



System Theory and Cybernetics of the British Industrial Revolution: Positive Feedback Between Smith-Young Growth and Schumpeterian Growth

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Abstract. This paper explores the conundrum why the industrial revolution firstly occurred in England. Such event should be defined as a revolution of commercial technological application rather than only the emergence of invention. Unlike the traditional explanations focusing on the single-factor model, the study in a holistic perspective introduces the system theory and cybernetics into analysis which concentrates on how the positive feedback mechanism resulted from multi-factor interaction contributed to the industrial revolution. The paper argues that England firstly erected the system around textile industry which facilitated the industrial revolution through the virtuous positive feedback between Smith-Young growth and Schumpeterian growth. The system consisted of market organizer, uniform market and specialization primarily. The Smith-Young growth incentivized invention through the interplay between deep specialization and market expansion, while the Schumpeterian growth emphasized the core role of market organizers in market establishment and technological application to achieve creative destruction. The economic transition was thus accomplished by the interplay between the technological invention and their commercial promotion led by market organizers. In the first stage regarding the system organization, the market organizers including British government and entrepreneurs exploited the market for domestic textile industry by mercantilism, war capitalism and proto-industrialization. Consequently, the interaction between market expansion and deep specialization incentivized experience-based inventions through roundabout method of production of textile industry in the second stage. The entrepreneurs then applied them widely whose spillover effects boosted related industries and further broadened the market scope. Eventually, the dynamic positive feedback loop among specialization, market expansion, and market organizers catalyzed the popularization of machine, railway and fossil fuels and the arrival of the industrial age in England. The British competitors lagged behind since the unqualified market organizer, fragmented market or ignorance of developing textile industry circumscribed the positive feedback mechanism of growth despite possessing a few significant factors.

Keywords: industrial revolution · system theory · cybernetics · Smith-young growth · Schumpeterian growth

1 Introduction: What is Industrial Revolution?

Why the industrial revolution firstly occurred in England is still an unsolved conundrum which have motivated consecutive explorations and controversies of scholars. As Clark (2002) [8] remarked, the interpretation of industrial revolution is the most fundamental economic research; however, generations of explorers dedicated but ended nothing. Industrial revolution is regarded as structural changes brought by a sequence of technological innovations in British textile industry from 1760s to 1840s. The unprecedented alterations were reflected in four major aspects: the appearance of machine, transportation, energy and factory system. The widespread adoption of steam engine, railway and coal was judged as the three most essential achievements. The invention of flying shuttle by John Kai in 1737 led to the upsurge in the demand for yarns, thus enhancing the birth of spinning Jenny innovated by Hargreaves in 1764 via which a worker could operate eight spools simultaneously. Nevertheless, the strong yarn with better resilience was still unavailable until the water-powered reeling frame was designed by Ricard Arkwright in 1769. Having combined the advantages of spinning Jenny and water-powered machine, Crompton innovated the mule spinning in 1779. James Watts ameliorated Newcomen steam engine which drove the leap of productivity. Moreover, during the innovative process, the manual production was gradually replaced by machine and therefore factory system and new production relations became prevalent. Additionally, fossil fuels were widely utilized in the mechanical production and horsing was substituted for railway transportation which saved the time of long-distance trade substantially.

However, the rough account of industrial revolution as a technological phenomenon is inaccurate. Such event should be defined as a dynamic revolution of technological application rather than merely the occurrence of invention at a specific moment. Schumpeter (1934) [20] distinguishes the nuance among invention, innovation and diffusion, which compose of the process of technological change. The former concerns the proposal of new ideas or radical technological changes while the latter two involve the commercial adoption and imitation of the invention. Without commercialization and promotion of the technology, the industrial revolution would not occur. The steam engine, for instance, had been adopted to open the gate of temple in Ptolemaic dynasty, but failed to prevail for thousand years until the era of Newcomen and Watts (Braudel, 1979) [5]. The long process from invention to application is the outcome of complex connection of diverse participants and factors including worker, merchant, government, mercantilism and etc. That is why the traditional explanations based on single-factor model are always equivocal and polemical. Thus, it is more reasonable to take into account the industrial revolution as the result of multi-factor interdependence in a system.

This paper detects the mystery why England could take the leading position in the industrial revolution. Compared with the traditional explanations focusing on the single factor, the research in a holistic perspective introduces the system theory and cybernetics into analysis which concentrates on how positive feedback mechanism resulted from dynamic multi-factor interaction contributed to the industrial revolution. The paper argues that England firstly established the system around textile industry which facilitated the industrial revolution through the positive feedback between Smith-Young growth and Schumpeterian growth.

The article is organized as follows: literature review and reflection about the system theory and British industrialization are presented in the second section, which is followed by the illustration of theoretical framework. The empirical evidence regarding two stages of how the system was organized and operated to catalyze the industrialization is evinced in fourth and fifth sector. The sixth section conducting the comparative research responds to why other competitors lagged behind. The final part is the conclusion and reflection.

2 Literature Review

2.1 System Theory and Cybernetics

North (1973) [17] concludes that economic growth originates from effective organization. The system theory proposed by Bertalanffy (1950) [4] stresses the significance of organization in a holistic perspective. It points out that it is misleading to resolve the phenomenon into isolated part, for the function of aggregation cannot be substituted by the simple sum of separate atoms. Therefore, the interaction of elementary units should be emphasized. Cybernetics is concerned with the control and operation of the system towards specific purposes (Wiener, 1948) [26]. The core concept of cybernetics is the feedback mechanism, the closed circular causality that the output is returned back as input to the system, which is categorized into negative and positive feedback. The latter one is an adjusted mechanism to stabilize the impact, whereas the latter is a self-reinforcing one to amplify the effect (Author, 1990) [2]. How to harness the virtuous positive feedback is critical to provide continuous momentum for industrial revolution.

2.2 British Industrial Revolution

Mokyr (1990) [15] maintains that the macro invention with radically creative ideas gave rise to the industrial revolution. Craft (1966) [9] also takes into account industrial revolution as the stochastic process and attributes it to the serendipity of the inventor. Nevertheless, they fail to recognize that supply cannot create demand spontaneously, because the pivotal of industrialization is the application of technology instead of the accidental invention. As mentioned by Braudel (1979) [5], the steam engine had been designed in Ptolemaic dynasty but was not widely promoted until thousand years later. Access to fossil fuels is focused by Pomeranz (2000) [18], but the extensive adoption of coals is the consequence of industrialization rather than the reason. The upsurged demand for coals was due to the practice of the steam engine and the judgement also cannot account for why Japan with scanty coals could accomplish industrialization successfully. Allen (2009) [1] stresses the substitution of machine for labor due to high real wage in England. Japan and China, nevertheless, achieved industrialization on the basis of the cheap labor force (Wen, 2016) [28]. The view of institutional school represented by North (1981) [16] who insists the essence of private property to stimulate innovation is popular. Despite the patent law enacted in England in 1617, the implementation was flawed. Griffiths (1992) [10] claims that 97 of 174 textile inventions from 1700 to 1800 were not patented. Hargreaves was patented after he innovated Jenny machine four years later. Chang (2003) [6] also casts doubt by illustrating that the enclosure movement broke

the property right of the common land but accelerated the industrialization. Wallerstein (2011) [24] who concentrates on the international trade dominated by England all cannot explain why these factors did not allow Spain, Portugal, Netherland and France to take the lead in the industrial revolution. Despite the population explosion as the necessary condition, it was the commonality of European countries after the black death. The neoclassical economists represented by Solow disregard the endogeneity of technology.

3 Theoretical Framework: Cybernetic System of the Industrial Revolution

The British industrial revolution signed as the occurrence and lucrative application of the nascent technology relied on the economic system around textile industry, which was composed of three primary elements: market organizer, market and specialization. As shown by Fig. 1, the circular causality among specialization, market expansion, roundabout production, invention and innovation constructed the cybernetic system of industrialization which operated through interplay between two categories of growth model: Smith-Young growth and Schumpeterian growth. The former incentivizes invention through the interaction between deep specialization and market expansion, while the latter emphasizes the core role of market organizers in market establishment and technological implementation. Based on the Smith-Young theorem that the specialization is limited by the extent of the market and vice versa, the theory interpretes invention and economic growth from the interaction between specialization and market expansion

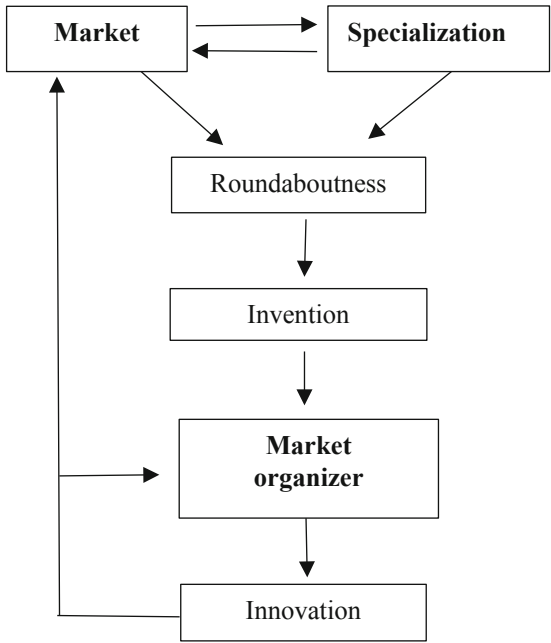


Fig. 1. Positive feedback between Smith-Young growth and Schumpeterian growth

(Smith, 1776; Young, 1928) [21] [29]. Schumpeterian growth portrays the progress as creative destruction promoted by entrepreneurs with the widespread substitution of new production function and organization for the outmoded one (Schumpeter, 1934) [10].

However, two significant theories are both problematic but supplementary. Smith-Young growth accounts for the birth of inventions in micro level but fails to elaborate how the division of labor and market are evolved. On the contrary, Schumpeterian growth accentuates the role of entrepreneurs in the rise of industry and the promotion of new technology. Yet, it misunderstands the innovation as accident and omits the previous accumulation, as most market organizers are not the direct inventors but only the promoters (Jia, 2011) [12]. Additionally, as neo-Schumpeterian economists criticized, in spite of the universal definition of entrepreneur who accomplishes the innovation, Schumpeter underplays the role of government in economic organization.

3.1 Schumpeterian Growth: Role of Market Organizer in Creative Destruction

Creative destruction refers to the metabolic change in numerous economic aspects brought by the extensive application of new technology. The Schumpeterian growth emphasizes the significance of entrepreneurs who participate and promote the innovation. The research extends the definition of entrepreneur to market organizer including government and entrepreneurs. The former is responsible for the stable environment and the rise of the industry. First, the economic prosperity is susceptible to the turbulence such as war and thus establishing a peaceful environment is critical for successful industrial upgrade (Chen, 2016) [7]. In addition, the economic system of textile industry would not be constructed spontaneously without the dedication of organizers. The government should enforce the industrial policy to get rid of the path dependence on the low-value added engagements and to create profitable opportunity for domestic merchants. List (1884) [13] corroborates that the economy in *laissez-faire* based on the comparative advantage would be fallen in the vicious positive feedback of poverty. The excessive reliance on agriculture and luxury industry for Eastern Europe and Spanish respectively resulted in their stagnation (Wallerstein, 2011) [24].

Beside government, Merchants with entrepreneur spirit engage in the exploration of market and the commercial promotion of the innovative technology. They seek for the business opportunities by arbitraging and thus link the dispersed rural area together to establish the uniform market network which facilitates the regional specialization. The international network concerning supply chain, transportation and financial credit system, therefore, could be built to drive the business efficiency. Moreover, entrepreneurs matched the supply and demand to unearth the business value of the invention and popularized them. For instance, they also took an essential action as the sponsor of technicians such as Watts subsidized by Boulton.

3.2 Smith-Young Growth: Specialization and Market

The rationale of Smith-Young growth was particularized as follows: the interaction between specialization and market expansion provided the momentum for economic growth. Adam Smith perceived the division of labor as the origin of growth for three reasons: (1) dexterity improvement (2) saving time of changing different works (3)

invention and application of machinery (Smith, 1776) [21]. However, he also summarizes that the division of labor is limited by the extent of the market, for the market scale restricts the power to exchange for other necessary products and to sell producers' own surplus. Hence, only market expansion could lead to the economies of scale and deepen specialization.

Nevertheless, Ally Young pointed out the fallacy of Smith that the specialization also has potential to broaden the market scope (Young, 1928) [29]. First, the productivity and real income enhancement brought by specialization could raise up labor's purchasing power to consume. Second, the deep specialization would generate the roundabout methods of production that bred the likelihood of innovation. The roundaboutness refers to the stretch of production where producing means of production was produced first, with the assist of which, final commodity was processed. The Jenny machine as a roundabout invention, for instance, was created firstly and then was utilized to weave cloths. The long-term specialization motivates the worker to design the machine which increased the market competition of products by learning by doing.

3.3 Positive Feedback Between Smith-Young and Schumpeterian Growth

The positive feedback mechanism was maintained by the interplay between the technological inventions and their application led by market organizers. As the nucleus of the system, market organizers are responsible for Schumpeterian growth by exploring the market for the industry, promoting innovations and connecting the two sorts of growth path. Smith-Young growth reflects that with the market establishment the roundabout production involving the invention of intermediary tools including machines and vehicles is derived from deep specialization and expansive market demand. The originalities conducive to increase productivity or save the time of transportation cater for the consumers and hence have tremendous commercial value to win the larger market share after the entrepreneurs apply them in the production. Furthermore, the widespread spread of new technology would broaden the market scope further and generate spillover effects to burgeon relevant industries by enlarging roundaboutness and hence repeating the circular growth path. The benefits of steam engine would spill over to the prosperity of the coal industry, for instance. Ultimately, the positive feedback between Smith-Young and Schumpeterian growth injects incessant momentum for industrialization.

3.4 Uniqueness of Textile Industry

The straits of textile industry in favor of the positive feedback growth should be stressed. Three major advantages of the textile industry could demonstrate its fundamental role (1) First, clothes or fabrics supplied by the industry are necessities for daily life and therefore have imperfectly elasticity of demand. (2) Additionally, the sophisticated production of textiles could be easily divided into numerous procedures including rinsing, carding, spinning, weaving and dying, which incline to accelerate the specialization and increase productivity. (3) Furthermore, the textile industry has the feature of economies of scale, which means that constant enlargement of the market scale is profitable because of the huge fixed cost of capital investment.

4 The First Stage: Organization of the System (The Rise of the Textile Industry)

As the engine of the industrial revolution, the British textile industry had been depressed for long period instead. The production of textiles was mainly comprised of two procedures: acquisition of raw materials and then weaving them into cloths. The wools or cottons were major sources of the material of textiles. England was a conventional exporter of wools with the factor endowments of Lindsey sheep and exchanged for cloths in Flanders. In contrast, due to the climatic limitation, cottons were mainly acquired from overseas, especially America, India and Egypt. Moreover, the world textile market in the era was dominated by the Indian textiles with high-quality cotton and subtle hand-craft (Beckert, 2014) [3]. Postan (1952) [19] describes that there were only 7 weavers in Oxford in 1290 and no successors after they died. In the meanwhile, only one artisan was in Lancaster in 1322 and no worker was in factory of Lincolnshire. Domestic cloth industry was squeezed by the foreign competition until the British government and entrepreneurs contributed to mercantilism, war capitalism and proto-industrialization which reversed the dilemma by exploiting the domestic and foreign market for British cloths.

4.1 Mercantilism

Mercantilism refers to the protective trade policy implemented by the government to buttress the domestic weaving industry. The Hundred Year's War between England and France in Flanders forced the former to get rid of reliance on the textile imports from the latter. British kings regarded the export tax on wools as an efficient measure to raise military expenditures and exert economic threaten on its enemies. When the war broke out in 1337, Edward III enforced people in England to wear domestic cloths and prohibited import of foreign fabrics (Thompson, 1928) [22]. The subsequent kings kept imposing the high export duties on wools until the end of industrial revolution. The tax was more than 40 to 50 shillings for domestic exporters and 4 lb for foreign ones. The Table 1 shows the effectiveness of the protective policy: the annual cloth exports increased from 4423 cloths on the outset of mercantilism to 120 thousand cloths at the end of 16th century while the wool exports decreased sharply. England had transferred from the net importer to the net exporter of cloths as a result of the protectionism which paved way for the proto-industrialization in 17th century.

Table 1. Annual British exports of wools and cloths from 14th century to 16th century

	1347–1348	1392–1395	15 th century	16 th century
Wool (sacks)	30,000	19,000	8000	-
Cloth	4423	43,000	54,000	120,000

Source: Postan (1952) [19]

4.2 Proto-industrialization

With the rise of textile industry owing to mercantilism, proto-industrialization as the first-stage of industrialization was campaigned and built the market network in the rural area (Mendles, 1972) [14]. The putting-out system in rural industrialization separating the production and sales was efficient to save the cost of production and extend the market. First, there were numerous surplus cheap labors especially in the slack season and the natural condition with many hills and rivers scattering in the countryside provided abundant hydraulic power for application of machines in rinsing, dyeing and weaving (Postan, 1952) [19]. Moreover, merchants eliminated the market barriers among villages by long-distance trade and facilitated the specialization of the manual cottage in the uniform domestic market. The extension of the market also stimulated the consumption, for the villagers were both producers and consumers could which gained higher income and hence had higher purchasing power.

4.3 War Capitalism

War capitalism based on the colonization aimed to expand the international market for British textiles by controlling places of origin of cottons, stifling foreign textile industry and dumping domestic manufactured cloths (Berkert 2014) [3]. The chartered companies like East India Company had conquered British major competitors and grabbed their market share. As the previous dominator of textile trade, India was prevented from exporting dyeing cloths in 1701 and their fabrics were entirely banned in England in 1721. Moreover, when it was colonized in 19th century, only planting cotton was allowed, whereas the textile industry was removed radically. As a result, the export of British textiles doubled and the contributed proportion of cloth industry rose from 2.6% to 22% in 18th century (Berkert 2014) [3].

5 The Second Stage: Operation of the Cybernetic System (Popularization of Machine, Railway and Fossil Fuels)

Commercial applications of machine, railway and coal were three crucial signals of the industrial revolution. The early-stage preparation laid the foundation for the economic system with the development of the domestic textile industry. Firstly, the business network of the domestic and international textile market was established by Mercantilism, war capitalism and proto-industrialization. Subsequently, the market extension facilitated the regional division of labor engaging in the production of cloths, while specialization also boosted the market demand, because the productivity enhanced owing to division of labor increased the purchasing power and also consumption. According to North (1973) [17], the British real wage grew by around 20 percent from 1600 to 1700. As Vries (1992) [23] defined as the industrious revolution, there was the virtuous circle of intra-household allocation concerning the increase of both labor supply to produce commodities and the demand for supplied goods.

The deep specialization and the extensive market demand begot the roundabout methods of production which bred the likelihood of Schumpeterian creative destruction.

Furthermore, the widespread application of new technology would generate spillover effects to burgeon relevant industries by increasing roundaboutness and hence replicating the circular growth path. The three representative innovations were all intermediary vehicles rather than the final consumed goods. The experience-based observation and reflection in the specialized production motivated textile workers represented by Arkwright, Hargreaves and etc. to refine the tools or design the machines. Additionally, the entrepreneurs like Roebuck and Boulton discerned the potential market value of steam engine and spared no efforts to favor Watts' research and promote the mature products. Moreover, the innovation of steam locomotive by Stephenson and development of railway network responded to the demand for time-saving long-distance transportation with the extension of the textile market scope. Therefore, the coal as the necessary energy source of the steam engine was widely utilized. Wrigley (2010) [27] claims that the annual growth rate of the coal consumption was only 1 percent during 200 years spanning from 1600 to 1800, while it soared to be 8.5 percent from 1850 to 1860 after the industrialization. The implementation of new machines and technology lowered the price and broaden the market scope further, launching a new round of feedback loop. Harley (2010) [11] demonstrates the substantial dip of cloth price by 50 percent amid the industrial revolution from 1780 to 1830, which indicates the incessant technological progress, specialization and economies of market scale. Overall, the positive feedback loop maintained the sustainable dynamics for industrialization and even the next industrial revolution.

6 Comparative Research

6.1 France

France lacked eminent organizers to achieve the precondition for the industrial revolution. Although French government had persisted the Colbertism that imposed the trade protection on domestic textile industry, the development was hindered by the frequent wars and fragmented market (Chang, 2003) [6]. England maintained the sustainable domestic peace after the Glorious Revolution, whereas France suffered from consecutive wars which demolished the economic accumulation, especially during the critical period after the French Revolution when England was experiencing the industrial revolution. Consequently, North (1981) [16] stresses that the French king had to levy heavy tax to raise up military expenditure and grant the noble with power of taxation. The advocacy of tax farming and establishment of 'five great farms' controlled by the noble circumscribe the unified market (Wallerstein, 2011) [25].

6.2 Netherland

With abundant peat, advanced financial system, joint-stock company, leading textile technology and global trade network, Netherland was caught up by England since it ignored the importance of cloth industry and mercantilism. Depending on free trade policy, fishing and boat industry, the country could not foster the modern industrialization. Ultimately, it was defeated by England in Anglo-Dutch Wars and thus lost the control of international trade and world market after signing up Navigation Act.

6.3 Spain

Similar with England, the sheep husbandry was thriving in Spain with the well-known merino wool. Nevertheless, to guarantee the fiscal revenue, the Spanish king entitled the Mesta, the organization of shepherds, with the monopolistic privilege because it charged 30 percent of the aggregate taxation (Thompson, 1928; North, 1973) [22] [17]. The path dependence on wools of Mesta restrained the development of cloth industry.

6.4 Eastern European Countries

The East Europe was diverged in the global specialization dominated by the west and became the semi-peripheral area (Wallerstein, 2011) [24]. The government failed to adopt the and brought the industrial upgrade so that the specialization in agricultural solidified the serf system curbing the industrialization.

6.5 India and Other Asian Countries

In spite of the prosperity of conventional textile industry, there was no powerful government and entrepreneurs to explore the market and spur the domestic industrialization to strengthen the military force. Consequently, these areas were colonized and lost the autonomy of industrial development.

7 Conclusion

In conclusion, the paper has corroborated that the reason why England took the leading position in accomplishing the industrial revolution as a transformation of technological application was that it firstly erected the economic system around textile industry available for the virtuous positive feedback between Smith-Young growth and Schumpeterian growth. The system consisted of market organizer, uniform market and specialization. The Smith-Young growth incentivized invention through the interplay between deep specialization and market expansion, while the Schumpeterian growth emphasized the core role of market organizers in market exploration and technological application. The economic transition was achieved by the interplay between the technological inventions and their commercial promotion promoted by market organizers. In the first stage regarding the system organization, the market organizers including British government and entrepreneurs exploited the market for domestic textile industry by mercantilism, war capitalism and proto-industrialization. Consequently, the interaction between market expansion and deep specialization incentivized experience-based inventions through roundabout method of production in textile industry in the second stage. The entrepreneurs then applied them widely whose spillover effects boosted related industries and further broadened the market scope. Eventually, the dynamic positive feedback loop among specialization, market expansion, and market organizers catalyzed the popularization of machine, railway and fossil fuels and the arrival of the industrial age in England. The British competitors lagged behind since the unqualified market organizer, fragmented market or ignorance of developing textile industry circumscribed

the positive feedback mechanism of growth despite possessing a few significant factors. However, since most of the inventions in the first industrialization were experience-based, the research does not delve into the significance of the scientific research.

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