DEVELOPMENT AND UNDERDEVELOPMENT: 1500 — 2000

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Abstract. The paper develops a two-country model of economic growth through endogenous technological change in the context of world trade. The model shows that under free trade multiple steady states, corresponding to development and underdevelopment, emerge as a consequence of the endogenous allocation of innovation sectors between countries, and positive innovation externalities between sectors. The main economic forces in the model are the disadvantage of trade specialization for innovation, and convergence through the transfer of ideas. The model is applied to explain the broad outlines of the history of development and underdevelopoment over the period 1500-2000, including the joint emergence of development and underdevelopment, their persistence, and the phenomenon of miracle growth as the characteristic route to development.

1. Introduction

What is underdevelopment? Low levels of income and health, poverty, poor institutions, backward technologies... most descriptions and explanations focus on *levels* of wealth and wellbeing. Here we take a more dynamic point of view, asking what holds back change. Underdevelopment can only be understood in relation to development. It appeared as a consequence of the Industrial Revolution. It is in a sense as a defective capitalism — a form of organization itself characterized by its dynamism. Underdevelopment is almost — but not quite, a failure to be engaged in this dynamism, or this dynamism gone wrong.

Underdevelopment is a long-term phenomenon, one of the most persistent in economics. Many countries have been underdeveloped for two hundred years — since the Industrial Revolution. Before that, all countries were poor, but we cannot talk of underdevelopement. And yet other countries have achieved development in two or three decades of rapid growth and transformation. How can this be?

Since about 1500, the Great Discoveries brought on an age of ever closer global contact, that began with trade and colonialism, themselves closely linked with economic growth and with underdevelopment. After the Industrial Revolution, the Great Divergence of per-capita incomes took place during the 19^{th} Century (Pritchett, 1997). This occurred during the "First Great Age of Globalization," approximately 1820 to 1914. After 1945, growing trade and later globalization have characterized the development of the capitalist world. Thus world trade and globalization have been the context of development and underdevelopment since its origins. The main protagonist has been innovation, which according to Schumpeter (1911, 1934, 1942) is the main source of capitalism's dynamism. Indeed,

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Preliminary and Unfinished Version.

two decades of recent empirical and theoretical studies on cross-country economic growth show that differences in per capita incomes between countries are mainly driven by differences in technological levels. Technological change is the engine of economic growth.[1]

The main economic theses of this paper are that (1) there are multiple steady states in the dynamics of technological change, higher steady states corresponding to development and lower steady states to development; (2) there are mechanisms in trade that focus innovation in larger and more advanced countries, that is, *disadvantages of trade specialization for innovation*. Although I do not go into this in detail, I consider institutional development as one of the dimensions that is subject to and responds to incentives for public innovation.

I construct a two-country Schumpeterian model of economic growth with free trade, incorporating a disadvantage of trade specialization for innovation. The model generates multiple steady states in technological change corresponding to development and underdevelopment. These occur because when trade assigns production it also assigns innovation. Larger and more advanced countries cover a broader spectrum of production than backward and smaller countries, and therefore are assigned more innovation sectors. When there are positive innovation externalities between sectors, a *disadvantage of trade specialization for innovation* ensues. This disadvantage, and Gerschenkron's (1952) *advantage of backwardness*, a convergence force consisting of the transfer of ideas, are the main economic forces in the model. The model is applied to explain the broad outlines of the history of development and underdevelopement over the period 1500-2000, including the joint emergence of development and underdevelopment, their persistence, and the phenomenon of miracle growth as the characteristic route to development.

It is widely accepted that after the Great Discoveries trade provided important incentives for institutional development and for transportation. The main historical theses of this paper are that (3) transportation and institutional developments — including the rise of capitalism itself — increased effective market size and private innovation incentives. When these incentives rose beyond a critical threshold, they triggered the Industrial Revolution. This occurred at the principal focus of world trade, which was then Great Britain. The advent of economic specialization, the watermark of trade, was triggered jointly with the Industrial Revolution, as Britain became the Workshop of the World, trading industrial goods for raw materials and agricultural goods. (4) Specialization under trade impacted the incentives for private and institutional innovation. Some countries converged to high while others to low steady states, depending on their initial size, technological lag, institutional development and trade policies, originating the Great Divergence. For example, the disadvantage of trade specialization for innovation implies the hypothesis that India fell far behind Latin America because of its much wider openness to trade, itself imposed by Britain.

During the second half of the 19^{th} Century, railways emerged as a new mode of transportation. It is argued that railway trade foci in Germany and the East Coast of the United States contributed to the emergence of these new industrial powers during the Second Industrial Revolution. On the other hand, the model shows that for Britain, the falling behind of its empire diminished its economic potential.

[1]See Aghion, Howitt and Mayer-Foulkes (2005), Howitt and Mayer-Foulkes (2005), and Mayer-Foulkes (2006), for extensive references.

Finally, (5) during the 20^{th} Century, these multiple steady states in trajectories of economic growth persisted, punctuated by episodes of miracle growth that were characteristic of the access to development. Countries experiencing such episodes are Denmark, Sweden, Italy, Japan (Pipitone, 1995), South Korea, Taiwan, Hong Kong, Singapore, Ireland, Germany in the 19th century, Western Germany after the War, Cyprus, Iceland, Spain, Malta, Portugal, Israel. In Wan's (2004) comparative case studies of the Asian Tigers' growth experiences, the reference convergence trajectories include at least two decades of growth higher than 5%, viewed explicitly as a transition to a higher stationary state. However, some countries experienced periods of miracle growth without fully reaching development, such as Argentina, India, Nigeria, Brazil, and Mexico in the sixties and seventies (Pipitone, 1995).

The remainder of this paper proceeds as follows. Section 2 constructs first a broad and then a more detailed historical outline of economic development over the period 1500-2000, giving evidence for it. Section 3 constructs the economic model. Section 4 gives the historical application of the model. Section 5 concludes.

2. The Historical Outline

Before 1500, there was only very slow technological change and approximately equally low incomes were prevalent throughout the world. In his millennium perspective, Maddison's (2001) includes a strand on the role of financial institutions and trade in molding long-term growth, for example in the flowering of Venice from the 11^{th} to the 16^{th} Century. Although by around the year 1000 income levels in Europe had fallen from Roman times to levels below those in Asia and North Africa, they caught up with China (the world leader) in the fourteenth century (Maddison, 2001). Slow improvements in navigation technology led to the Great Discoveries. Columbus' discovery of America in 1492 and Vasco da Gama's voyage to India in 1498 opened trade between Europe, Asia and America.

I analyze the history from 1500 to 2000 in two stages. In the first, approximately from 1500 to 1750, transport technology, institutions, and other capabilities slowly developed, partly due to the incentives of trade, while the structure of production remained essentially autarchic. In the second, approximately from 1750 to 2000, global trade and specialization emerged. The initial transition occurred from about 1750 to 1820, when systematic innovation based on importing raw materials and exporting industrialized products began in Britain, the leading commercial power. World trade and the Industrial Revolution took off simultaneously. Then world incomes bifurcated. The processes of development, underdevelopment and divergence appeared and have persisted to the present day. Table 1 outlines the characteristics of these stages from this point of view.

2.1. **1500-1750: Foundations of Global Trade.**

The economic incentives generated by trade in the Age of Discovery modified the course of European history. Commercial dominance shifted from Venice and other Italian cities to Atlantic countries (Findlay and O'Rourke, 2002). Portugal, Spain, Holland and Britain became dominant colonial and commercial powers in turn. In the process, they engaged in a navigation technology race and, to make trade feasible, developed military power, financial institutions, and integrated their economies.

Columbus' and da Gama's voyages of discovery were motivated by the spice trade. Da Gama's arrival in India in 1498 and its conquest of Malacca in 1511

opened the way for Portuguese dominance of the spice trade until the rise of the Dutch East India Company.

Although Spain obtained a large empire, trade was not amongst its objectives, concentrating instead on extraction, mainly of silver. A series of problems including poor institutions; a complicated legal system (Coatsworth and Tortella, 2002); resistance of guilds to industrialization; and agrarian problems related to the expulsion of the Moors, led to Spanish decline over the period 1598-1700 (Vives, 1970).

After its independence from Spain in 1581, Holland gained commercial ascendancy. The Dutch East India Company, with a base in Batavia (now Jakarta, Indonesia), was founded together with the Amsterdam Stock Exchange in 1602. It was the first company to emit stocks. In 1609 the Bank of Amsterdam introduced interest bearing debt. The success of the Dutch East India Company rested on its institutional and financial innovations (Harley 2002; p. 3). In 1641, Holland acquired Malacca from the Portuguese and took control of the spice trade. The Dutch Golden Age came to end in the period of the Anglo-Dutch wars, when Dutch industrial production declined. By 1799 the Dutch East India Company, formerly the world's largest went bankrupt.

Trade and institutional development were closely intertwined in England as well. Her colonial history begins with policies by King Henry VII (reigned 1485-1509) aimed at consolidating its merchant marine system in relation to wool trade. The Commonwealth of England, unifying England, emerged in 1529-1660, together with a strengthened navy. The British East India Company was founded in 1600. The statute of monopolies (on patents) was enacted in England in 1623. As British naval power rose, Navigation acts were imposed restricting foreign shipping (1651, 1660,), leading to the Anglo-Dutch wars and eventually wresting commercial leadership from Holland. Insurance for shipping became available from Lloyd's in 1688. The Bank of England was founded in 1694. By revolutionizing the credit markets, it lowered interest rates, in turn strengthening Britain's military power, which depended on the borrowing capacity of the crown. In 1707, the Kingdom of Great Britain was consolidated. British presence in India was favored by the Moghul tax exemption in Bengal in 1717. In 1757 the British East India Company took control of Bengal, gaining supremacy in India. The Dutch East India Company, in its time the largest company in the world, began its decline. By 1799 it was bankrupt.

However, although trade rose substantially, Findlay and O'Rourke (2002) find no evidence of secular, intercontinental commodity price convergence before the 1820's. They characterize the composition of trade from 1500 to 1780 as non-competing: spices, silk, silver, slaves; goods with extremely high value to bulk ratios. O'Rourke and Williamson (2002) also consider 1500-1750 as an essentially autarchic period. Thus the period 1500-1750 can be considered as autarchic from the point of view of production.

Summarizing this period, Maddison (1982) states "the leading European countries exploited their superior technology in navigation, shipbuilding and armaments to develop international trade through monopolistic trading companies. In the earlier case of Spain, mercantile aims and colonial policy were not merchant capitalist but more akin to those of ancient imperialism. Having squeezed out the plunder, Spain declined. But in the Netherlands, France, and the UK, the overseas empire of the merchant capitalist period had a more beneficial effect on the productive capacity of the domestic economy, because it not only augmented capital resources

but helped considerably to enlarge the size of markets." Trade led to institutional development including economic integration and financial development (national union, banks, the stock exchange, insurance, patents). In the leading countries, income per capita rose through the period (Maddison, 2001).

By contrast, colonialism retarded institutional development in the colonies. In the case of colonies such as Brazil, it was only until "independence ... that the country could create its own banking system" (Maddison, 2001).

Thus, during the period 1500-1750 the foundations for global trade were established. To a great extent due to their commercial engagement, the leading countries reached higher institutional and technological initial conditions for the next period. Table 2 summarizes gives an outline of institutional innovation, hegemonic succession and trade over this period.

2.2. **1750-1914: Industrialization and underdevelopment.** Although the Voyages of Discovery led to the emergence of global trade flows, the type of goods being traded evolved only gradually in the 16^{th} and 17^{th} Centuries. At first, traded goods were 'non-competing', in the sense that they were available in some continents but not in others (Findlay & O'Rourke 2002: 7). It was only until the late 18^{th} Century that true specialization began to emerge. British firms in a few key industries developed technological superiority over producers elsewhere and captured world markets (Harley 2002: 1). Eventually, the transport revolutions of the 19th Century led to inter-continental trade in bulk commodities which could be produced anywhere, such as wheat, iron and steel (Findlay & O'Rourke 2002: 7).

Thus, the transition from autarchy to specialization in trade occurred in the second half of the 18th Century, beginning around 1750 (O'Rourke and Williamson, 2002). This transition coincides with protoindustrialization and then with the Industrial Revolutions. Trade, the division of labor, and innovation facilitated each other. The higher level of production for larger markets through trade facilitated the division of labor as reported by Adam Smith (1776). World incentives provided through trade made innovation possible in a preexisting context of specialization. Finally, innovation increased exports and made cheaper imports available.

Additional evidence for dating the regime switch in trade at 1750 is provided by an analysis of the growth rate of shipping tonnage of the British East India Company. This rose from 0.8% in the period 1610-1750 to 2.4% over 1750-1813, when the Company's monopoly ended (see Figure 1).

Table 3 gives a synopsis of hegemonies, trade, the demographic transition, and the diverse trajectories of economic growth that occurred during this period, which we subdivide into three subperiods, the Industrial Revolution from 1750 to 1820, Pax Britannica and the appearance of underdevelopment from 1820 to 1870, and the US and German overtake of Britain with the Second Industrial Revolution, 1870 to 1914.

2.2.1. *1750-1820: The Industrial Revolution.* The period 1750-1820 was one of pivotal historical change. Britain rose to colonial and naval dominance through the Seven Years' War, the Industrial Revolution, and the Napoleonic Wars. Britain emerged as a world commercial and military power, dominating the seas, and exchanging manufactured goods for raw materials. The wars also led to independence in the America's.

From the point of view of our model, we use the dates 1750-1820 for the period in which the initially leading country, Great Britain, experienced the transition from exogenous technological change to systematic innovation, and became a technological leader. The new economic dynamics became dominant by 1820, and most other countries became involved in the new dynamics of development or underdevelopment. An examination of the timing of wars, specialization, trade, industrialization, and population growth in this period shows the working of a clear logic of feasibility.

The Seven Years' War (1754 and 1756-1763) involved all major powers of Europe: Prussia, Great Britain and Hanover against Austria, France, Russia, Sweden, and Saxony. France's power in the Americas ended and Great Britain emerged as the world's leading colonial and naval power, including the strongest position within India, the "jewel" of the British Empire. Intercontinental trade in cotton with India, the pivotal sector of the industrial revolution, now became feasible. However, In Britain's American colonies, the Seven Years' War led to the formation of an army that later fought the American War of Independence (1775-1783) when Britain sought to impose new taxes.

The impact of trade on market size and on the subdivision of labor and therefore productivity, was evident by 1776. This is the publication date of "The Wealth of Nations", in which Adam Smith explains how markets coordinate the division of labor, determine wages and interest, and argues for free trade. The beginning of the Industrial Revolution is dated between 1760 and 1780 by various historians, although there was a period of protoindustrialization before, of the kind recorded by Adam Smith. By increasing market size, trade promoted "Smithian growth". This subdivision of labor then made the introduction of machines in production feasible and raised the incentives for innovation.

The leading sector of the Industrial Revolution was cotton textiles. This industrial sector was closely linked with trade. The demand for raw cotton imports into Britain and for slaves to the Americas expanded as a consequence of the innovation in Manchester in the 1780's (Findlay and O'Rourke, 2002). Cotton exports rose from 6% of total British exports in 1784-6 to a peak of 48.5% in 1834-6 (Chapman, 1999). The growth of this sector and the incentives for its increased productivity were directly linked with imports of cheap raw materials from India, while manufactured textiles were exported to Europe (Broadberry and Gupta, 2005). This sector flourished through the success of labor-saving technological progress that made unit labor costs lower in Britain than in India despite a high wage differential (ibid). A measure of the transformation of this period is given by the growth of British navigable waterways, which quadrupled between 1750 and 1820 (Girard 1966, p. 223 in O'Rourke and Williamson, 1999; canals offered a transport option 50-75 percent cheaper than roads).

The impact of the Industrial Revolution abroad was immediate. India, the most prominent open colony, lost its textile export market during this period (Clingingsmith and Williamson, 2005). Also, population growth began to accelerate in Britain, climbing to 0.9% in 1780 and 1.5% in 1820 (Wrigley, 1985).

The Napoleonic Wars (1792-1815) weakened France, and Britain, which was less severely damaged, emerged again as the leading commercial and military power. British cotton pulled decisively ahead of its Indian competition after the Napoleonic Wars (Broadberry and Gupta, 2005). Napoleon's invasion of Spain (1808) was the

turning point for independence in Latin America, all of which was free by 1825 except for Puerto Rico and Cuba. Brazil achieved independence in 1822.

2.2.2. *1820-1870: Pax Britannica: Income Bifurcation.* With the Industrial Revolution and the growth of trade, Britain became the "Workshop of the World," and capitalism fully emerged in Britain. Industrialization implied specialization wherever it spread—and equally, where it didn't—as countries traded among themselves, exchanging manufactures for primary products and vice versa. A fundamental international division of labor emerged that had not been seen before on such a scale, and also heralded the Great Divergence of incomes and productivity in the last two centuries" (Taylor, 2002: 6).

While world trade grew at a little over 1% per annum between 1500 and 1800 (O'Rourke and Williamson 2002a), it grew at around 3.5% per annum since 1820 (Maddison 1995) and through the 20^{th} Century.

Some historians (Hyam, 2002, Smith, 1998) refer to the period 1815 to 1914 as Britain's "imperial century." During this period 10,000,000 square miles of territory with a population of roughly 400 million people were *added* to the empire. By 1922, the British Empire held sway over about 458 million people, one-quarter of the world's population (Maddison, 2001) and covered more than 13,000,000 square miles, approximately a quarter of Earth's total land area (Ferguson, 2004). The steamship and the telegraph, invented in the second half of the 19^{th} Century, underpinned British imperial strength; and "the sun never set on the British Empire."[2]

Even so, one of the lessons Britain had drawn from the independence of the US had been that free trade and "informal empire" could be more profitable than colonial rule and its costs of defense and administration. The slave trade was abolished in 1807 and slavery in the colonies in 1833. Britain granted self-government to white settler colonies such as Canada and Australia. Free trade, following the thought of Adam Smith and David Ricardo, was established in 1846 with the derogation of the Corn Laws, import tariffs first enacted in 1815 to protect British farmers and landowners against cheap grain imports. Average per capita income growth rose from 0.25% over the period 1700-1820 to 1.25% per year. Britain dominated overseas markets and favored a strategy of informal colonialism, epitomized by the opium wars, 1839-1842 and 1856-1860. China was forced to sign trade treaties with England, Germany, Russia, Japan, and the United States, and suffered two extreme famines twenty years after each opium war in the 1860s and 1880s.

Gunboat diplomacy was also used by the United States on Japan. Commodore Perry arrived at Uraga Harbor in Kanagawa Prefecture in 1853; superior military force enabled him to negotiate a treaty allowing American trade with Japan, ending a 200-year period in which trading with Japan was only allowed to the Dutch.

By contrast with India and China, this was a period of high tariffs in Latin America, where the newly independent states used taxes on trade to finance government.

According to our theory, Britain's trade with its formal and informal empire focused innovation in Britain. An idea of the relative size of this effect is given in Figure 2, which compares the populations of different political and economic units over the period 1700-1992, as percentages of the world population. From 1820 to 1940 Britain's *formal* empire was about the size as China's, with the US, Russia,

[2]This paragraph contains extracts from Wikipedia, http://en.wikipedia.org/wiki/British_Empire.

France, Germany and even the whole of Western Europe without the UK, and the whole of the non-colonized world, much smaller.

However, maybe the main point here in comparing Britain with China is that there was no region in China where innovation was focused. This gives a strong reason why Britain had an advantage over China for the emergence of the Industrial Revolution.

In this context of British world leadership in technology and trade, the Great Divergence took place (Figure 3, constructed using data from Maddison, 2001). The United Kingdom, Western European Countries and Western offshoots such as the US, Canada, Australia, and New Zeland, grew much faster than Eastern Europe, Latin America, and in turn these grew much faster than Asia or Africa.

Data on manufacturing provide another look at these events. This was a period of pronounced deindustrialization, as can be appreciated in Figure 4, which shows the percentage of world manufacturing output that occurred in the developed core, India, China, and the rest of the periphery.

Both Figures 2 and 3 show that the process of divergence in per capita income and of concentration of manufacturing in the developed core continued well into the 20^{th} Century.

2.2.3. *1870-1914: Second Industrial Revolution.* The Second Industrial Revolution involved the mass-scale production of steel, manufacturing technologies as well as consumption goods based on electricity, the use of chemicals in consumer goods such as paper, soaps, textiles, and fertilizer; synthetic dyes, petroleum refining. The internal combustion engine was used for factories.

During this period Germany, the United States and Japan industrialized. The first two overtook Great Britain in manufacturing output, also reducing its leadership in exports (Figures 6 and 7).

The focusing of innovation by trade is also displayed in this period of economic growth, but with a different mode of transportation. By the 1860's, railways had emerged as a primary mode of transportation. Figure 5 shows their rise in Europe, Germany's system being particularly large. In the US, there was also an enormous railway building boom from 1830 to 1870. The first transcontinental railway link was achieved in 1869. In both Europe and the US, railways replaced canals as the primary mode of industrial transportation. Railways were also important in Japan. The Tokyo-Yokohama railway opened provisionally in 1872, and by 1907, 17 private railways were nationalized.

Railways completely reshaped the geography of trade. Landmasses now served as trade catchment areas, without recourse to maritime or canal transportation, on which the British empire was based.

Germany. The German Customs Union was formed in 1834, in the first steps to German unification. This partly followed Economist Friedrich List's views on protecting infant industry to achieve the Industrial Revolution. The customs union began in Prussia in 1818 and evolved through 1888, including agreements with Luxembourg, Sweden and many other areas. The unification of Germany into the German Empire came in 1871. Also central to German economic growth was the University system. Germany invested more heavily than the British in science and pure research, especially in the chemical industry, and came to control 90% of the world's chemical market.

The United States. In the US, the American System was put in place from 1816 to 1970, but especially in the period 1861 to 1932. Here the Northern States served as a focus of trade conducted by railway, selling industrial products to the South and to the West Coast, in exchange for agricultural products such as cotton, and for raw materials. At the same time, Northern infant industry was protected from British competition. Again trade, this time domestic, focused innovation in the North.

Japan. The Japanese Meiji restoration, from 1868 to 1912, coincided with this period. During this time, Japan started its modernization and rose to world power status. Japan employed of over 3,000 foreign experts teaching English, science, engineering, the army and navy etc.; and dispatched many Japanese students to Europe and the US. It also adopted technologies from the West, and gradually took control of much of Asia's market for manufactured goods, beginning with textiles. Japan imported raw materials and exported finished products. The Meiji rulers embraced the concept of a market economy and free enterprise. Economic reforms included a unified currency, banking, commercial and tax laws, stock exchanges, and a communications network. Establishment of a modern institutional framework conducive to an advanced capitalist economy took time but was completed by the 1890s. By this time, the government had largely relinquished direct control of the modernization process, primarily for budgetary reasons. While the government was initially involved in economic modernization, after the first twenty years of the Meiji period, the industrial economy expanded rapidly. Japan emerged from World War I as a major industrial nation.

Empires. Figure 8 compares the GDP of different political and economic units over the period 1700-1992, analogously to Figure 2, which compares populations. As a proportion of world production, from 1820 to 1870 the British Empire overtook China. So did Western Europe without the United Kingdom, an approximate measure of Germany's trading area. By 1913, Western Europe overtook the British Empire, and the US almost equaled it. This is the economic basis of the main powers involved in the First World War. By 1940, the US was the foremost economic unit, followed by Western Europe and closely by the British empire. This is the economic context of World War II.

The concentration of innovation by trade referred to by the model was going on in each of these units, or "empires" Thus in each case "empire" GDP divided by home GDP gives an idea of the multiplier effect that was contributing to each home country's rate of technological change. Figure 9. shows these multipliers for the British empire in relation to Britain and for Western Europe in relation to Germany. According to this measure, while Britain had an evident advantage in 1820, by 1870 Germany's trade with Western Europe had more punch than the British empire's with Britain. In 1913 the two multipliers were approximately equal.

Indeed empire, a source of raw and agricultural materials as well as markets, was viewed at the time as an important determinant of economic growth, prosperity and power on the global scene. The scramble for Africa beginning in the 1880s and lasting until 1914 illustrates this point.

2.3. **World Wars and interwar period.** World War I was in some sense the climax of colonial competition. Empires viewed themselves as competing economic and military entities and antagonism and conflict was the result. After World War I, there was no clear hegemony. Europe was devastated by war. In the US, first there

was economic growth (the Roaring Twenties; boom in the automobile industry), but then came the Great Depression in 1929. In Germany, the Weimar Republic gave way political and economic turmoil, the German hyperinflation of 1923 and later the rise of Nazism. In Asia, Japan became an ever more assertive power, especially with regards to China. Other powers were the Soviet Union and Mussolini's Italy. Meanwhile in the United States there was a resurgence of isolationism.

Globalization retreated in the interwar period. There were no major emergences into development during this period and country's developed and underdeveloped status persisted through it.

2.4. **1945-2000: US Hegemony.** After World War II the US emerged as the leading capitalist country. With the weakening of Great Britain, colonialism entered its decline. Most colonies gained independence by the 1960's. The era of competing empires gave way to the Cold War between the United States and the Soviet Union, and their respective allies.

2.4.1. *1945-1989: The Cold War.* Observing that the retreat from free trade had tended to antagonism and conflict, after World War II the leading powers sought to reconstruct multilateral free trade. At the July 1944 Bretton Woods Conference, 44 Allied nations signed agreements to set up the International Bank for Reconstruction and Development (IBRD, the original institution of the World Bank Group); the General Agreement on Tariffs and Trade (GATT, precursor of the World Trade Organization); and the International Monetary Fund (IMF).

In Europe, economic union was also used to promote economic growth as well as preserve and foster peace. The Marshall Plan was put into place to reconstruct Western Europe. The European Coal and Steel Community (1951) was formed, followed by the European Economic Community (1957). West Germany experienced miracle growth and Europe as a whole achieved an average growth rate of 3.9% per year over the period.

The United States also enjoyed an unprecedented period of internal growth and prosperity with the baby boom generation.

However, during the period underdevelopment and divergence persisted for 168 countries (Maddison, 2001). At the same time, miracle growth was experienced in Japan, Hong Kong, Taiwan, Korea, Israel; and fast growth in Cyprus, Spain, Portugal, Malta, Ireland and Iceland.

2.4.2. *1989-2000: Global Capitalism.* Several events contributed to produce a single global market. The Berlin Wall fell in 1989, ending the Cold War. China had began to introduce market mechanisms in its economy in December 1978. The Western economies were faced with the stagflation crisis of the 1970's and the first oil crisis. This led to the freeing of trade and investment by Ronald Reagan and Margaret Thatcher, and the emergence of liberalization and new classical economics. The Washington Consensus (a term coined in 1989) implemented a standard liberalization reform package in any developing country that faced a crisis. The World Trade Organization was established in 1995.

The combination of events sparked a new era of globalization and restarted economic growth. Between 1983 and 1998, foreign direct investment grew at an average rate of 29% per year. The European Union was formed in 1992, and European and US grew at an average rate of 1.9% per year.

Transport and communications technologies continued to play important roles, for example containerized shipping and the internet.

Results in economic growth and development were mixed in underdeveloped countries. There was fast growth in China and India; Latin America had mixed results; Africa stagnated.

3. The Model

The Schumpeterian model presented here builds on a series of papers. These first introduce endogenous technological change in the theory of economic growth (Aghion and Howitt, 1992); then show that technological transfer can induce convergence (Howitt, 2000); and finally go on to address problems generating divergence and underdevelopment. These include human capital thresholds for R&D can separate implementing from R&D countries into convergence clubs and explain long-term divergence (Howitt and Mayer-Foulkes, 2002); financial development can determine technological absorption rates and also explain long-term divergence (Aghion, Howitt and Mayer-Foulkes, 2005). The cited papers may be consulted for further discussion of endogenous technological change. The present paper moves beyond closed economies and includes trade. It shows how disadvantages to innovation under trade specialization can arise and generate convergence clubs and divergence.

3.1. **Production.** Country 1 and Country 2 produce a continuum of tradeable goods indexed by $i \in [0,1]$, where each i refers to a sector.

There is a single innovator in each sector who invests in innovation, innovates with certainty, and becomes a national or world monopolist, under autarchy or trade, producing in the presence of a competitive fringe. The character of domestic innovation races will be described below. Under trade, however, there will be no international innovation races, because when comparative advantage assigns production it will also assign an advantage in innovation competition.

To introduce comparative advantage, I use two variables $\eta_1, \eta_2 \in [0,1]$ to enumerate the production sectors, with $\eta_1 = 1 - \eta_2$. Comparative advantage will be described by a sector-specific productivity fixed effect that will be a descending functions of variables η_1, η_2, in opposite directions for each country. Domestic production in Country j is on sectors $\eta_j \in [0, \xi_{jt}]$, where ξ_{jt}, $j = 1,2$ refers to the same sector, a boundary sector endogenously determined by trade, with

$$\xi_{1t} + \xi_{2t} = 1. \tag{3.1}$$

Under autarchy, all goods are domestically produced and each economy produces in all sectors. We return to this case presently. Under free trade, in every sector innovators produce monopolically supplying, world consumption and innovation investment. The variables ξ_{1t}, ξ_{2t} designate the boundary sector but are also measures of the set of domestic sectors.

Let the production function for domestically produced goods in sectors $\eta_j \in [0,1]$ in Country j be the Cobb-Douglass:

$$y_{jt}(\eta_j) = \eta_j^{-\kappa} Q_{jt}^{\beta} A_{jt}^{1-\beta} l_{jt}(\eta_j), \quad j = 1,2. \tag{3.2}$$

Here $y_{jt}(\eta_j)$ is the amount produced in sector η_j. and $\eta_j^{-\kappa}$ is the productivity fixed effect just mentioned. Trade will assign each country's production to the sectors $\left[0, \xi_{jt}\right]$. (Note that close to $\eta = 0$ productivities are infinite.) Next, Q_{jt} is an

economy level public good, A_{jt} is the country's technological level, and $l_{jt}(\eta)$ is labor employed. By assuming that there are different technological levels in each country, it is implicitly assumed that mastering foreign technologies and adapting them to the local environment is costly. Some of the variables in the equations of technological change refer to comparisons between the two countries.

Definition 1. *Define the productivities*

$$B_{jt} = Q_{jt}^{\beta} A_{jt}^{1-\beta}, \quad j = 1, 2,$$

and the relative state variables

$$a_t = \frac{A_{2t}}{A_{1t}}, q = \frac{q_2}{q_1},$$
$$b_t = \frac{B_{2t}}{B_{1t}} = \frac{Q_{2t}^{\beta} A_{2t}^{1-\beta}}{Q_{1t}^{\beta} A_{1t}^{1-\beta}} = q^{\beta} a_t,$$
$$\lambda = L_2/L_1.$$

Here each economy has population L_j, assumed to be fixed. Since it is assumed that $A_{2t} \leq A_{1t}$, it follows that $a_t \leq 1$.

Remark 1. *Given wages w_{jt}, the private cost of each unit of domestic good η_j is:*

$$z_{jt}(\eta_j) = \frac{\eta_j^{\kappa} w_{jt}}{B_{jt}}. \tag{3.3}$$

We suppose that institutional quality is the result of continual innovation adapting to conditions changing with the arrival of new technologies and conditions of production. However we do not describe the institutional innovation process, but simply assume that it occurs in proportion to the private innovation process. Hence public goods are supplied in proportion to the technological level, whether they are institutions or services. Services need to be provided in proportion to the technological level to be effective. Thus

$$Q_{jt} = q_j A_{jt}, \tag{3.4}$$

where q_j is a constant. This constant represents the country's deep "institutional kernel."

Each domestic sector produces monopolically (with or without a competitive fringe) with a mark up $\chi > 1$ therefore selling at a price:

$$p_{jt}(\eta_j) = \chi z_{jt}(\eta_j) = \chi \frac{\eta_j^{\kappa} w_{jt}}{B_{jt}}, \tag{3.5}$$

This is a common assumption in models of endogenous technological change. As choice of numeraire, set nominal prices in each country equal to:

$$p_{jt}(\eta_j) = \eta_j^{\kappa}, \tag{3.6}$$

Wages are proportional to domestic productivity; from equations (3.5) and (3.6) it follows that:

$$w_{jt} = \frac{1}{\chi} B_{jt}. \tag{3.7}$$

Let the instantaneous consumer subutility function C_t for an agent consuming $c_t(\eta)$ units of sector η goods, $\eta \in [0,1]$, be the Cobb-Douglass:

$$\ln(C_t) = e^{-\kappa} \int_0^1 \ln(c_t(\eta))\, d\eta. \tag{3.8}$$

(The factor $e^{-\kappa}$ renders the expression mean preserving under changes of κ.) Suppose also that innovation investment uses a composite good with the same kernel as consumption, so that the composition of consumption and investment demand are equal. Then aggregate world expenditure across sectors, given in the nominal units of country j. is some constant x_{jt}.

Definition 2. *The exchange rate E_t expressing prices in Country 2 in terms of prices in Country 1 is given by equalization of prices at sector ξ_j:*

$$\xi_{2t}^{\kappa} = E_t \xi_{1t}^{\kappa}, \text{ so } E_t = \frac{\xi_{2t}^{\kappa}}{\xi_{1t}^{\kappa}}. \tag{3.9}$$

Remark 2. *Since x_{jt} both represent the same real expenditure,*

$$x_{2t} = E_t x_{1t}, \text{ so } \frac{x_{2t}}{x_{1t}} = E_t = \frac{\xi_{2t}^{\kappa}}{\xi_{1t}^{\kappa}}. \tag{3.10}$$

Proposition 1. *The amount of labor $l_{jt}(\eta)$ assigned to production is constant across sectors in each economy,*

$$l_{jt}(\eta_j) = l_{jt} \equiv \frac{x_{jt}}{B_{jt}}. \tag{3.11}$$

Hence the quantities produced are:

$$y_{jt}(\eta_j) = \eta_j^{-\kappa} x_{jt}. \tag{3.12}$$

Proof. First consider domestic sectors. Aggregate expenditure is:

$$\begin{aligned} p_{jt}(\eta) \times y_{jt}(\eta) &= \eta_j^{\kappa} \times \eta_j^{-\kappa} B_{jt} l_{jt}(\eta_j) \\ &= B_{jt} l_{jt}(\eta_j) = x_{jt}, \end{aligned} \tag{3.13}$$

using expressions (3.2) and (3.6). This yields (3.11). □

Corollary 1. *The ratios between expenditure, wage payments, capital payments, domestic profits and FDI profits are either fixed or depend on the relative state variables,*

$$w_{jt} l_{jt} = \frac{1}{\chi} x_{jt}, \tag{3.14}$$

$$\pi_t = \left(1 - \frac{1}{\chi}\right) x_{jt}. \tag{3.15}$$

Similarly the ratios between employment levels l_{1t}, l_{2t} is:

$$l_{1t} = \frac{x_{1t}}{x_{2t}} b_t l_{2t}. \tag{3.16}$$

Proof. Expression (3.14) follows from (3.7) and (3.11). Hence domestic profits levels can be written

$$\pi_t = p_{jt}(\eta) \times y_{jt}(\eta) - w_{jt} l_{jt} = \left(1 - \frac{1}{\chi}\right) x_{jt}.$$

□

Remark 3. *The labor market clearing equations, setting demand equal to supply, are:*

$$\xi_{1t} l_{1t} = L_1, \tag{3.17}$$

$$\xi_{2t} l_{2t} = L_2. \tag{3.18}$$

These two equations complete the instantaneous description of the economy. Note that it follows that employment levels can be expressed as functions of the sectoral measures ξ_{1t}, ξ_{2t}; using ratios (3.16),

$$l_{1t} = \frac{L_1}{\xi_{1t}}, \quad l_{2t} = \frac{L_2}{\xi_{2t}}. \tag{3.19}$$

3.2. **Trade.** We can now work out how production is allocated across the two economies.

Theorem 1. *International assignment of production. The sectoral measures ξ_{1t}, ξ_{2t} are given by:*

$$\xi_{1t} = \frac{1}{1 + (\lambda b_t)^{\frac{1}{1+\kappa}}}, \tag{3.20}$$

$$\xi_{2t} = \frac{(\lambda b_t)^{\frac{1}{1+\kappa}}}{1 + (\lambda b_t)^{\frac{1}{1+\kappa}}}. \tag{3.21}$$

Hence

$$l_{1t} = L_1 \left(1 + (\lambda b_t)^{\frac{1}{1+\kappa}}\right) \tag{3.22}$$

$$l_{2t} = L_2 \frac{1 + (\lambda b_t)^{\frac{1}{1+\kappa}}}{(\lambda b_t)^{\frac{1}{1+\kappa}}} \tag{3.23}$$

Proof. To solve for ξ_{1t} and ξ_{2t}, obtain

$$\frac{\xi_{2t}}{\xi_{1t}} = (\lambda b_t)^{\frac{1}{1+\kappa}}.$$

from (3.10), (3.16) and (3.19), and solve as a simultaneous equation with (3.1). For l_{1t} and l_{2t}, use (3.19) again. □

Corollary 2. *The exchange rate E_t expressing prices in country 2 in terms of prices in Country 1 is given by equalization of prices at sector ξ_j:*

$$\xi_{2t}^{\kappa} = E_t \xi_{2t}^{\kappa}, \text{ so } E_t = \frac{\xi_{2t}^{\kappa}}{\xi_{1t}^{\kappa}} = (\lambda b_t)^{\frac{\kappa}{1+\kappa}}$$

When countries have a strong nominal anchor, exchange rates are increasing in aggregate capacity, represented here by population × technology.

Corollary 3. *The expenditure levels x_{jt} are:*

$$x_{1t} = B_{1t} L_1 \left(1 + (\lambda b_t)^{\frac{1}{1+\kappa}}\right) \tag{3.24}$$

$$x_{2t} = B_{2t} L_2 \frac{1 + (\lambda b_t)^{\frac{1}{1+\kappa}}}{(\lambda b_t)^{\frac{1}{1+\kappa}}} \tag{3.25}$$

Aggregate national products are:

$$\begin{aligned} Y_{1t} &= B_{1t}L_1 \\ Y_{2t} &= B_{2t}L_2 \end{aligned}$$

Proof. For x_{jt} use (3.11), (3.19), (3.22), (3.23). For Y_{jt} note $Y_{jt} = \xi_{jt}x_{jt}$ and use also (3.20), (3.21). □

3.3. **Technological change.**

3.3.1. *Resource costs.*

Definition 3. *The composite good s_t used for innovation is the combination of $s_t(\eta)$ units of sector η goods, $\eta \in [0,1]$, according to the Cobb-Douglass:*

$$\ln(s_t) = e^{-\kappa}\int_0^1 \ln(s_t(\eta))\,d\eta. \tag{3.26}$$

The optimal amounts of goods $s_t(\eta)$ used to produce the composite s_t is different under free trade than under autarchy, because of the operation of comparative advantage: the prices of goods bought abroad are cheaper than their domestic counterparts. Under autarchy, an innovator in Country 2 will face prices η_1^κ for domestic goods and $E_t\eta_2^\kappa = \frac{\xi_{2t}^\kappa}{\xi_{1t}^\kappa}\eta_2^\kappa$ for foreign goods. Suppose a researcher allocates a budget z_t. Her expenditure will be constant across sectors, with total budget $\int_0^1 z_t d\eta = z_t$. The quantity used of each intermediate good is inversely proportional to the price so the effective investment resource generated is given by:

$$\begin{aligned} s_t &= e^{-\kappa}\exp[\sum_{j=1,2}\int_0^{\xi_{jt}} \log\left(\frac{\xi_{jt}^\kappa}{\xi_{1t}^\kappa}\nu_j^{-\kappa}z_t\right)d\nu_j] \\ &= e^{-\kappa}\exp[\sum_{j=1,2}\int_0^{\xi_{jt}} -\log\left(\frac{\xi_{jt}^\kappa}{\xi_{1t}^\kappa}z_t\right)\kappa\log(\nu_j)\,d\nu_j] \\ &= e^{-\kappa}\exp[\xi_{1t}\log(z_t) + \xi_{2t}\log\left(\frac{\xi_{2t}^\kappa}{\xi_{1t}^\kappa}z_t\right) - \kappa\sum_{j=1,2}[\nu_j\log(\nu_j) - \nu_j]_0^{\xi_{jt}}] \\ &= e^{-\kappa}z_t\frac{\xi_{2t}^{\kappa\xi_{2t}}}{\xi_{1t}^{\kappa\xi_{2t}}}\exp[-\kappa(\xi_{1t}\log(\xi_{1t}) - \xi_{1t} + \xi_{2t}\log(\xi_{2t}) - \xi_{2t})] \\ &= z_t\frac{\xi_{2t}^{\kappa\xi_{2t}}}{\xi_{1t}^{\kappa\xi_{2t}}}(\xi_{1t}^{\xi_{1t}}\xi_{2t}^{\xi_{2t}})^{-\kappa} = z_t\xi_{1t}^{-\kappa}. \end{aligned}$$

Thus under trade, gains from comparative advantage lead to a price $\xi_{1t}^\kappa \leq 1$ which is lower than the autarchic price of 1 (obtained from $\xi_{1t} = 1$). In Country 2 currency, $s_t = z_t\xi_{1t}^{-\kappa}E_t^{-1} = z_t\xi_{2t}^{-\kappa}$. Hence the first order condition for research, calculated for each country in its own currency, is:

3.3.2. *Technological change in the two economies.*

In the appendix we shown how innovators with infinitesimal foresight choose a rate of technological change that depends on market size and resource prices. We now consider other factors affecting

the rate of technological change, under trade, and postulate the following two-economy model.[3]

$$\frac{A'_{1t}}{A_{1t}} = \max\left[\xi_{1t}^{\alpha} q_{1t}^{\rho} g_1\left(a_t\right)\left(\frac{\xi_{1t}^{-\kappa} x_{1t}}{A_{1t}}\right)^{\mu}, \sigma_1\right], \tag{3.27}$$

$$\frac{A'_{2t}}{A_{2t}} = \xi_{2t}^{\alpha} q_2^{\rho} g_2\left(a_t\right)\left(\frac{\xi_{2t}^{-\kappa} x_{2t}}{A_{2t}}\right)^{\mu}. \tag{3.28}$$

Here

$$g_1\left(a_t\right) = \gamma_0 h_1^{a_t - 1}, \tag{3.29}$$

$$g_2\left(a_t\right) = \gamma_0 h_2^{1-a_t}. \tag{3.30}$$

The terms ξ_{jt}^{α} represents a sectoral research externality. The higher the number of innovation sectors, the more ideas flow between them, for example due to shared public goods such as scientific and educational infrastructure and to cross fertilization in sectoral knowledge production. q_j^{ρ} represents the impact of public goods Q_{jt}^{ρ} on research, in proportion to A_{jt}, $g_1\left(a_t\right)$ represents the costless transfer of ideas from Country 2 to Country 1, with $g_1\left(1\right) = 1$, so that γ_0 represents the maximal transfer rate, and $g_1\left(0\right) = h_1^{-1} < 1$, so that we assume $h_1 > 1$. In the reverse direction, representing the costless transfer of ideas from Country 1 to Country 2, $g_2\left(a_t\right)$ is an increasing function in a_t, since there is a larger transfer the larger the technological lag, corresponding to a convergence effect, Gerschenkron's (1952) *advantage of backwardness*. Here $g_2\left(1\right) = \gamma_0$ represents the minimal transfer rate, when both countries have the same technological level, implicitly assuming that technological transfer then takes place at the same rate in both directions, and $g_2\left(0\right) = \gamma_0 h_2$ is the maximal transfer rate, again with $h_2 > 1$. Term $\left(\xi_{jt}^{-\kappa} x_{jt}/A_{1t}\right)^{\beta}$ represents the impact on innovation of market size combined with the operation of comparative advantage, relative to the technological level, to take account of the fishing out effect. Below some market size, purposeful innovation does not take place, instead of which we have a *natural* growth rate, taking place through the spontaneous appearance of ideas through time. To model the idea that the leading country grew somewhat faster than the rest of the world for a prolonged period until a critical market size was reached, we suppose this natural rate of growth is σ_1 for Country 1 and, for simplicity, 0 for Country 2.

In the case of autarchy we postulate the same equations but with $\alpha = \kappa = 0$, because there is no specialization or comparative advantage, with γ_0^A instead of γ_0, with $\gamma_0^A \leq \gamma_0$, because it may be supposed that under autarchy there is less communication and therefore a lower rate of transfer of ideas, and with $x_{jt}/A_{jt} = q_{jt}^{\beta} L_j$.

Definition 4. *Innovation is viable in Country 1 at any given relative technological level a_t if its growth rate is faster than the natural rate.*

Proposition 2. *Innovation is viable in Country 1 on the "innovation" interval $\left[a_1^V, a_2^V\right]$.*

[3]Having shown that a Solow-style model of technological change can be microfundamented fundamented, we do not write out the innovation functions R that yield these results.

Proof. Writing C for constant terms,

$$\begin{aligned}\ln\left(A'_{1t}/A_{1t}\right) &= C + a_t \ln\left(h_1\right) - \left(\alpha - \mu\left(1+\kappa\right)\right) \ln\left(1 + \left(\lambda q^{\beta} a_t\right)^{\frac{1}{1+\kappa}}\right), \\ \frac{d}{da_t} \ln\left(A'_{1t}/A_{1t}\right) &= \ln\left(h_1\right) - \frac{\left(\alpha - \mu\left(1+\kappa\right)\right) \lambda q^{\beta} \left(\lambda q^{\beta} a_t\right)^{\frac{1}{1+\kappa}-1}}{\left(1+\kappa\right)\left(1 + \left(\lambda q^{\beta} a_t\right)^{\frac{1}{1+\kappa}}\right)}.\end{aligned}$$

Since this is decreasing, $\ln\left(A'_{1t}/A_{1t}\right)$ and therefore A'_{1t}/A_{1t} is quasiconcave. □

For simplicity we assume that $a_2^V = 1$, that is, innovation viability in Country 1 is questionable when Country 2 is small, but not when it catches up technologically.

Remark 4. *.On the innovation interval $\left[a_1^V, 1\right]$, the differential equation for the relative technological level a_t is:*

(1) under trade,

$$\frac{a'_t}{a_t} = H\left(a_t\right) \equiv \xi_{2t}^{\alpha-\mu(1+\kappa)} q_2^{\rho+\beta\mu} \gamma_0 h_2^{1-a_t} L_2^{\mu} - \xi_{1t}^{\alpha-\mu(1+\kappa)} q_1^{\rho+\beta\mu} \gamma_0 h_1^{a_t-1} L_1^{\mu}.$$

(2) Under autarchy,

$$\frac{a'_t}{a_t} = H^A\left(a_t\right) \equiv q_2^{\rho+\beta\mu} \gamma_0^A h_2^{1-a_t} L_2^{\mu} - q_1^{\rho+\beta\mu} \gamma_0^A h_1^{a_t-1} L_1^{\mu}.$$

On $\left[0, a_1^V\right]$, $H\left(a_t\right)$ and $H^A\left(a_t\right)$ are both understood to be defined putting $A'_{1t}/A_{1t} = \sigma_1$.

Proof. Observe from (3.24), (3.20), that $x_{jt}/A_{jt} = q_{jt}^{\beta} L_j \xi_{jt}^{-1}$. The case of autarchy is obtained by substituting $\xi_{1t} = \xi_{2t} = 1$. □

Remark 5. *Terms L_j^{μ} represent a scale effect. This may be taken to be small by letting μ be small. The effect could be bounded if a bounded function were used to represent the market size effect. However, this makes the model less tractable.*

Definition 5. *Trade specialization is advantageous, neutral or disadvantageous, for innovation according to whether $\alpha - \mu\left(1+\kappa\right)$ is negative, zero or positive.*

Because innovation is so multifaceted, and often comes up with multiple, general purpose ideas, and because these ideas flow much easier within than between countries, I take the point of view that trade specialization is usually *disadvantageous* for innovation. This does not negate the advantages of comparative advantage in enlarging markets and increasing efficiency. Indeed the term $\xi_{2t}^{\alpha-\mu(1+\kappa)}$ includes these impacts. It says that if Country 2 becomes relatively more backward, so that ξ_{2t} decreases, in its interaction with Country 1 the impact of market size and comparative advantage on innovation, expressed in the coefficient $\mu\left(1+\kappa\right)$, will be larger. Note however that these impacts must in reality be bounded. On the other hand, as Country 2 lags further behind, it also looses production sectors, and any remaining sector has now to fend on its own in research, so to speak, loosing externalities as expressed by coefficient α. There can of course be exceptions in which trade specialization is advantageous for innovation.

Definition 6. *A steady state a^* of the dynamic systems for a_t diverges in levels if $a^* > 0$ and $H\left(a^*\right) = 0$; a^* represents an equilibrium lag in technological levels. Instead, a^*diverges in growth rates if $a^* = 0$ and $H\left(a^*\right) < 0$; Country 2 grows at a rate $H\left(a^*\right)$ slower than Country 2.*

When $a^* = 0$ and $H(a^*) = 0$ it is possible for levels to diverge to infinity while growth rates converge.

Lemma 1. *(1) Suppose trade specialization is disadvantageous for innovation, $\alpha - \mu(1+\kappa) > 0$. $H(a_t)$ can be written as a the ratio of a quasiconcave denominator and a non-zero numerator. In this case $H(0) < 0$ and, if in addition both countries have equal parameters, so $\lambda = q = 1$, and, without loss of generality, $q_1 = L_1 = 1$,*

$$H'(1) \text{ has the same sign as } \sigma \equiv \frac{\alpha - \mu(1+\kappa)}{1+\kappa} - \ln(h_2) - \ln(h_1). \tag{3.31}$$

This implies $H(1^-)$ is negative if for equal economies the marginal disadvantageous for innovation of trade specialization is stronger than or equal to convergence, $\sigma > 0$, and negative if $\sigma \leq 0$.

(2) Suppose trade specialization is advantageous for innovation, $\alpha - \mu(1+\kappa) < 0$. $H(a_t)$ can be written as a the ratio of a decreasing denominator and a non-zero numerator.

(3) If trade specialization is neutral for innovation, $\alpha - \mu(1+\kappa) = 0$, $H(a_t)$ is a decreasing function.

(4) In the autarchic case, $H^A(a_t)$ is a decreasing function.

Proof. (1) On interval $\left[a_1^V, 1\right]$, write $H(a_t) = N(a_t)/D(a_t)$ with

$$\begin{aligned} D(a_t) &= \left(1 + \left(\lambda q^\beta a_t\right)^{\frac{1}{1+\kappa}}\right)^{\alpha-\mu(1+\kappa)} \\ N(a_t) &= T_2(a_t) - T_1(a_t) \\ T_1(a_t) &= q_1^{\rho+\beta\mu}\gamma_0 h_1^{a_t - 1} L_1^\mu, \\ T_2(a_t) &= \left(\lambda q^\beta a_t\right)^{\frac{\alpha-\mu(1+\kappa)}{1+\kappa}} q_2^{\rho+\beta\mu}\gamma_0 h_2^{1-a_t} L_2^\mu. \end{aligned}$$

Setting $T_{2C} = \left(\lambda q^\beta\right)^{\frac{\alpha-\mu(1+\kappa)}{1+\kappa}} q_2^{\rho+\beta\mu}\gamma_0 h_2 L_2^\mu$,

$$\ln(T_2(a_t)) = \ln T_{2C} + \frac{\alpha - \mu(1+\kappa)}{1+\kappa}\ln(a_t) - a_t \ln(h_2)$$

is a concave function, being the sum of a positive multiple of a logarithm (which is concave, note $\alpha - \mu(1+\kappa) > 0$) and a linear function. Hence $T_2(a_t)$ is quasiconcave, first rising and then decreasing. Since $T_1(a_t)$ is convex, it follows that $N(a_t) = T_2(a_t) - T_1(a_t)$ is quasiconcave. Note that $T_2(a_t)$ continues to be quasiconcave if it is extended to $[0,1]$ by holding it constant at the value $T_1\left(a_1^V\right)$, because $T_1(a_t) = \max[c, h_1^{a_t}]$, where c is a constant, is still convex.

Since $T_1(0) > 0$ and $T_2(0) = 0$, $H(0) < 0$. In the case of countries with equal parameters, so $\lambda = q = 1$, assuming also $q_1 = q_2 = L_1 = L_2 = 1$,

$$N'(1) = \gamma_0\left(\frac{\alpha - \mu(1+\kappa)}{1+\kappa} - \ln(h_2) - \ln(h_1)\right).$$

Note that $N(1) = 0$ so also $H(1) = 0$. Hence if $N'(1) \geq 0$, since the denominator $D(a_t) > 0$ then the quasiconcavity of N, and its analyticity, implies $N(a_t) < 0$ for $a_t < 1$, and similarly with H. If instead $N'(1) < 0$, $N'(1^-) > 0$ in some neighborhood.

(2) In this case $T_2(a_t)$ is a strictly decreasing function.

(3), (4). By inspection. □

The following theorem classifies the steady states in the model.

Theorem 2. *Multiple steady states in the dynamics of technological change.*

(1) Suppose trade specialization is disadvantageous for innovation, $\alpha-\mu(1+\kappa)>0$. $a_0^*=0$ *is a steady state divergent in growth rates.*

If $H(1)\leq 0$ *then either* $a_0^*=0$ *is the only steady state, or there are only two values* $a_1^*<a_2^*$ *for which* $H(a_1^*)=H(a_2^*)=0$*, with* H *positive on* (a_1^*,a_2^*) *and negative outside* $[a_1^*,a_2^*]$*. Thus* a_1^* *is an unstable steady state, and* a_t *converges to* a_0^* *(or* a_2^**) if its initial value is below (correspondingly above)* a_1^**.*

If instead $H(1)>0$ *then there is a unique value* a_1^* *for which* $H(a_1^*)=0$*, with* H *positive on* $(a_1^*,1]$ *and negative on* $[1,a_1^*)$*. Thus* a_1^* *is an unstable steady state, and Country 2 overtakes Country 1 if its initial value is above* a_1^**, or diverges in growth rates to* $a_0^*=0$*.*

(2) In the remaining cases, when trade specialization is advantageous or neutral for innovation, or under autarchy, there are four possibilities. Independently of the initial conditions, (a) $H>0$ *everywhere and Country 2 overtakes Country 1; (b)* $H<0$ *everywhere and Country 2 diverges in growth rates; (c) there is a unique steady state* $a^*\in(0,1]$ *such that* $H(a^*)=0$*, at which Country 2 diverges in levels; (d)* $a^*=0$*,* $H(a^*)=0$*. In particular, when trade specialization is advantageous for innovation, so* $\alpha-\mu(1+\kappa)<0$*,* $H(0)=\infty$ *so case (b) cannot exist, and divergence in growth rates is impossible. There is either divergence in levels or catch up and overtake.*

(3) All of these possibilities exist between countries with identical parameters.

(4) When Economy 2 diverges in growth rates, for Economy 1 the steady state is equivalent to autarky.

Proof. Each of these is a direct application of Lemma (1), or follows directly from calculation. □

Suppose trade specialization is disadvantageous for innovation. Country 2, faced with the possibility of divergence in growth rates, may adopt the strategy of first growing in autarchy and then opening to free trade. When would this be successful?

Theorem 3. *Suppose* a^{*A} *is an autarchic steady state. When Country 2 opens to free trade, it will only tend to converge towards Country 1 if its productive capacity is higher than Country 1's.*

Proof.

$$\begin{aligned} H^A\left(a^{*A}\right) &= 0 \Rightarrow \frac{q_2^{\rho+\beta\mu}\gamma_0^A h_2^{1-a_t}L_2^{\mu}}{q_1^{\rho+\beta\mu}\gamma_0^A h_1^{a_t-1}L_1^{\mu}}=1 \\ &\Rightarrow \frac{\xi_{2t}^{\alpha-\mu(1+\kappa)}q_2^{\rho+\beta\mu}\gamma_0 h_2^{1-a_t}L_2^{\mu}}{\xi_{1t}^{\alpha-\mu(1+\kappa)}q_1^{\rho+\beta\mu}\gamma_0 h_1^{a_t-1}L_1^{\mu}}=\frac{\xi_{2t}^{\alpha-\mu(1+\kappa)}}{\xi_{1t}^{\alpha-\mu(1+\kappa)}} \end{aligned}$$

so

$$H(a_t)>0 \Leftrightarrow \frac{\xi_{2t}}{\xi_{1t}}>1 \Leftrightarrow \lambda b_t>1.$$

□

4. Historical Application of the Model

The model shows that specialization in production induced by trade induces also specialization in innovation. Since specialization is in proportion to economic size, advanced and larger countries specialize in a wider spectrum of innovation.

In the presence of innovation externalities, this yields a focusing effect of trade on innovation which generates at the same time strong forces for economic growth and development in the leader, and advantages insurmountable to the follower.

Innovation is understood here to include from R&D to technological adoption and imitation. In the model higher technological levels also translate to higher institutional levels, according to an economy-specific parameter representing some kind of institutional quality kernel. This stands in lieu of a better understanding of institutional formation. Note, however, as shown above, that multiple steady states can exist between countries with identical parameters. This implies that institutional and geographic difference are not necessary components of persistent differences in income and economic growth.

Although the model is strictly a two-country model, one can also think that a leading Economy 1 trades with n lagging Economy 2 countries. This could represent, for example, the First Great Age of Globalization, with Great Britain as Economy 1. Then the same innovation focusing mechanism would occur. Some of the lagging countries could catch up, and others could diverge in levels, and yet others in growth rates.

4.1. **Emergence of Development and Underdevelopment.** The model applies to the joint emergence of development and underdevelopment in the following way. First there is a threshold for the appearance of purposeful private innovation, before which technological change proceeds at the natural rate. As we have seen, between 1500 and 1750 the appearance of global trade motivated the formation of financial institutions since the time of the dutch, and the formation of Great Britain as one of the first nation states. Europe and in particular Britain slowly consolidated an economic and institutional advantage over the rest of the world.

Now, the hypothesis here would be that, as transportation technologies evolved, the threshold for the appearance of purposeful private innovation, which involves market size, institutional quality and scientific development, was overcome at some point. Other things being equal, the innovation threshold would be reached sooner in a market with trade dominated from a central point, also enjoying institutional and scientific development, because then the focusing effect of trade would come into effect, even under protoindustrialization. Technological innovation and trade would take off at the same time.

Broadberry and Gupta (2005) document how at the very birth of the Industrial Revolution in England, the incentives for innovation in the textile industry were intimately connected with raw materials from India and markets for cloth in Europe. We have also shown how trade growth jumps to a new level after 1750 (Figure 1). We have also discussed how the impact of industrialization was felt immediately in India, which lost its textile export market and then fell into deindustrialization. Development and underdevelopment emerged jointly.

One way of modelling this would be to think of Britain as Economy 1 and the rest of the world as n slightly lagging Economies. At first, there is autarchy, and purposeful innovation is infeasible. Countries grow at their natural rate. At time 1750, trade becomes feasible. In the enlarged market, purposeful innovation is now possible. Having an initial advantage, Economy 1 is the leader. Depending on their initial technological and institutional conditions, some of the n lagging

economies converge while others diverge. This explains the emergence of the Industrial Revolution, and the consequent bifurcation of incomes into the developed and underdeveloped world.

By 1820 Britain consolidated a leading advantage and the model describes the main characteristics of the First Great Age of Globalization: Britain's eventual turn to free trade; a conscious policy of informal empire, simultaneous with formal empire; gunboat diplomacy; the Opium Wars; consolidation of the two main steady states, development and underdevelopment; The Great Divergence; British hegemony.

Deindustrialization is explained by the model as follows. When a lagging country falls further behind the leader, its comparative size diminishes. This means that the proportion of production allocated to it by trade diminishes, so that it specializes in fewer sectors. Just loosing sectors is a process of deindustrialization in itself. However, in addition innovation slows in the backward country, so that surviving sectors become relatively less modern, as compared to the leader, another dimension of deindustrialization. For an extreme example, spinning cotton with 19^{th} Century machines would not be industrial in the 20^{th} Century.

Now, in the case of closed economies, the model predicts slower technological change because smaller markets yield smaller innovation incentives. This again implies the concentration of industrial production in the developed core.

The model predicts two kinds of divergence, in levels and in growth rates. Broadly speaking, India, China and Africa diverged in growth rates, and Latin America in levels. The United States and Western Europe converged. In this respect, it is instructive to compare the initial conditions (see Table 5).

Although India and China were very large countries, their institutions were weak in that they did not serve their own interests and had not much market integration. They were opened by force, India in 1757 and China in 1842. Our model explains their divergence to very slow growth rates. Between 1820 and 2000, GDP per capita grew form \$533 to \$1,910 in India, 0.71% per year, and from \$600 to \$3,425 in China, 0.97% per year (1990 International Geary-Khamis dollars, Maddison, 2004). These countries diverged in growth rates. By contrast, Mexico and Brazil were also endowed with a poor, but not with a subordinate institutional framework, inherited from a non-market context. They were also relatively closed economies. Mexico grew from a similar level \$759 to \$7,218 and Brazil from \$646 to \$5,556 in the same period, 1.25% and 1.20% per year respectively. We can think of these countries as diverging in levels at an at least partially autarchic equilibrium. Finally, the US, which almost doubled Mexico and Brazil in population, inherited a strong institutional system from Britain, started at a considerably higher income of \$1,257 and grew to \$28,129, or 1.73% per year. As mentioned above, it applied protectionist policies to take off and also enjoyed innovation focusing in the Northeast. The US converged to development, later overtaking Britain.

The theoretical model shows that if the specialization of production generated by trade were advantageous for innovation, divergence in growth rates would be impossible. Institutional differences might lead to divergence in levels, but not in growth rates. On the other hand, disadvantages for innovation due to specialization explain the existence of both types of divergence. They also explain why the relatively autarchic Latin American economies did better than the larger and more open India and China.

4.2. **Overtake by US and Germany.** In Europe and the US there was some degree of convergence. during the first half of the 19th Century. But with the appearance of the railroads, from about 1870, the geographic context of trade changed significantly. Now trade could focus innovation in railway hubs. We have shown how Germany can be considered a railway hub in Europe, an advantage it took advantage of by forming a single economic unit through establishing a Customs Union. We have also seen how the US established a railway hub in the Northeast, focusing trade from the South and West, by establishing the American System and protecting its infant industry from Britain. Japan also used railways and focused maritime trade with Asia. At the same time, as Britain surged ahead of its empire, much of which diverged in growth rates, its effective market size decreased, so that it lost some of the advantage of trading with it (see Theorem 2.4).

All this occurred in a context in which the US and Germany enjoyed forces for convergence in any case. Other elements also contributed to the US and Germany overtaking Britain, such as the German scientific investments mentioned above, availability of natural resources in the US, and higher sunken industrial costs in Britain making renewed investments less attractive. Low education in Britain is also thought to have slowed the second industrial revolution.

Another attractive application of the model is the comparison of different empires, each viewed as a pair of countries described by the model. This is the sense of the empire multipliers mentioned above (Figures 2 and 8). These empires tended to seek control of their subject country's trade. Conceived as different economic entities they tended to foster antagonism and conflict.

4.3. **Post World War II.** Seeking to a more peaceful architecture for international relations, since 1945, under US hegemony, capitalism became a single block. Thus in applying the model, one can again think that a leading Economy 1 trades with n lagging Economy 2 countries, with Economy 1 either the US or the developed core. Now, corresponding to the already existing developed and underdeveloped countries were widely different initial conditions in income, institutions and other parameters. Many countries in Asia and Africa only became independent in this period!

The model thus explains the continued persistence of multiple steady states. In turn, the existence of these multiple steady states explains the phenomenon of miracle growth as a transition between them consequent on changes in policies or circumstances, the typical way in which countries which have achieved development have done so. This phenomenon is not exclusive of the 20^{th} Century, witness the rapid growth of Sweden, Denmark and Japan in the late 19th Century (Pipitone, 1995), as well as that of Germany. The US appears to be the only notable exception to this rule. Yet the 20^{th} Century has seen remarkable examples of miracle growth in South Korea, Taiwan, Hong Kong and Singapore, viewed explicitly as a transition to a higher stationary state by Wan's (2004). There have also been other recent cases of rapid growth, including Cyprus, Iceland, Spain, Malta, Portugal, Israel and more recently China and India.

Note that while the model shows that autarchy can be better than openness under some conditions, it also implies that openness is a condition for development, so long as developed countries are open and their incentives for innovation for the global economy are higher than the incentives under autarchy in the lagging, autarchic country. In the sixties and seventies, Argentina, India, Nigeria, Brazil,

and Mexico experienced rapid growth (Pipitone, 1995), but did not achieve development. Perhaps this was because they reached the limits of relatively autarchic development, represented by import substitution.

The relation of human development and income inequality to this model is discussed in Mayer-Foulkes (2008). The present model is extended to include foreign direct investment in Mayer-Foulkes (2009), an important feature of globalization both in the 19^{th} and 20^{th} Centuries; this article also gives an explanation for the long-term fundamentals of the 2008 economic crisis.

5. Conclusions

We give a dynamic description of underdevelopment, as a lower steady state in technological change, defined in relation to leading countries in higher steady states. Institutions are described as a process defined by a long-term parameter representing a "deep" long-term institutional kernel and contributing to steady state selection, and a process of institutional development paralleling technological change. Thus when the model compares underdeveloped countries with developed countries, they are described as less dynamic and their organization less effective — the forces of innovation are smaller and institutional development is lower.

Our description is based on a two-country model of economic growth through endogenous technological change, in the context of world trade. We observe that when production is assigned between countries by trade, it simultaneously assigns innovation. Larger and more advanced countries specialize in more sectors than smaller and more backward countries. When there are positive innovation externalities between sectors, this implies the existence of disadvantages of specialization for innovation, which also reflect in institutional formation. The model gives rise to multiple steady states in endogenous technological change. These can take the form of divergence in growth rates or divergence in levels, and overtaking can also occur.

The theoretical model shows that if there were instead advantages to specialization, then divergence in growth rates would be impossible, inconsistently with the Great Divergence. On the other hand, disadvantages to specialization generate a focusing effect of trade on innovation that gives rise to multiple steady states. Such multiple steady states can exist for economies with identical parameters, differing only in initial conditions, implying that institutional or geographic differences are not necessary conditions for underdevelopment.

The features displayed by the model serve to explain the main features of the history of economic growth and development. These include the emergence of the Industrial Revolution at a focal point of trade; the subsequence appearance of specialization in world trade; the simultaneous emergence of development and underdevelopment, that is, the Great Divergence; "informal empire" based on trade; the role of railroad transportation in generating new focal points for economic growth in the US and Germany; the continued persistence of underdevelopment through the 20^{th} Century; and the phenomenon of miracle growth as the usual path that countries transit to emerge from backwardness.

6. Appendix. Infinitesimal foresight

In this section we model technological change under infinitesimal foresight, and show that this yields a Solow-style model.

For simplicity suppose there is a single innovator for each sector. Over a time period Δt, an incumbent in Country 1 can invest $s_t A_{1t} \Delta t$ units of a composite good (defined below) in R&D (or technological absorption) at price p_{1t}^s to obtain a technological level

$$A_{1t+\Delta t}^{1-\alpha} = A_{1t}^{1-\alpha} \left(1 + R\left(s_t\right) \Delta t\right),$$

where R is an innovation function that is increasing in s_t and has decreasing returns tending eventually to zero, thus satisfying $R\left(0\right) = 0$, $R'\left(s_t\right) > 0$, $R''\left(s_t\right) < 0$ for $s_t \geq 0$ and $\lim_{s_t \to \infty} R'\left(s_t\right) = 0$. Multiplication of s_t by A_{1t} represents the fishing out effect. Suppose also that initial returns to innovation investment are finite, $R'\left(0\right) = R_0'$.

Consider first an incumbent in Economy 1 that is not subject to competition. According to expression (**??**), because costs are inversely proportional to $A_{1t}^{1-\alpha}$, her profit flow at time $t + \Delta t$ is:

$$\Pi_{t+\Delta t}\left(s_t\right) = \left(1 - \frac{\Delta t}{\chi(1 + R(s_t))}\right) x_t - p_{1t}^s A_{1t} s_t \Delta t$$

Remark 6. *The profit flow $\Pi_{t+\Delta t}\left(s_t\right)$ has a unique maximum at an investment rate $s_t = s^*(\frac{x_t}{A_{1t}})$ which is increasing in market size $\frac{x_t}{A_{1t}}$.*

Proof. Observe that $\Pi'_{t+\Delta t}\left(s_t\right) = \frac{x_t \Delta t}{\chi}(1 + R(s_t))^{-2} R'(s_t) - p_{1t}^s A_{1t} \Delta t$, from which it is easy to see $\Pi'\left(s_t\right) < 0$. The maximum profit flow at $t + \Delta t$ occurs when $\frac{x_t}{\chi}(1 + R(s_t))^{-2} R'(s_t) = p_{1t}^s A_{1t}$. Observe that the LHS decreases from $\frac{x_t}{\chi} R_0'$ to 0 as s_t goes from 0 to ∞, and has negative derivative. If $\frac{x_t}{\chi} R_0' \leq p_{1t}^s A_{1t}$, it is optimal not to invest. Otherwise $\Pi'_{t+\Delta t}\left(s_t\right)$ has a unique optimum $s^*\left(\frac{x_t}{p_{1t}^s A_{1t}}\right) > 0$ which is increasing in market size $\frac{x_t}{A_{1t}}$ and decreasing in the price p_{1t}^s of the investment good. □

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Table 1. Periods of Trade, Hegemonies, and Economic Growth, 1500-2000

Autarchy	1500-1750	1st Colonial Wave	• Large scale transportation slowly developed • Europe consolidates initial advantage
Transition	1750-1914	Industrial Revolution British commercial and industrial leadership 2nd Industrial Revolution and New Imperialism	• Large-scale trade and specialization • Systematic innovation • Free trade embraced • The Great Divergence begins • US and Germany overtake Britain • Catch-ups in Europe and Japan
Global Trade	1914-1945	World Wars Inter-war protectionism	Climax of colonial competition
	1945-2000	US commercial and industrial leadership. Cold War Single capitalist trading block Fall of socialism Accelerated Globalization	• Reconstruction of multilateral free trade • Fall of colonialism • Persistence of underdevelopment and divergence • Miracle growth in East Asia, several European countries, Israel • Accelerated globalization: free trade and foreign direct investment

Table 2. Institutional innovation, Hegemonies, and Trade, 1500-1750

Portugal	**1415-1612** • Dominates Spice trade		
Holland		**1584-1702** **Dutch Golden Age** • Dutch republic 1581 • East India Company and Amsterdam Stock Exchange 1602 (stocks and bonds) • Bank of Amsterdam pays interest 1609	
England	**1500-1700** **Commercial, political and military consolidation of England** • Commonwealth of England 1529-1660 – towards nation state • Patents, monopolies from 16th C. Statute of Monopolies 1623 • East India Company 1600 • Navigation acts restricting foreign shipping (1651, 1660, …) lead to Anglo-Dutch wars • Lloyd's insurance for shipping 1688 • Bank of England founded: bank of banks 1694		**1700-1750** **Emerging British Power** • Kingdom of Great Britain 1707 • England dominates trade with India 1717 • Merchant capitalism

Table 3. Hegemonies, Trade, Demographic Transition, and Diverse Economic Growth Trajectories, 1750-1914

	1750 – 1820	1820 – 1870	1870 – 1914
World Context	• Seven Years' War • Napoleonic Wars	• Pax Britannica	• Transport revolution • New imperialism • Scramble for Africa
United Kingdom Industry:	• Industrial Revolution • British commercial dominance	• Capitalism fully emerges • "Workshop of the world" • Free trade policy 1846	• Leadership lost
Demographic Transition:	• Population growth rises above 0.9% in 1780	• Population growth reaches 1.5% in 1820	• Population growth peaks • Low education slows 2nd Industrial Revolution in Britain
Main Converging Countries	• US independence, more independent trade policy	• "American System" 1816 –1970, especially 1861-1932	• 2nd Industrial Revolution • Germany unified, gold standard • US and Germany overtake GB
Open Periphery	• India looses textile exports	• India looses domestic textiles • China opened: opium wars 1834 –1843. "Gunboat diplomacy"	
Closed Periphery	• Latin American independence	• High tariffs in Latin America	

Table 4. Hegemonies, Trade, Demographic Transition, and Diverse Economic Growth Trajectories, 1945-2000

	1945 – 1989	1989 – 2000
World Context	• Cold War (1945-1989) • Single capitalist trading block • Reconstruction of multilateral free trade • OEED, OECD, IMF, World Bank, GATT • Fall of colonialism	• Liberalization • Fall of Socialism • Capitalist dominance from 1989 • Washington Consensus (1990-2000) • Accelerated globalization, WTO • FDI growth 1983 – 1998: 29%
Core	• US leadership; growth: 1.3% • Marshall Plan, European convergence • European Free Trade Association (1957) • European growth 3.9%	• G8 (1973) • European Union (1992) • European and US growth 1.9%
New Core	• Miracle growth in Japan, Hong Kong, Taiwan, Korea, Israel • Fast growth in Cyprus, Spain, Portugal, Malta, Ireland and Iceland	
Peri-phery	• Persistence of underdevelopment and divergence for 168 countries (Maddison, 2001)	• Africa stagnates • Latin America opens: mixed results • Fast growth in China and India

Table 5. Comparison of Initial Conditions in Several Peripheral Countries in 1820, India and China, Latin America, United States

	India and China	Latin America	United States
1820 Population	India: 200M China: 381M	Mexico: 6.5M Brasil: 4.5M	10 M
Institutions, governance	Weak, serving British interests	Weak, closed	Strong, inherited from Britain
Trade	Open by force: India: 1757 China: 1842	High tariffs, many cities inland	Discretionary: "American System" based on industrial protection
1820 GDP per capita[†]	India: $533 China: $600	Mexico: $759 Brasil: $646	$1,257
2000 GDP per capita[†]	India: $1,910 China: $3,425	Mexico: $7,218 Brasil: $5,556	$28,129
Growth factor	× 3.6 × 5.7	Mexico: × 9.5 Brasil: × 8.6	× 22.3

[†]1990 International Geary-Khamis dollars. Source: Maddison (2004)

[‡]UK population in 1820: 21M. UK income: $1,250 in 1700, $1,706 in 1820.

Figure 1. British East India Company Shipping Tonnage, 1610-1813
Yearly Growth Rate Before and After 1750

$$\ln(\text{tons}) = \underset{(-4.26)}{-4.45} + \underset{(13.3)}{0.00826}\ \text{year} + \underset{(-7.3)}{27.6}\ D_{1750} + \underset{(7.45)}{0.0159}\ D_{1750} \times \text{year}$$

(t statistics in parenthesis)

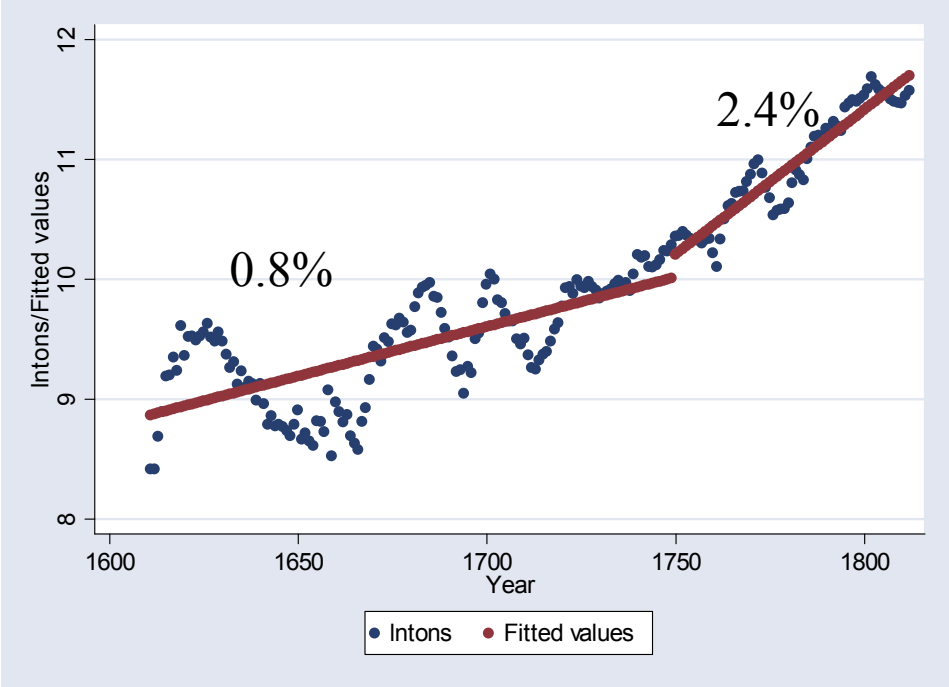

Figure 2. Empire Populations, 1700-1992

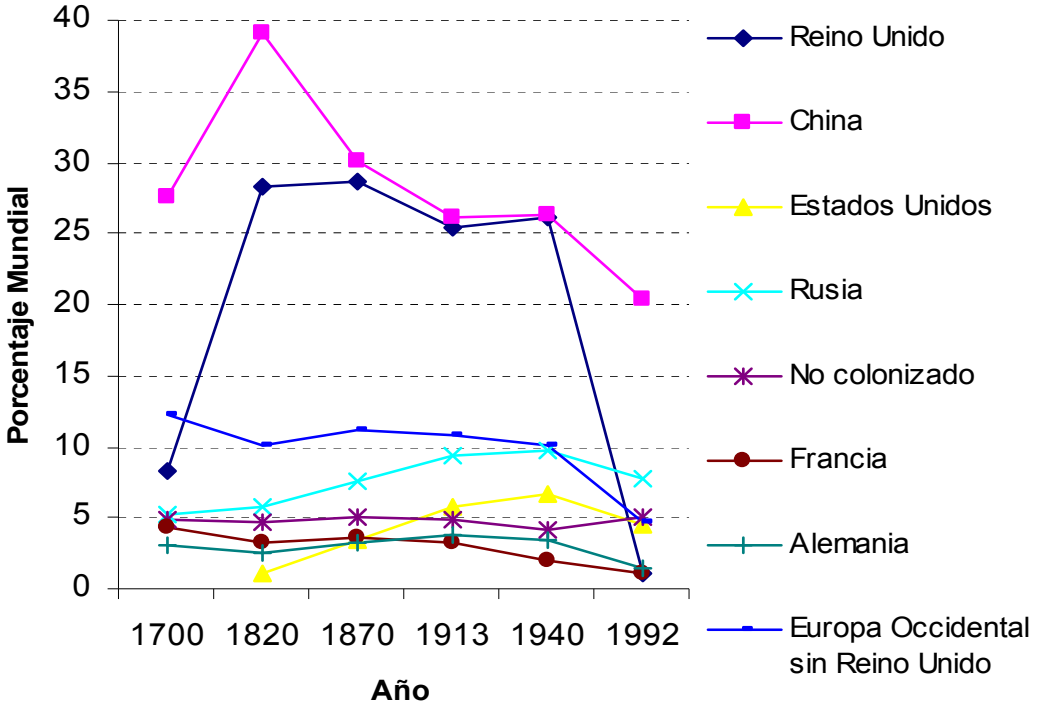

Figure 3. The Great Divergence (Maddison, 2001)

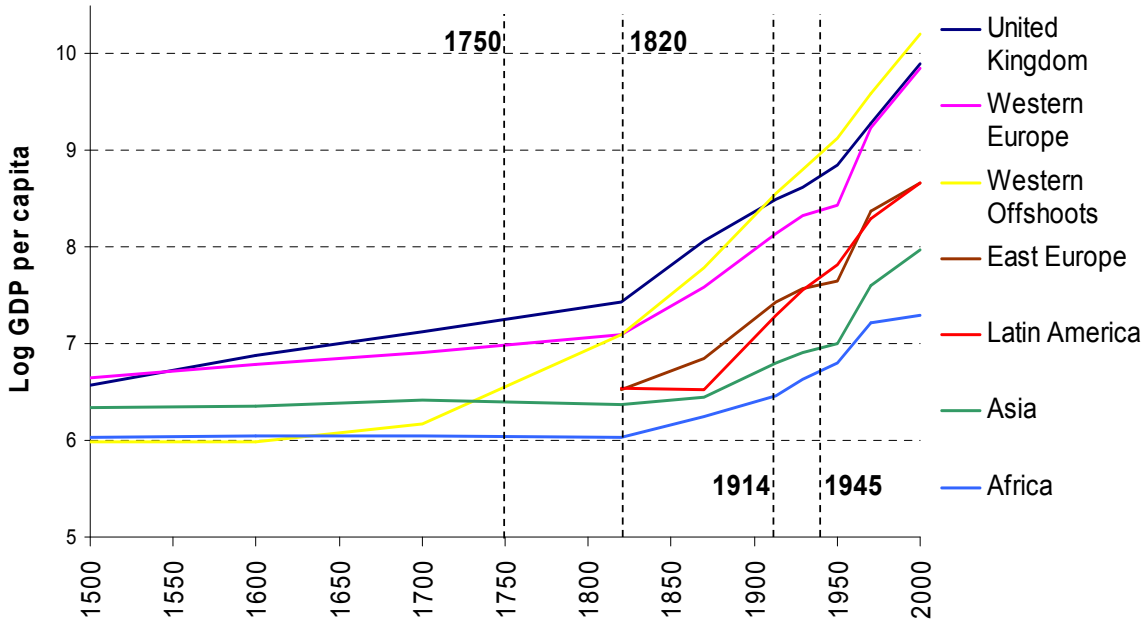

Figure 4. Deindustrialization, 1750 – 1938:
World Manufacturing Output 1750-1938

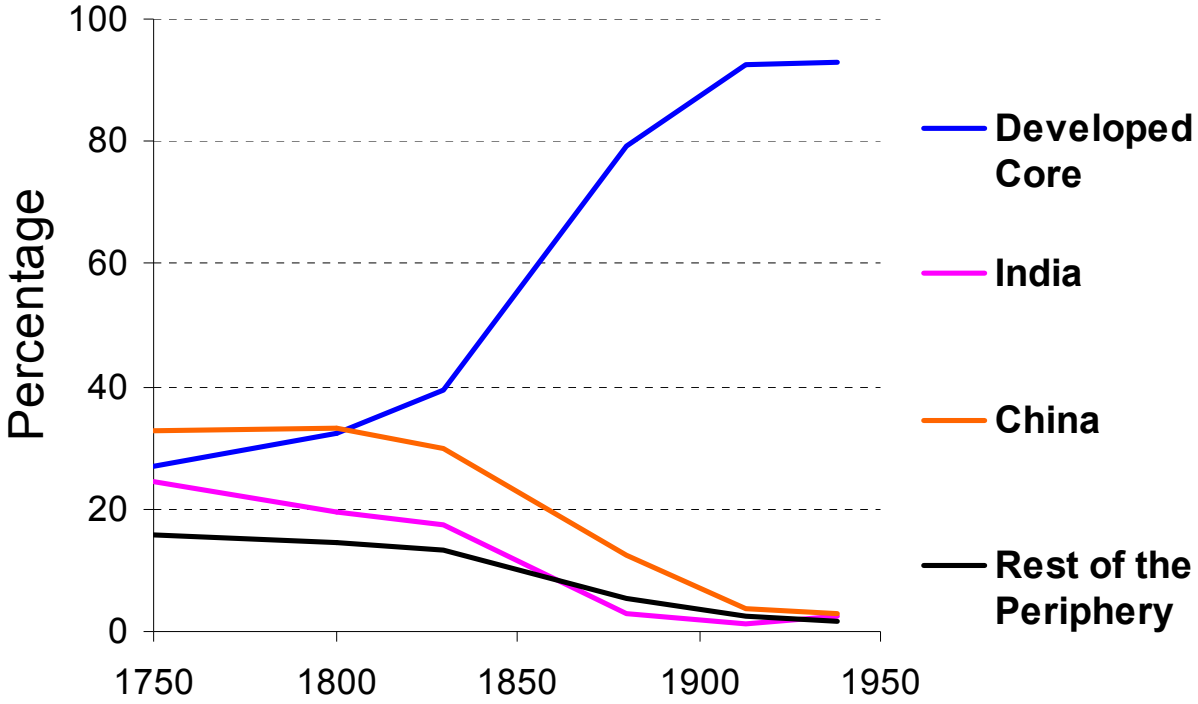

Figure 5. The Rise of Railways in Europe, 1840-1900

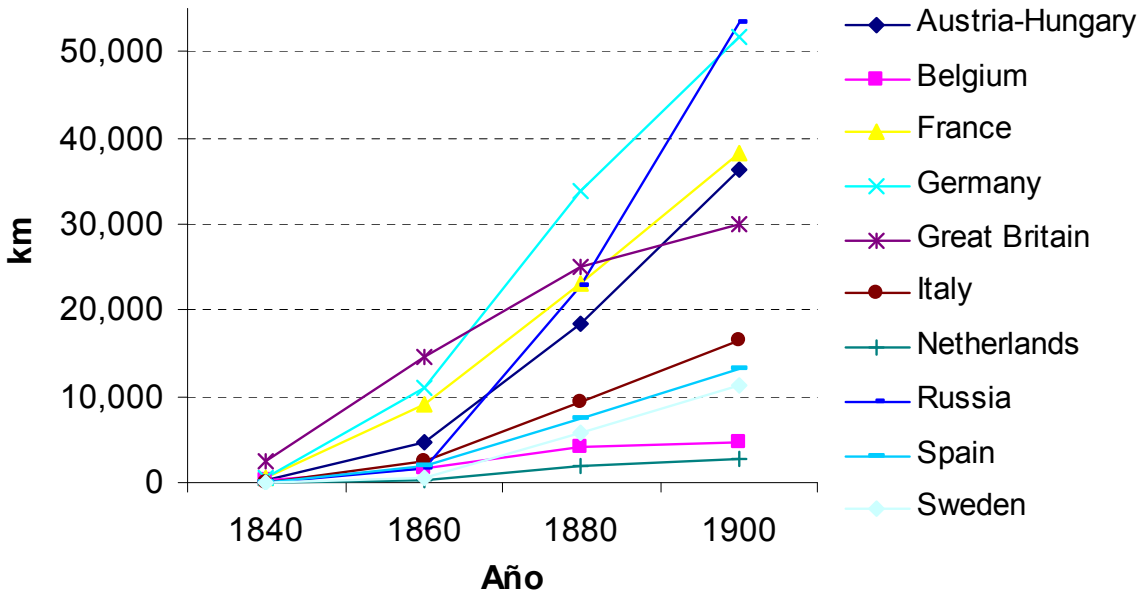

Figure 6. Percentage Distribution of the World's Manufacturing Production, 1870-1913.

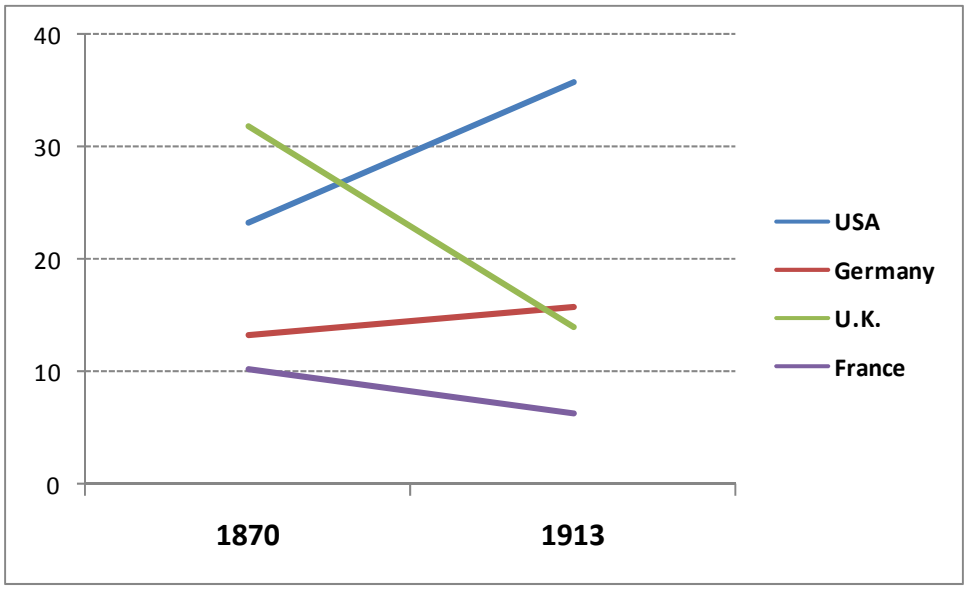

Figure 7. Percentage Distribution of the Aggregate Exports of Fifteen Largest Countries Representing 72% of World Population and World Income, 1870-1913.

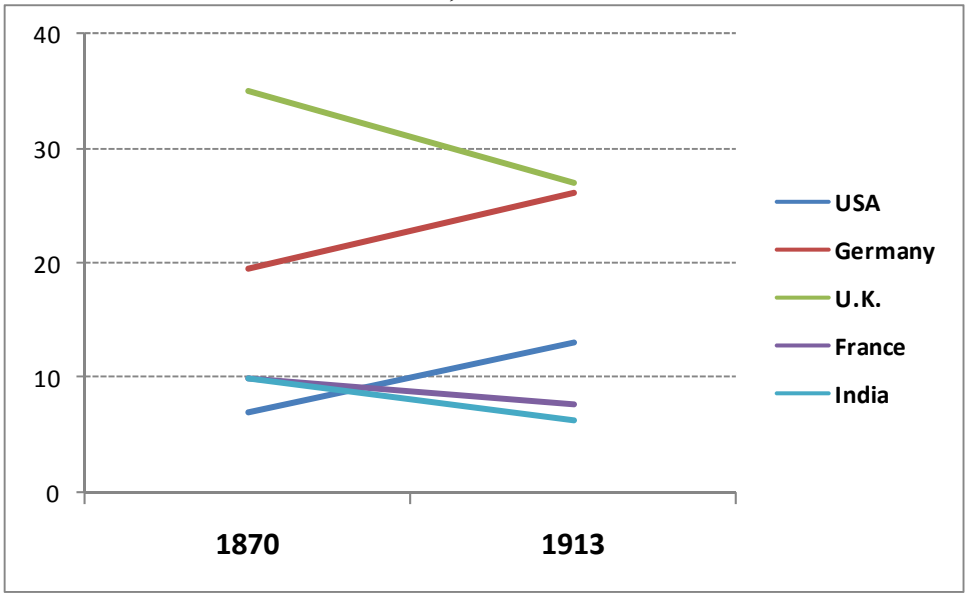

Figure 8. Empire GDP, 1700-1992

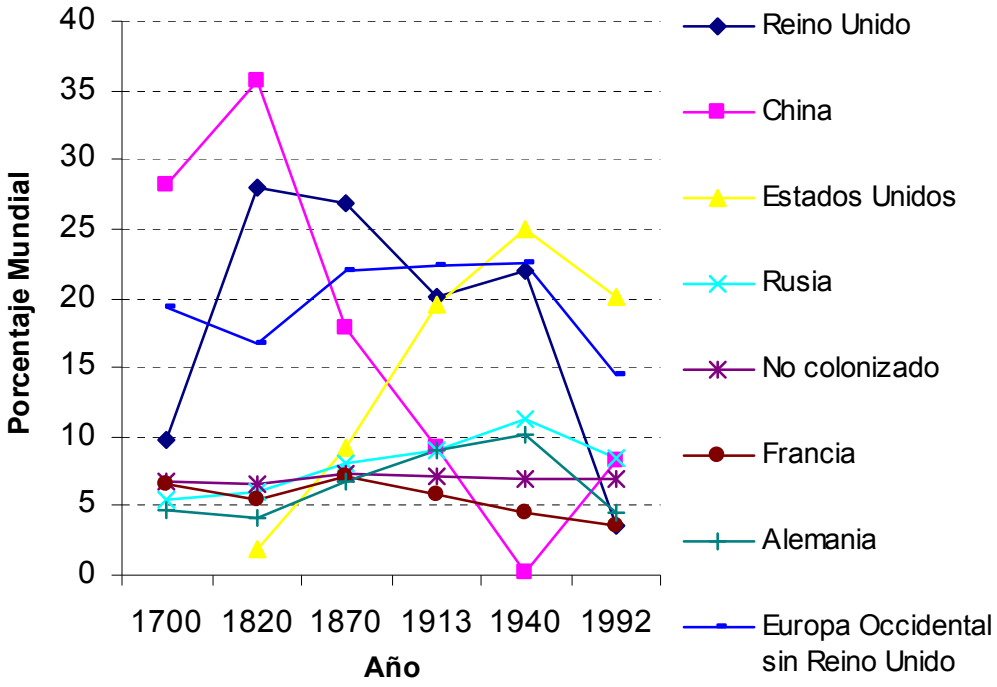

Figure 9. Empire Multipliers, 1700-1992