.2.
The limitations of our approach should be noted. Firstly, as our study draws on works published in English the narrative might suffer from source bias. To address this issue we attempted to locate studies on different countries or studies with an international dimension [38-40]. Secondly, given our focus on the engineering dimension, the narrative might somewhat overstate the prominence of USA while downplaying the contribution of different countries to the correlates of mass production in other dimensions (economy, policy, everyday life, culture), e.g. interwar era Soviet experiments with centralized planning as a precursor for large-scale state intervention in the entire Transatlantic region after World War II.

**Box 1.** Examples of rules in secondary literature.

*It appears, therefore, that conveyors and gravity slides were adopted either immediately before the assembly line experiments or resulted from the “work in motion” principle brought to life by the assembly line [36, pp. 238-239, on Ford’s experiments].*

*Mass production of automobiles, as developed by Henry Ford in the half-dozen years before the First World War, depended on three basic principles: the standardisation of the product, the use of special-purpose equipment, and the elimination of skilled labour in direct production [41, p. 153].*

*“Thorough elimination of wasteful practices” is the basic concept of the Toyota production system. This concept is supported by the following two fundamental principles: 1. “Right on time”; 2. “Automation” [42, p. 87].*
Figure 2. Genealogy of mass production.

- **Make components interchangeable**
- **Use hand tools for making the products**
- **Arrange machines according to the sequence of work**
- **Delegate single tasks to single machines**
- **Optimize the work process as a whole**
- **Optimize a single task**
- **Separate planning from execution**
- **Standardize the products**
- **Optimize a single task**
- **Embed entire task sequences in a single machine**
- **Design production for regular product change**
- **Electrify factories, work environments and machines**
- **Move work to worker**
- **Design production for continuous product and process improvement**
- **Anyone should be able to stop production upon spotting an error**
- **Provide supplies exactly where/when required**
- **Tap worker expertise for production improvement**
- **Minimize changeover time**
- **Design products so that they would be easy to manufacture**
- **Maintain close and cooperative relations with external actors**
- **Organize production in teams of multi-skilled workers**

**Legend**
- Rules part of historical dead-ends
- Rules part of American-style mass production
- Rules part of Japanese-style mass production
4. Case study: The evolution of mass production, 1765-1972

The following section presents a narrative overview of the historical evolution of mass production between 1765 to 1972. In order to establish clearer connections with the theoretical framework (see section 2) the results have been divided in different phases, with each phase focusing on three trends – variation, diffusion and contestation. Note, however, that because of continuous interactions (e.g. new rule-sets emerging and starting to compete with each other) the following narrative cannot always maintain as neat analytical separation of the three trends as implied by the respective titles of each sub-section.

4.1. Gestation (1765-1907)

4.1.1 Variation

Before the 20th century flexible specialty production was a dominant mode in the entire Transatlantic region. It relied on one worker performing all tasks, the use of customizable special-purpose machinery, the imperative to compete on novelty and/or quality (rather than price), making systematic use of shop-floor worker knowledge for production improvements, and maintaining personal and informal relations inside the enterprise and between different enterprises [43]. From the 18th century experiments in various niches started to challenge these principles.

The precursors of mass production can be broken down to four broad streams: standardization, continuous movement, electrification and efficiency. The first stream began with the ideal of interchangeable components in armsmaking that emerged in the French military from 1765 and was realized with hand tools in 1790 [44]. During the first half of the 19th century US state armouries (Harpers Ferry, Springfield) added two important rules: using special-purpose equipment to perform one function only and placing machines in a sequence according to the work process [36,45]. By mid-19th century the alignment of these three principles constituted a rule-set of distinctive character, named American System of Production by contemporary observers [36]. Closely related to the interchangeability of components was also the emerging idea of product standardization which allowed to minimize changes in design and to avoid expensive and time-consuming retooling [38, pp. 27-28].

Another stream was related to experiments with continuous movement and flow production in various applications such as flourmilling, bakeries, breweries, cigarette-making, canning, oil and chemical industries, foundries and bicycle production. Other important antecedents were the disassembly lines used in meat-processing in Cincinnati (from the 1860s, see figure 3) and Chicago (from the 1880s) as well as Edison's iron mining facility in Ogdenburg, which was visited by Henry Ford [36,38, p. 26;40].

A third strand entailed the electrification of factories. Electric motor was first introduced in the 1880s, first as an add-on to the central steam engine but gradually moving toward unit drive, i.e. 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 [15,38, p. 27].
Figure 3. Flow production techniques of meat processing in Cincinnati, 1873. Source: chromolithograph by Henry François Farny, published by Ehrgott & Krebs. Library of Congress Prints and Photographs Division Washington, LC-DIG-pga-03169.
The fourth stream aimed to increase the efficiency of labour and resource use. This included a division of production into specific tasks to be carried out by a specific worker, introduction of a clear separation between engineering, management and executive roles, and replacing workers' rules of thumb with ones devised by experts. These principles were central to the thinking of Frederick Winslow Taylor whose work experience in steelmaking gradually led him to formulate a system of 'scientific management' [47,48]. As part of a wider Efficiency Movement gaining strength in industrial nations from the late 19th century other ideas on systems management and factory organization gradually led to an idea to optimize the work process as a whole [46,49]. Similar concerns also directed attention to the need to minimize waste of resources and, where possible, re-use waste materials in the production process.

4.1.2 Diffusion
The precursors of mass production originated from both Europe and USA. Interchangeability had a French origin but the ideas were transferred to the USA by Thomas Jefferson, French military experts and books. The idea to sequence machines according to the work process was developed by Thomas Blanchard at the US Springfield armoury around the late 1810s but the idea built on the British example of wooden blockmaking from the 1790s [36, pp. 25-27, 41]. The benefits of subdivision of work into specific tasks had been famously described by Adam Smith in 1776 but the idea was taken to another level by Taylor's scientific management more than a century later. In terms of sectoral origin there was even greater variety: armsmaking, mobility, food, energy and chemical industry all contained niches for experimenting with new principles of production.

The initial barrier to the adoption of the American System of Production was cost-related: achieving full interchangeability turned out to be more expensive than hand-fitting [36, pp. 48-49). However, over the second half of the 19th century a number of broader factors in USA started to favour increasing mechanization of production. These included a shortage of skilled labour (thereby providing incentives for investing in machinery), road and rail network enabling nationwide markets, fast population growth coupled with rising purchasing power, the emergence and growth of large-scale corporations able to capture various economies of scale, the rise of the engineers as a new and increasingly influential social group but also the American cultural values favouring the development of a highly accelerated society [15,38, pp. 5-10;46].

During the second half of the 19th century the American System spread in a gradual and piecemeal fashion to various industries such as private armsmaking, clockmacking, sewing machines and typewriters [36]. Perhaps the most notable example of pre-Fordist large-scale production was the Pope Manufacturing Company where the automation of work on a moving assembly line, interchangeable parts across a wide variety of bicycle models and specialization of work process management in functional departments were combined for bicycle production [50].

Interchangeability and standardized parts were first introduced to the automobile industry by the Cadillac company in 1908 [46, p. 298].

4.1.3 Contestation
Since the precursors of mass production were dispersed in various niches interactions between these rules and specialty production remained fairly sporadic. Enterprises relying on flexible production did occasionally employ new principles when it suited them, e.g. printing industry in New York being early adopters of electric drive systems [43, p. 129], but overall this did not lead to a fundamental overhaul of the mode of production itself. Occasionally, new rules were explicitly contested. For example, French experiments with new modes of weapon production were terminated for political reasons at the beginning of the 19th century [44]. Another example concerns Taylor's attempts to rationalize production at Bethelem Steel company, leading to stiffened worker
resistance and culminating in his dismissal in 1901 [47, p. 195].

4.2 Irruption (1908-1919)

4.2.1 Variation

From 1908 Henry Ford and his team of engineers undertook a wave of experimentation to mechanize car production, turning simultaneous attention to gauging, fixtures, machine tool design, materials handling, factory layout and many other areas [36, p. 219]. In so doing the team made use of various principles pioneered during the gestation phase (see figure 2 and 4.1.1) but often realized them in a novel manner. 'Move work to worker' rule is a good example: whereas the 19th century bicycle industry had used runners to deliver parts to stationary machinists Ford's engineers developed a moving assembly line for the same purpose; whereas meat-processing had used a sequential approach to disassemble the corpse, Ford reversed the process.

Between 1913-1915 the team in Ford's Highland Park factory managed to align the streams of interchangeability, continuous movement, electrification and efficiency into a new regime of mass production. This constituted a qualitative as well as quantitative transformation in productive capacities: between 1911-1916 output increased from 53,488 to 585,388 Ford Model T-s whereas retail price decreased from 690$ to 360$ [36, p. 224]. By 1914 Ford's sales equalled the rest of US car production [51, p. 327] and USA had captured most of the global market.

Figure 4. Shares of world motor-vehicle production by region, 1900-1980 [51, p. 13].

The success of Ford Motor Company also exposed a crucial difference between 'Fordism' and 'Taylorism'. Although both approaches offered solutions for increasing the volume of production and were seen by contemporary observers as similar and complementary, Taylor focused on task optimization while Ford directed his attention to the work process as a whole. The supremacy of the
latter approach was clearly demonstrated early on: in 1914 Ford's production exceeded the 'Taylorist' Packard factory by 30 times [38, p. 250]. Despite Taylor's search for 'one best way' turning out to be a historical dead end as a rule-set for production organization, his legacy proved to be much more enduring for labour management [48,53].

4.2.2 Diffusion

The Highland Park factory quickly became a widely publicized international phenomenon, drawing visitors already before World War I from Germany, UK and France with Soviet Union following suit in 1919 [53, p. 56]. Another channel of diffusion was the establishment of Ford plants in Europe and elsewhere, e.g. Britain (1909) or Argentina (1916). Ford's success also inspired early imitators: in 1912 French Renault began to plan a shift from artisanal methods to American-style production [38, p. 67].

As a major landscape shock, World War I accelerated the diffusion of mass production in various ways. It created a massive demand for mobility: for example, the number of motorized vehicles in the French army grew from 265 in 1914 to 265,000 in 1918 [54, pp. 48, 54] and Ford supplied around 125,000 vehicles on the front [38, p. 69]. WWI also provided a stimulus to extend the new regime to the defence system, e.g. Citroën using mass production techniques to produce artillery shells (ibid.). Sending men and horses to the front facilitated the mechanization of agriculture, reflected in the introduction of the Fordson tractor in 1917. However, not all attempts to apply mass production were successful, e.g. Ford's failure to deliver submarine patrol boats as quickly as anticipated [55].

4.2.3 Contestation

High degree of task fragmentation and the accompanying routineness of work imposed severe demands on labour who were de-skilled and had very little control over the work process. As such mass production was contested from the outset. In 1912, Ford broke a strike in Buffalo plant by closing it and sending the machinery to Detroit; his right-hand man, Charles Sorensen, had to go to Britain to break the Metal Workers Union [54, p. 45]. Nevertheless, high labour turnover remained a pressing problem, reaching 380% in 1913 [36, p. 11]. In order to counter this Ford famously introduced a 5-dollar day in 1914, prompting immediate discussions about the societal impacts of this move. Whereas American socialists and radical press celebrated the rise in worker income, conservative voices in industry, media and church worried that Ford's high wage policy may aggravate worker inequality and drive out other businesses thus leading to social unrest and overall decrease in local prosperity [38, pp. 98-102].

Whereas Ford's mass production was starting to push aside its competitors (e.g. Taylorism) in the mobility system, specialty production continued to thrive elsewhere. In USA it contributed roughly about 1/3 of the value added in 1909 [43, pp. 13-16] whereas in Europe the craft tradition remained largely unchallenged. In many areas such as jewellery or furniture quickly changing consumer demand made mass production techniques non-viable. However, whereas the gestation period had been characterized by loose borrowing of selected principles, some specialty producers now started to establish more symbiotic relationships with mass producers, e.g. machine shops supplying specialized single-purpose machinery for early automobile manufacturers [43, p. 218].

4.3 Frenzy (1920-1938)

4.3.1 Variation

Whereas Ford had inaugurated a new regime of mass production his continued focus on productivity maximization and price-cutting of a single product made him less responsive to
variations in demand. From the 1920s General Motors had begun to seek for alternatives in order to balance the economies of scale offered by mass production with diversity in demand characteristic of market economies. This led GM to introduce many business-related innovations such as the installation of multi-divisional decentralized management structure, use of consumer credit or the facilitation of used-car trade-ins.

However, GM's strategy also implied changes in production leading to a new variation, 'flexible mass production' [36]. As a guiding rule production had to be designed for annual model change, often involving minor stylistic changes. The combination of uniformity and variety was achieved by using similar components across different car models. The flexibility of production was further increased by the customization of general-purpose machinery (vs. highly specialized single-purpose machines that had characterized Ford's production). The overall effectiveness of increased flexibility was reflected in the fact that in 1927 GM's Chevrolet outsold Ford in the American market for the first time [54, p. 69].

4.3.2 Diffusion
From the 1920s mass production consolidated its foothold in the systems of mobility (increasing diffusion of cars, especially in USA), defence (mechanization of war as an anticipated direction of evolution) and food (continued mechanization of agriculture, new techniques of fruit canning and baking, introduction of toasters). New consumer durables often acted as vehicles for introducing mass production to new systems, e.g. communication (radio sets) and housing (washing machines, vacuum cleaners, electric irons) [38, p. 51]. The take-up of mass production often resulted in three types of outcomes: 1) consolidating existing links within a system, e.g. oil production and car diffusion in the mobility system; 2) acting as one of the building blocks for system transitions: for example, in the food system mechanization was increasingly combined with the principles of chemicalization (e.g. the use of nitrogen fertilizers and pesticides) and selection of plants and animals suitable for standardized production, gradually paving way to the intensive agriculture regime [56, pp. 375-376]; 3) consolidating or creating new links between systems, e.g. drive-in cinemas linking mobility and communication systems or electrical appliances in the housing system intensifying production in the energy system.

Mass production also started to become 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” [37, p. xvii]. This was reflected in using the term as a loose metaphor to describe various technical and social activities (energy production, education, artistic performances), the influence of machine aesthetic on industrial designers and artists (e.g. Soviet Constructivists, Walter Gropius, Le Corbusier), or relegating 'Fordism' to the status of a general philosophy of the era [36, pp. 303-330;38, pp. 57-63;47, pp. 295-352] (see box 2). This provided the notion of Fordism with a degree of flexibility allowing it to be used as a rhetorical promise in a broad range of systems across the entire Transatlantic region [37,40, p. 134].

At the same time attempts to extend mass production through direct imitation often resulted in failures. US automotive dealers largely resisted Ford's efforts to introduce routinized work procedures, division of labour, specialized machinery and progressive layout of equipment [57]. In both Europe and USA various attempts were made (and abandoned) to produce houses on the assembly line. American mechanical engineers also advocated the increasing use of mass production in woodworking and furniture industry on the grounds of increased efficiency, largely neglecting consumer preferences favouring diversity [36, pp. 311-316].
The transatlantic flow of mass production was ensured by various means, e.g., new Ford and General Motors divisions in Belgium, Canada, Denmark, France, Japan, the Netherlands and Sweden, various engineering and scientific publications, engineering and management consultants, world’s fair exhibitions and government programs [38, pp. 70-71;53]. Rationalization of industry also started to be promoted by semi-state institutions in many European countries such as the British Higher Productivity Council (UK), Reichskuratorium für Wirtschaftlichkeit (Germany) or Work Efficiency Organization (Finland) [60, p. 219].

Whereas Ford himself though that mass production could be transferred everywhere with minimal changes its take-up in Europe can be better described as selective adoption and modification. The French car industry quickly adopted the assembly line, starting with Citroën in 1919, followed by Berliet (1920), Renault (1922) and Peugeot (1929) [60, p. 219]. However, the enterprises soon found themselves lagging in interchangeable parts, quality of steel and, as a result, the speed and efficiency of the assembly line [39, pp. 408-411, 479-482]. The newly created Soviet Union saw the combination of Ford’s and Taylor’s ideas as means to industrialize the country which, in turn, was part of a broader plan to provide a full-scale societal alternative to capitalism. This drove the adoption of mass production despite immense difficulties in actual implementation, e.g. lack of industrial management skills and educated workforce [38, pp. 76-78;61,62]. In Germany resistance to de-skilling made the industrial establishment resist the adoption of American techniques until the Nazi rule and its vision of mass motorization [63]. In the UK a strong craft tradition coupled with a different working culture – for example, workers in Ford’s Manchester factory insisting on stopping the assembly line for tea breaks [38, p. 83] – held back the adoption of American techniques. Various attempts to apply a mixture of ideas from Ford and Taylor often resulted in local variations such as Fayolism and Bedaux system in France or Bataism in Czechoslovakia [40, pp. 125-139;60].

### 4.3.3 Contestation

During the 1920s-1930s the contestation of mass production gradually changed from an individual worker strategy of ‘voting with one's feet’ to organized resistance. Added to the familiar concerns about repetitiveness and de-skilling were the various tactics of the American automobile industry for increasing the pace of work without a corresponding rise in wages, e.g. increase of line speed after installing new machinery or setting special daily production goals [64]. Until the end of the 1920s the industry’s high wages had generally neutralized the need for worker organization. However, with the Great Depression the power of management over labour was further increased as worker job security turned ever more fragile. This situation eventually led to the establishment of

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**Box 2. Examples of 'generalized fordism' in public rhetoric.**

*The combination of the Russian revolutionary sweep with American efficiency is the essence of Leninism* (Joseph Stalin, 1924, quoted in [47, p. 251]).

*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”* (Hoover Report, 1929, quoted in [11, p. 292]).

*A standardized, all-purpose ape is the ideal laid down in the blueprints ... At present ... practically all these thoughtful procedures on the part of the apes' supervisors are directed towards the eventual mass production of a standardized chimpanzee* ([58] on breeding efforts in Yale’s Ape Colony).
the United Automobile Workers union in 1935 and the introduction of sit-down strikes [38, pp. 116-120]. Although the automotive industry started making gradual concessions to workers, the conflict was not entirely resolved by the end of the 1930s: the link between mass production and labour organization was to be consolidated only after WWII.

The relationship between mass and specialty production was characterized by important regional differences. In European countries with a strong craft tradition, mass production was claimed to be an American phenomenon that, because of smaller markets, lower incomes and diversified consumer preferences, could not be copied [65]. In USA, however, a shift from symbiosis to competition between mass and specialty production was taking place. For example, in the early 1920s several clothing manufacturers installed two or more assembly lines, one for standardized and the other for customized production [66]. However, by the end of the decade the prevalent rhetoric of 'simplification', advocated by president Hoover, engineering societies and managers, started to associate industrial diversity with inefficiency and waste. The Federal Trade Commission and Department of Justice also countered attempts at regulating competition through price coordination and exclusive sales agreements. This effectively forced specialty producers to compete on price, making them lose one of their distinctive characteristics, and initiating the gradual waning of flexible production in USA [43].

Increasing public visibility of mass production raised wildly ranging hopes and fears about its societal effects. For example, Ford's waste handling practices were initially argued to contribute to the preservation of America's timber resources [67, p. 151]. An influential advocate of Fordism argued that the abundance enabled by mass production would lead to the “abandonment of all class thinking and the substitution of fact-finding for tradition” [68, p. 1]. Mass production was also associated with the possibility of shorter working hours leading, in turn, to worries about future technological unemployment. These utopian promises initially made mass production attractive to radical political forces and totalitarian governments [69]. However, by 1930s widespread optimism had given way to two streams of critique. The Great Depression had problematized the necessity of connections between mass production, high employment, rising wages and increasing living standard. Especially in Europe mass production was argued to lead to the homogenization of products, consumers, personality and culture [38, pp. 88-93]. For example, a French satirical film “À Nous la Liberté” from 1931 drew parallels between industrial working conditions and life in prison (see figure 5).

4.4. Turning point (1939-1945)

4.4.1 Variation

Existential threats posed by wartime conditions prompted several experiments to improve the performance of weapons and to reduce the number of defects. Strategies for seeking trade-offs between product quality and quantity led to differing national strategies: whereas German and British managers preferred increasing quality and constant modifications, American and Soviet industrialists stressed quantity and refrained from changes preventing the full deployment of assembly line techniques [70, p. 358]. The management of this balance led to experiments with continuous improvement and just-in-time strategy in airplane production [71]. German concentration camps 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 [38, p. 132]. However, these experiments largely failed to spill over to the civil sector after the war when both USA and Europe largely reverted to better established techniques of mass production.
4.4.2 Diffusion

War requirements greatly increased the need for standardized products, including clothing, weaponry and food. Government procurement, investments in factory equipment and other subsidies directly facilitated mass production [72] as did cooperation needs between allies. Especially important was the Lend Lease Act (1941) through which USA began to provide supplies to allies, e.g. trucks, boots and food for the Soviet Red Army or car parts to Britain for the manufacturing of Jeeps [38, p. 135;70, p. 354]. Whereas WWI had provided a stimulus to extend the nascent mass production regime to the defence system, WWII helped to consolidate its centrality for war in the entire region. In the American food system, where the adoption of mass produced vehicles was well underway, WWII proved to be a literal turning point (see figure 6).

The war also demonstrated possibilities for extending the meta-regime from one application to another. For example, the construction tycoon Henry J. Kaiser established the California Shipbuilding Corporation in 1941 for the purpose of mass producing military ships and although he had no prior experience in the field, the enterprise became the country's leading shipbuilder [73]. Another example is the hiring of Henry Ford's chief engineer to design the Willow Run production line for assembling B-24 heavy bombers [74]. The established infrastructure often facilitated dual use: in the USA aircraft engines were produced in converted automobile factories [75] whereas in Germany wartime aircraft production led to the development of a strong supply network forming a basis for post-war automobile industries [76].
4.4.3 Contestation
Wartime conditions heightened the need for 'mass loyalty' which meant putting labour conflict on hold and mobilizing the entire population in the name of cooperation and shared sacrifice [38, pp. 128-131;78]. In this way the combination of direct and indirect effects of WWII paved way for the post-war dominance of mass production. The lack of demand for specialty production together with state investments in mass production created a productive capacity that could be converted for civil purposes after the war. The forced savings of a substantial amount of soldiers [72] created a possibility for post-war mass consumption. The devastation of war also raised pressing concerns for which mass production seemed to provide appropriate solution. The food system is a case in point. Although organic farming had started to gain public visibility in Britain shortly before WWII, severe post-war food shortages provided strong incentives for industries and newly founded international organizations such as FAO to favour intensive agriculture instead [79, pp. 115-120].

4.5 Synergy (1946-1959)
4.5.1 Variation
The post-war era can be described as the societal embedding of mass production: connecting it to horizontally integrated and multi-divisional big enterprises in the economic dimension, social contract between employers, labour and policymakers within the framework of a nationally-bounded welfare state in the political dimension, individualized private mass consumption in everyday life and the ideology of material and social progress in the cultural dimension [11,80]. The combination of these features put a foundation to long-lasting economic growth in various regions of the world, enabling them to catch up with the USA.
Table 1. Economic growth in various regions, GDP per capita, 1900-1973 [81, pp. 253, 256].

|        | Europe | Eastern Europe | Western offshoots | Latin America | Asia |
|--------|--------|----------------|-------------------|---------------|------|
| 1900-1913 | 1.1    | 1.6            | 2                 | 2.2           | 0    |
| 1913-1950 | 0.9    | 1.4            | 1.5               | 1.5           | 3.6  |
| 1950-1973 | 4.1    | 3.5            | 2.6               | 2.6           | 3.5  |

Notes: Europe = 15 EU members + Switzerland; Eastern Europe = Bulgaria, Czechoslovakia, Hungary, Poland, Romania, USSR, Yugoslavia; Western offshoots = USA, Canada, Australia; Latin America = Argentina, Brazil, Chile, Colombia, Mexico, Peru, Venezuela; Asia = Bangladesh, Burma, China, India, Indonesia, Pakistan, Philippines, South Korea, Taiwan, Thailand.

Mass production continued to develop in two directions. In USA, labour unrest had prompted a managerial vision of a fully automated factory. Underlying this vision were two principles: embedding the task sequences of skilled workmen in machine tools (initially through 'record and playback' systems) and using the idea of feedback to increase the flexibility of machine tools. The full realization of these principles was envisioned to result in computer-controlled assembly lines staffed with robots that would enable to replace not only semi-skilled blue-collar workers but also skilled blue-collar and white-collar employees [38, pp. 157-161].

Whereas the rhetoric of automation was also embraced in post-war Japan, experiments undertaken in Toyota from 1948 focused much more on improvements in product quality, reorganization of work and increasing labour involvement. Responding to constraints that had made Europeans largely reject mass production in the interwar era — relative lack of capital, smaller volumes of production and higher variety of models — Toyota started to introduce novel production principles. These included an imperative to design production for continuous product and process improvement (vs. the fairly limited flexibility of the American approach), using worker expertise as a constant input for production improvement (vs. restricting workers to the role of task execution), allowing workers to stop the production process upon spotting an error (vs. having to succumb to the dictate of the assembly line) and 'just-in-time' provision of an exact amount of supplies (vs. 'just-in-case' buffering of stocks) [42,82-84] (see figure 7). Similarly to Ford's early activities these rules emerged in a piecemeal fashion: by the end of the 1950s Toyota's practices had not been even formally codified yet [85].

4.5.2 Diffusion
Post-war decades were characterized by the continued deepening of mass production in systems where it had been previously employed, reflected in a move from vehicles and consumer durables to other system components. For example, in order to employ picking machines in the American food system, a standardized tomato with a thicker skin had to be bred, picked green, chemically ripened and 'enhanced' with salt and sugar to compensate for the loss of flavour [86, pp. 291-293]. Another way of deepening involved a shift from previously attempted full-scale imitation to more selective adoption. For example, whereas the 'move work to worker' principle had been abandoned in the housing system, the use of standardized components and architecture still enabled a rapid construction of blocks of identical-looking houses [38, pp. 149-151]. As a result couplings between systems became consolidated in a manner that would stimulate the further deployment of mass production. This was the case for US mobility and housing systems: mass produced cars enabled to live further from the city centre facilitating urban sprawl, whereas the creation of new suburbs without efficiently functioning public transport amplified the need for vehicles.
Figure 7. ‘Provide supplies exactly where/when required’ and ‘Anyone should be able to stop production upon spotting an error’ rules contrasted to traditional mass production [42, p. 92]. Note the use of the word ‘automation’ for describing the latter.
Cold War provided another stimulus for the take-up of mass production as the competition between two superpowers also involved claims about living standard. Through channels such as the Marshall Plan, the Productivity Mission, Fulbright Program and United States Information Agency mass
production techniques, corporate organization structures, management styles, advertising, and consumer goods started to flood the Transatlantic region. Although the adoption of mass production remained selective and uneven [87] in many ways European countries started to become more similar to USA [60]. These influences extended beyond the Iron Curtain, e.g. the idea of mass produced people’s car à la Volkswagen Beetle was present in East Germany, Soviet Union and Czechoslovakia [88]. However, as the Socialist Bloc prioritized the needs of the military-industrial complex both the availability and quality of consumer goods remained notably lower [89].

As a new direction automation was highly visible. By 1958, USA had 16,000 ‘automatic assembly machines’ applied to the production of automobiles, electric motors, TV-s and radios. The role of automation in post-war industrial reconstruction was also stressed in Germany, France, USSR and Japan [38, pp. 161, 166-167]. In contrast, very little was known about Japanese experiments in the West. Toyota’s engineers themselves, however, acquired information from diverse sources, including US factory visits and thorough studies of various production practices. A strive towards continuous improvements was realized through the deployment of statistical methods of quality control which had been pioneered in USA during WWII but largely abandoned thereafter. Just-in-time supply was derived from the supply chain practices of American supermarkets, whereas the self-stoppage mechanisms of Toyota’s pre-war era automatic looms inspired an idea to let the workers stop the assembly line upon spotting an error [38, pp. 187-201; 42].

4.5.3 Contestation
Although the post-war era was initially characterized by the immediate eruption of major strike waves in the entire region [90], a general trend was the gradual institutionalization of labour conflict in the entire region. On one hand unions came to be acknowledged as a legitimate part of state-capital-labour nexus; on the other hand their activities were increasingly restricted by law (e.g. the introduction of Taft-Hartley Act in USA in 1947). Continued but decreasing level of strikes was thus accompanied by the increasingly routine and ritual nature of these activities [91]. The increasing acceptance of mass production was also evident in its relation to possible alternatives such as specialty production. Instead of asking whether to adopt mass production, different countries outside USA now focused on the question of how to make best use of these techniques in given national conditions [38, pp. 135-140; 60].

In terms of societal effects mass production was heavily propagated as a basis for postwar reconstruction with rising productivity linked to higher living standards and social progress. The general theme of prosperity was now dominant in the entire region. However, the cultural critique of mass production also started to spread in a similar manner. Increasingly influential authors of the Frankfurt School argued that alienation was a consequence of the concentration of production into large-scale monopolistic corporations, the division of labour between mental and manual work and the increasing routineness and monotony of work tasks [48]. Importantly, the sources of alienation were not seen as specific to particular economic or political systems but rather the underlying features of all modern industrial societies. For example, Fromm claimed that both capitalist and communist countries were developing into managerial societies that “make machines that act like men and produce men who act like machines” [92, p. 33].

4.6 Maturity (1960-1972)

4.6.1 Variation
In the 1960s the excesses of mass production started to provoke radical responses from niches. Counterculture activists increasingly experimented with food cooperatives and small-scale enterprises under local ownership, emphasizing home-made goods, recycling, organic food, small-scale technologies, and do-it-yourself furniture, food, energy and shelter [38, pp. 175-177]. In parallel, with the initiation of Border Industrialization Program in 1965 some American corporations started to shift manufacturing jobs to northern Mexico [93]. This enabled to sustain profitability by cutting the labour costs while also decoupling production in one location from end use in another. Although the broader implications were not fully understood at the time, the expansion and knock-on effects of offshoring – de-industrializing the West and putting an end to the post-war welfare state compromise – would come to exhibit significant global impacts over the following decades [94,95].

The American ideal of computer-aided design and manufacturing continued to hold sway as reflected, for example, in the development of numerically-controlled machine tools [96]. Although influential experts such as Norbert Wiener expected full factory automation to occur by the 1960s, numerous technical difficulties resulted in far more modest outcomes: by mid-1970s the number of robots in US enterprises was still around 6,000 [38, pp. 159-161]. Continuing large investments in R&D and various experiments in the field of information technologies nevertheless helped to establish a foundation to the 5th great surge of development, unfolding from the early 1970s [10,11].

Whereas automation had run into difficulties in USA, the Japanese alternative was gradually maturing to take the world by surprise in the 1970s. Novel principles included a strive to implement changeover as quickly as possible (e.g. Shigeo Shingo's single-minute exchange dies), designing products so that they would be easy to manufacture, organizing work in teams of multi-skilled workers and maintaining close and cooperative relations throughout the entire supply chain [82,83,97,98]. In the mid-1960s the new approach was formally documented for the first time as the Toyota Production System [85].

4.6.2 Diffusion

Further consolidation of mass production in different systems and countries continued to be the dominant theme in the 1960s, reflected in the diffusion of various consumer goods such as automobiles, refrigerators or TV sets (see figure 8). The logic of mass production and consumption had also pervaded the Socialist Bloc: for example, the Soviet Seven-Year Plan for 1958-1965 promised to match the USA in housing and consumer durables. The resulting 'consumer socialism' [99] attempted to emulate the West in terms of product quality and availability. As a result, one could observe the homogenization of energy and materials usage profiles in the region: whereas the consumerist West was producing increasing amounts of waste, the more limited consumption in the East was amply offset by the deployment of inefficient production technologies [100] and general disregard of environmental impacts.

The situation with American and Japanese approaches to mass production continued to be similar: high international visibility of the automation discourse whereas Toyota's experiments remained largely unknown outside Japan. Notably, the increasing reach of mass production stimulated niche responses on the same scale, e.g. the internationalization of organic farming [79, pp. 156-183] and appropriate technology movement [47, pp. 453-459].

Figure 8. Number of TV sets (thousands) in selected countries, 1946-1972.
4.6.3 Contestation
By 1960s two broad trends in the contestation of mass production had become visible: geographical homogenization and broadening of resistance. As European countries increasingly followed the US lead in adopting mass production, the societal critique associating mass production with cultural homogenization, loss of individuality, creativity and spontaneity was now increasingly present in the USA. By the end of the decade, the contestation of mass production had escalated into an all-out attack on industrial society and its underlying values of efficiency, standardization and business-drivenness [38, pp. 168-170]. These sentiments were expressed in many influential works by Herbert Marcuse, Jacques Ellul, Theodore Roszak and Lewis Mumford [102-105]. A novel strand of critique [106,107] attacked the Western lifestyle for its high use of energy, materials, food and water, increasing production of waste, throw-away consumer culture, and the environmental consequences of these practices.

The different tensions culminated in 1968 as mass anti-establishment protests spread over the US and Europe, most notably in France and Czechoslovakia, involving a wide range of people from workers to students. In 1970 the first Earth Day celebration in USA brought together 20 million people, including students and housewives' organizations, further demonstrating the power of citizen activism [108, p. 264].

5. Analysis and discussion
The analysis in this section follows the structure of section 2 where we describe our theoretical framework. We begin by comparing the empirical patterns evident in every period to the phase-specific model of DT consisting of six propositions (gestation, irruption, frenzy, turning point, synergy, maturity). We then move to comparing the patterns that we detected throughout the periods to the three overall trends prescribed by the DT framework (variation, diffusion, contestation).

5.1 Model assessment
For all six phases we cover main trends in niches and single systems (rules/regimes), interconnected systems (meta-rules/meta-regimes) and on the landscape level. This yields 18 cells presented in table 2. Each cell has been colour coded to facilitate obtaining a quick visual overview of the main results. Green was used when the authors agreed that the development of mass production was
largely in line with the theoretical propositions. Yellow was used when the authors either failed to find empirical support for a particular proposition or when unexpected findings were detected. These assessments reflect the authors’ interpretive consensus as decisions whether the findings are 'largely in line' or 'sufficiently deviant' entail an unavoidable and irreducible amount of subjectivity. Although below we try to substantiate each theoretical claim with empirical illustrations, the reader is referred back to section 4 for more empirical detail backing up our conclusions.

Table 2. Propositions of the Deep Transitions framework vs. case study results.

| Theoretical proposition | Empirical observations |
|-------------------------|------------------------|
| **1765-1907** | Rules/regimes: new principles emerge in various niches (armsmaking, electrical industry, food processing) and locations (France, UK, USA) involving occasional alignment (American System of Manufacturing, Scientific Management) Meta-rules/meta-regimes: – Landscape: various factors in USA (e.g. skilled labour shortage, road and rail networks, population growth, big corporations, rise of engineering, cultural values) set the stage for the emergence of mass production |
| **1908-1919** | Rules/regimes: alignment of various rules into mass production regime in the mobility system (Ford, USA) Meta-rules/meta-regimes: early experiments with mass production in food and defence systems (tractors, artillery shells), including some initial setbacks (submarine patrol boats) Landscape: WWI stimulates the extension of mass production to new systems and locations (Europe) |
| **1920-1938** | Rules/regimes: 'flexible mass production' emerges in the mobility system (General Motors, USA) Meta-rules/meta-regimes: competition between rule-sets (Fordist vs. flexible mass production), selective adoption of US rules in Europe resulting in regional variations (Bataism, Bedaux system); emergence and consolidation of links within and between systems (e.g. energy-housing, mobility-communication) Landscape: Great Depression decreases the utopian promises of mass production, while stimulating increasingly organized worker resistance |
| **1939-1945** | Rules/regimes: experiments with flexible and just-in-time production of airplanes (USA and Europe) Meta-rules/meta-regimes: consolidation of mass production in some systems (food) and extension in
In general we assess that the development of mass production largely matches the theoretical expectations in 12 cells out of 18. Furthermore, apart from frenzy, all phases contained minimally a 2/3 match with the expected dynamics. The frenzy phase was also the only one where yellow colour was partly used because of our inability to find supporting evidence. Namely, whereas the theory stressed the role of transnational organizations in meta-regime building, our evidence pointed to the role of national organizations instead (e.g. BHPC in UK, RKW in Germany). This might reflect a source bias of our study as historians of technology have fairly recently started to focus on transnational organizations [40,109].

In all other instances yellow colour denotes unexpected findings that indicate the need to extend the DT framework. First, based on our analysis of meta-regime building in the frenzy phase we propose that in addition to structural and functional couplings systems also link to each other through shared discourses or 'rhetorical couplings'. These couplings manifest themselves in three ways: 1) claims about the paradigmatic system as a direct source of imitation, e.g. interwar era beliefs that assembly line techniques from car production can be applied to prefabricated housing; 2) downplaying the difficulties associated with cross-system or cross-regional knowledge transfer, e.g. Ford's belief that mass production can be adopted anywhere with minimal changes; 3) abstracting the technical principles of the meta-regime into more general concepts, e.g. the use of mass production as a loose mobilizing metaphor or part of an overall societal philosophy. Whereas the first two strategies often led to setbacks and failures when attempting to move from rhetoric to practice, the diffuseness, openness and flexibility of 'generalized Fordism' enabled to connect different systems on a rhetorical level in the entire Transatlantic region. Somewhat paradoxically these findings suggest
that, at least in early stages, rhetorical couplings facilitate meta-regime building because of the high degree of abstraction of claims involved, not because of their specificity.

The rest of the deviations in each phase (from irruption to maturity) relate to the effect of landscape dynamics on the evolution of rules and rule-sets throughout the entire surge. Based on our data we distinguish between three types of landscape impacts: 1) stimulating new rules and rule-sets, e.g. the set of various broad factors in USA facilitating the precursors of mass production (gestation phase); 2) amplifying existing rules and rule-sets, e.g. the role of WWI (irruption phase) and the Cold War (synergy and maturity phases) in extending mass production to new systems and locations; 3) closing off alternative directions, e.g. the role of Great Depression in detaching mass production from its utopian promises of societal overhaul (frenzy phase). Importantly, as a turning point event WWII exerted all three types of effects, e.g. experiments with flexible production of airplanes, extension of mass production in defence and food systems, and the reduction of possibilities for alternative practices such as organic farming.

Our findings complement the theoretical model of DT that restricts the importance of landscape impacts largely to early stages and the turning point. They also call for more reflections on the role of the landscape in the study of single system transitions where exogenous pressures are often relegated to the role of early enablers [13,32]. Moreover, the results call into question conceptualizations in long wave literature claiming surges to be driven by an internal logic, e.g. the shifting balance between production and finance capital in Perez's [10] model. This suggests two possibilities: either these literatures have so far paid insufficient attention to landscape dynamics or meta-regimes are somehow distinctive in requiring continuous landscape support. In any case, further theorization of the stimulating, amplifying and terminating effects of landscape dynamics is warranted.

5.2 Trend assessment

We now move forward to assessing the cross-phase trends related to the variation, diffusion and contestation of rules. The main results are presented on figure 9. Note that similarly to interpretive accounts in long wave and transitions literature [10, p. 30; 13, p. 83] the curves are meant as a visual aid for the reader and do not reflect the results of a strict quantitative measurement. As with the previous section, the assessments rather reflect the authors' interpretive consensus.
Figure 9. The variation, diffusion and contestation of mass production: cross-phase trends.
The results largely confirm the expected pattern in variation: gestation was characterized by high variety in different niches, irruption to synergy by the emergence, gradual improvements and societal embedding of mass production, and maturity by the resurgence of radical alternatives to mass production. However, we also found that major experiments with mass production continued in the post-war era, e.g. automation in USA and constant improvement of production in Japan. This suggests that the existing DT model has somewhat overstated the incremental nature of innovation during the synergy phase. The DT framework thereby downplays the possibility that niche experiments directed at improving the existing meta-regime might eventually accumulate into a significant transformation of this meta-regime. This is precisely what happened in Japan where Toyota's experiments in the late 1940s gradually grew into a distinctively novel 'lean' version of mass production that started to reshape global manufacturing from the 1970s [85]. More research is thus required to find out what conditions facilitate the emergence of radical internal variations of meta-regimes and what factors enable to scale up these variations.

The general trend was also confirmed for diffusion: despite various setbacks, mass production spread through selective adoption to successive systems and countries throughout the entire surge. However, our analysis also revealed specific channels of early diffusion: 1) mass production was more likely to move from one location to another when the underlying systems were similar, e.g. the early adoption of US techniques by French car producers; 2) mass production was more likely to move from one system to another in a given location, e.g. an early extension of mass production to the food system in USA; 3) in different systems mass production was first more likely to be applied to similar technologies, e.g. the use of mechanized vehicles in the American food system preceding the standardization of tomatoes. These findings are in line with evolutionary economic geography which has demonstrated the role of different forms of proximity (cognitive, organizational, social, institutional and geographical) in facilitating learning and innovation [110-112].

However, explanations relying on differing forms of proximity fail to explain why radical movements and totalitarian governments were initially most receptive to mass production [69]. In our view this observation might be better explained by the mechanism of social differentiation as used in sociological and marketing research [113,114]. Works in these disciplines show that consumers use new products to express individual identity, to highlight their group affiliation and to signal their distinctiveness from other social groups. McMeekin and Southerton [115] have applied this idea to socio-technical systems, arguing that contrasting group definitions of users can either support or hinder transitions. Our findings suggest that the mechanism of social differentiation can be further extended to entire societies and to the diffusion of meta-regimes. This is in line with recent historical literature, highlighting the central role of Fordism in the attempts of Nazi Germany and Soviet Union to create a societal alternative to Western liberal capitalism [62,116].

In terms of contestation our findings confirmed that irruption and synergy were characterized by lower degrees of conflict than frenzy and maturity phases. However, the specific forms of contestation turned out to be quite different before and after WWII. During irruption and frenzy phases we observed a high degree of initial uncertainty about the societal impacts of mass production (e.g. celebration of and worries about the 5-dollar day in USA) and individualized worker resistance being reduced to fewer but regionally varying themes by the 1930s (organized worker resistance in USA where mass production was being adopted, cultural critique in Europe where mass production was resisted). During synergy and frenzy phases we first observed the homogenization of themes of contestation across the entire region (e.g. institutionalization of labour conflict in Western Europe, cultural critique of mass production being taken up in USA). This was followed by the generalization of contestation to broader societal and environmental themes of
which mass production was only a part (e.g. revolutions of 1968, Earth Day in 1970). We suggest that the homogenization of contestation mirrors the Transatlantic diffusion of rules (i.e. equalization of both experienced issues and anticipated fears), whereas the generalization of critique reflects the impacts of the meta-regime on the socio-material landscape.

6. Conclusions
In this paper we have provided the first systematic empirical assessment of the co-evolutionary rule-based model of Deep Transitions [1] by studying the development of mass production in the Transatlantic region between 1765 to 1972. Our main findings are as follows:

1. In general the historical evolution of mass production matches the expected phase-specific patterns of the model. Unexpected findings include the lack of empirical evidence of the role transnational actors in the frenzy phase, the importance of landscape dynamics throughout the entire surge and the role of rhetorical couplings in connecting different systems.

2. Expected cross-phase patterns were also largely detected in the variation, diffusion and contestation of rules and rule-sets. Unexpected findings include the emergence of alternative versions of the dominant meta-regime in niches even during synergy and maturity phases, the role of various forms of proximity and social differentiation in facilitating the diffusion of meta-regimes, and contestation mirroring the increasing scale, scope and societal embeddedness of the meta-regime.

3. Landscape dynamics were found to support the evolution of the emerging meta-regime by a) stimulating new rules and rule-sets; b) amplifying existing rules and rule-sets; and c) closing off alternative directions. The turning point event exerts all three types of impacts.

4. Meta-regime building is facilitated by three mechanisms: rhetorical couplings, proximity and social differentiation. Interestingly, we found that the optimistic expectations maintained by rhetoric and utopian promises of societal differentiation can counterbalance the considerable difficulties of implementing the meta-regime in practice.

Although our results have largely confirmed the DT model, the support offered by an exploratory qualitative case study remains tentative. The next step is to move from solely qualitative assessments to mixed method approaches, combining historical narratives with text mining techniques. This enables to quantify the emergence and alignment of rules but also to interpret the findings in a historically informed manner [blinded, forthcoming]. Also, mass production constituted a case most likely to follow the theoretical propositions. Further work is required to find out whether the model applies to more recent meta-regimes such as digitalization or circular economy. These cases also offer opportunities to look into the operation of mechanisms uncovered by our study, e.g. the Fourth Industrial Revolution [117] as a rhetorical coupling connecting the digitalization of industry to the promise of sustainability, or societal differentiation as a mechanism connecting big data, AI, facial recognition software and social credit schemes to the Chinese vision of 'harmonized' society [118,119]. One can also analyse the role of landscape events in shaping these meta-regimes, e.g. the role of 9/11 or the current coronavirus pandemic in facilitating the societal embedding of digitalization towards increased citizen monitoring and surveillance in USA and China respectively [18,120].

Similarly to the early applications of the Multi-level Perspective the DT framework has so far primarily focused on the identification of broad patterns. Although empirical work has begun on the role of transnational actors in shaping emerging meta-regimes [121], van der Vleuten [122] has argued for the need to broaden the analysis to 'system entanglers', producing cross-regional similarities and differences between systems. Another theme which has not been tackled by transitions studies, long wave literature or the DT framework itself, is the continued evolution and transformation of mature meta-regimes during new surges. The interactions of mass production, IT
revolution and sustainability pressures will be the topic of our forthcoming paper.

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