Technology and theories of economic development: Neo-Schumpeterian approach (Techno-economic Paradigms)

(Structural Crises of Adjustment. in G. Dosi et al. (eds.), Technical Change and Economic Theory. London: Pinter, pp.38-66)
The Waves of Technological Change

- Kondratieff (1925): roughly half century phases of development as cycles
- Schumpeter (1939): these long waves were due to the introduction of major new technologies into the economic system
- Each business cycle was unique because of the variety of technical innovations as well as the variety of other historical events such as wars
- The ability and initiative of entrepreneurs created new opportunities for profits which in turn attracted imitators and improvers to exploit the new opening with a wave of new investment, generating boom conditions
- The “successive industrial revolutions” were based on the qualitative transformation of the economy by new technologies rather than the simple quantitative growth of individual industries
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The Waves of Technological Change

• Techno-economic Paradigm
  – The new paradigm (pattern) develops over a long period before it becomes dominant
  – It embraces many radical and incremental innovations
  – It is subjected to selective economic pressures
  – It interacts with fundamental science and responds to the limitations of the established technologies and business organizations
  – At the end, it crystallizes as the new common sense of engineers, designers and managers
Early Mechanization Kondratieff

• 1780s-1840s: Industrial revolution
  – factory production for textiles
• Science technology, education and training
  – Apprenticeship, learning by doing, scientific societies
• Transport-communication
  – Canals, carriage roads
• Energy systems
  – Water power
• Universal and cheap key factors
  – Cotton
Early Mechanization Kondratieff

• 1770s & 1780s to 1830s & 1840s
• **Upswing:** Industrial revolution
• **Downswing:** Hard times
• **Main carrier branches and sectors:** textiles, textile chemicals, iron-working, water power, potteries
• **Infrastructure:** canals and roads
• **Key factor industries offering abundant supply at descending price:** cotton, pig iron
• **Other sectors growing from small base:** steam engines and machinery
• **Organization of firms:** individual entrepreneurs and small firms, local capital and individual wealth, partnerships between financial managers and technical innovators
Early Mechanization Kondratieff

- Limitations of previous paradigm: scale and process control in domestic system, hand-operated tools and processes
- Solutions which new paradigm offers: mechanization and factory organization
- Technological leaders: Britain, France, Belgium
- Newly industrializing countries: German states
- National regime of regulation: breakdown of privileges on trade and competition, laissez-faire
- International regime of regulation: emergence of British supremacy in trade and international finance
- Features of national systems of innovation: learning by doing, local scientific and engineering societies, reform of patent systems
- Other sector developments: rapid expansion of trade, merchants as source of finance
Industrial Revolution

• Adam Smith: *Wealth of Nations*

• Why British standard of living was higher than in other European countries?
  – The growth of national income due to agricultural productivity
  – Manufacturing industry and trade

• The division of labor in manufacturing facilitated the use of new machines and the accumulation of specialized skills

• The opening of markets enabled these manufacturers to compete, to enlarge their market
Industrial Revolution

- Technical change, capital accumulation and specialized skills
- The embodiment of inventions in new machines through capital investment
- A fundamental organizational change from a system of cottage production of textiles to a system of factory production with political change and cultural changes
- Acceleration of British industrial output, investment and trade in the last two decades of 18th century
- The manufacturing industry and the transport infrastructure as well as agriculture
- Social and economic changes in agriculture was one of the main factors facilitating mobility of labor and capital
Industrial Revolution

- Not balanced growth of all industries but rapid growth of a few leading sectors, the cotton industry and iron
- Big increases in productivity based on system of factory (mill) production
- The improvements in process technology made possible the rapidly falling prices which in turn provided competitive strength for British exports to undercut Indian and other Asian textiles
- Exports of cotton textile increased
- The speed with which inventions became innovations
- The inventions were incremental improvements to existing processes and products that were often made by workers
Industrial Revolution

• Innovations in the cotton industry was time-saving that also resulted indirectly to savings in capital, labor and land

• The capital accumulation through a developed capital market, the wealthy class of landlords and family

• The coal-mining regions, the new industrial textile regions, the ‘village industries’

• The manufacturing interests also determined government policy, merchant and landed interests, “bourgeois”

• Inventor-entrepreneurs
  – Wedgwood in pottery industry
Industrial Revolution

• The cotton industry: Arkwright and Crompton
• Hand spinners to spinning mill
• Arkwright’s spinning frame
  – Protect his leading position through patent applications, design and market innovations
  – For large-scale machine production collaborated with a partner
  – Entrepreneurial advantages
• Crompton’s mule
  – Technical advantages
  – Problem in financing the costs of his invention
• The source of power was slowly shifting to steam engine
Steam Power and Railway Kondratieff

• 1840s-1890s: Age of steam power and railways

• Science technology, education and training
  – Professional mechanical and civil engineers, institutes of technology, mass primary education

• Transport-communication
  – Railways (iron), telegraph

• Energy systems
  – Steam power

• Universal and cheap key factors
  – Coal, iron
Steam Power and Railway Kondratieff

- 1830s & 1840s to 1880s & 1890s
- **Upswing**: Victorian prosperity
- **Downswing**: Great depression
- **Main carrier branches and sectors**: steam engines, steamships, machine tools, iron, railway equipment
- **Infrastructure**: railways, world shipping
- **Key factor industries offering abundant supply at descending price**: coal, transport
- **Other sectors growing from small base**: steel, electricity, gas, heavy engineering, synthetic materials
- **Organization of firms**: larger firms employing hundreds, limited liability and joint stock company, small-firm competition
Steam Power and Railway Kondratieff

- **Limitations of previous paradigm**: water power in terms of inflexibility of location, scale production, reliability and range of applications
- **Solutions which new paradigm offers**: steam engine and new transport system
- **Technological leaders**: Britain, France, Belgium, Germany, USA
- ** Newly industrializing countries**: Italy, Netherlands
- **National regime of regulation**: Laissez faire
- **International regime of regulation**: ‘Pax Britannica’, international free trade, gold standard
- **Features of national systems of innovation**: growing specialization, development of professional education, internationalization of patent system
- **Other sector developments**: growth of domestic service, transport, distribution, financial services, universal communication services
Electrical and Heavy Engineering Kondratieff

• 1890s-1940s: Age of electricity and steel
• Science technology, education and training
  – Industrial R&D labs, chemicals and electrical, national laboratories
• Transport-communication
  – Railways (steel), telephone
• Energy systems
  – Electricity
• Universal and cheap key factors
  – Steel
Electrical and Heavy Engineering Kondratieff

- 1880s & 1890s to 1930s & 1940s
- **Upswing:** Belle époque
- **Downswing:** Great depression
- **Main carrier branches and sectors:** electrical engineering, electrical machinery, heavy engineering, steel ships, heavy chemicals
- **Infrastructure:** electricity supply and distribution
- **Key factor industries offering abundant supply at descending price:** steel
- **Other sectors growing from small base:** automobiles, aircraft, telecommunications, radio, aluminum, consumer durables, plastics, oil
- **Organization of firms:** emergence of giant firms, monopoly and oligopoly, concentration of banking and finance capital
• **Limitations of previous paradigm:** iron in terms of strength and durability, inflexible belts

• **Solutions which new paradigm offers:** group drive for electrical machinery, power tools, standardization in worldwide operations

• **Technological leaders:** Germany, USA, Britain, France

• **Newly industrializing countries:** Italy, Canada, Japan

• **National regime of regulation:** nationalist state, social legislation, growth of state bureaucracy

• **International regime of regulation:** imperialism and colonization, destabilization of international financial and trade system

• **Features of national systems of innovation:** ‘in-house’ R&D, university scientists

• **Other sector developments:** domestic service industry, department and chain stores, education, tourism and entertainment
The Age of Electricity and Steel

- So far → Inventor- entrepreneur, invention coupling with a potential market defined as innovation, specific innovations
- Systemic aspects of innovations and the linkages between various industrial sectors
- Leading sectors, steel and electricity, had linkages with almost all other industries
- US imported much of its technology from Europe but modified and reshaped to national circumstances
- British colony: transfer of innovative thinking and institutions
- Higher relative price of labor interacted with the resource abundance advantage to induce substitution of capital and natural resource inputs for skilled labor
- Labor-saving, capital-intensive technological trajectory of mechanization and standardized production
The Age of Electricity and Steel

• Development of new production techniques in steel led to large-scale production and usage, reduction in the costs and application in many new products
• The interdependence of developments in steel and electrification
• A wide range of new applications: machinery, electric furnaces, electrical transformers, generators, stainless steel, consumer goods like cans, bicycle, construction
• The complementarities between innovations affecting every branch of industry and services
• The applications of electrification started in 1860s but diffusion with further series of inventions in steel
• The role of laboratory science in the development of electricity was important
The Age of Electricity and Steel

- The electric power generation for tramways and electric railways, communication, lightning, industrial applications in electrochemistry, wire and copper, aluminum industry, electric engines, electric phones
- The new investment opportunities based on cheap steel and electric power, new infrastructure, new regulatory framework
- The new flexible source of energy overcome the inflexibility of the old system (steam engine) saving energy and factory floor space
- Giant firms (Germany: Siemens and AEG, US: General Electric and Westinghouse) (capitalist enterprise) and management innovation (office organization, professional manager)
- The emergence of specialized R&D department in electrical and chemical firms
Fordist Mass Production Kondratieff

• 1940s-1990s: Age of mass production (Fordism) of automobiles and synthetic materials
• Science technology, education and training
  – Large-scale industrial and government R&D, mass higher education
• Transport-communication
  – Motor highways, radio and TV, airlines
• Energy systems
  – Oil
• Universal and cheap key factors
  – Oil, plastics
Fordist Mass Production Kondratieff

• 1930s & 1940s to 1980s & 1990s
• **Upswing**: Golden age of growth and Keynesian full employment
• **Downswing**: Crisis of structural adjustment
• **Main carrier branches and sectors**: automobiles, trucks, aircraft, consumer durables, process plant, synthetic materials, petrochemicals
• **Infrastructure**: highways, airports, airlines
• **Key factor industries offering abundant supply at descending price**: energy (especially oil)
• **Other sectors growing from small base**: computers, drugs, nuclear weapons and power, microelectronics, software
• **Organization of firms**: oligopolistic competition, multinational corporations based on FDI, increasing concentration, ‘techno-structure’ in large corporations
Fordist Mass Production Kondratieff

- **Limitations of previous paradigm:** batch production
- **Solutions which new paradigm offers:** assembly line production techniques, new patterns of industrial location, cheapening of mass consumption products
- **Technological leaders:** USA, Germany, Japan
- **Newly industrializing countries:** Korea, Brazil, Mexico
- **National regime of regulation:** welfare state, high levels of state expenditure and investment, Keynesian techniques
- **International regime of regulation:** ‘Pax Americana’, US military and economic dominance, decolonization, Cold War, US dominating international trade and financial regime
- **Features of national systems of innovation:** specialized R&D departments, military R&D, technology transfer through licensing
- **Other sector developments:** decline of domestic service, self-service, researchers and financial services
Information and Communication Kondratieff

• 1990s-: Age of microelectronics and computer networks
• Science technology, education and training
  – Data networks, R&D global networks, lifetime education and training
• Transport-communication
  – Information highways, digital networks
• Energy systems
  – Gas, oil
• Universal and cheap key factors
  – Microelectronics
Information and Communication Kondratieff

- 1980s & 1990s ?
- **Upswing:**
- **Downswing:**
- **Main carrier branches and sectors:** computers, electronic capital goods, software, telecommunications equipment, robotics, information services
- **Infrastructure:** digital, telecommunications, network, satellites
- **Key factor industries offering abundant supply at descending price:** chips (microelectronics)
- **Other sectors growing from small base:** ‘third generation’ biotechnology products, space activities, fine chemicals
- **Organization of firms:** networks of large firms based on computer, just-in-time production
Information and Communication Kondratieff

• **Limitations of previous paradigm:** inflexibility of assembly line, energy and material intensity

• **Solutions which new paradigm offers:** electronic control systems, networking and integration of design, production and marketing

• **Technological leaders:** USA, Japan, Germany

• **Newly industrializing countries:** Brazil, Mexico, China

• **National regime of regulation:** regulation of ICT, regulation of financial institutions and capita markets

• **International regime of regulation:** ‘multi-polarity’, institutions

• **Features of national systems of innovation:** computer networking and collaborative research, factory as laboratory

• **Other sector developments:** ICT, integration of services and manufacturing in publishing, growth of information services