A Dynamic Model of Historical Economies

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Introduction: Imbalances as the engine of development in history

In 1870,[1] to common astonishment, the Prussian army of "green" reservists[2] destroyed the seasoned French army.[3] What is remembered, however, is the first step of a heavily armed German army toward world supremacy. Today, personalities of von Moltke and Bismarck, its main architects, acquired nearly

[1] As usually, dating of vital transformations, in this case, of the Prussian army, remains controversial. It would be reasonable to date its reorganization from 1857, when von Moltke became the head of the general staff after a career directing the railroad Hamburg – Berlin, where he could fully appreciate the usefulness of railroads for logistical purposes during a military deployment. Another date, of the 1864 Second war with Denmark for Schleswig-Holstein, also seems quite acceptable, if we do not forget that Austria, the Prussian ally, remained so unaware of exceptional Prussian fighting prowess, that, barely 18 months later, it dared to fight it, with ignominious results. We may also see the root of this transformation at a much earlier date. During the Napoleonic wars, the unmitigated initial defeat of the Prussians led to the concept of the army of reservists, which was much cheaper, while allowing training and deployment of a large contingent despite the limit of 43 thousands in a standing army as a condition of a peace accord. Even more important might have been the emancipation of the serfs and the abolishment of social stratifications, yet another condition enforced by the victorious Napoleon. Instead of weakening the Prussians, his adversary, as he, perhaps, intended, greatly increased the citizens' access to education, improving the quality of the future technologically-based army. It is also possible to start from the date of the French-Prussian war as it was done above. At that moment, the Prussian military strength became self-evident and uncontested. Similarly, only the salvos of Russian cannons during the Poltava battle, an episode of the Great Northern War, said it loud and clear for the entire Europe that Russia under Peter the Great became a European country to be reckoned with. However, for this to happen, Peter had to spend many years on a thorough reorganization of the Russian industry by developing a new important center of metallurgy in the Urals.

[2] Even though the Prussian army already had victories in two wars under its "belt" – the second 1864 war with Denmark for Schleswig-Holstein and the Austrian-Prussian war 18 months later – its army, according to the European common opinion, was seen as weaker than the French army of veterans. First and foremost, they differed in the concept. The French army was much more traditional and lots more expensive. It was a standing army of 400 000 soldiers, with 260 000 reservists and the ability to mobilize 400 000 more. Prussia developed a new military doctrine, born in its defeat to Napoleon. According to the Konigsberg Peace Treaty the standing Prussian army was limited to 43 000 soldiers. Turning this into an advantage, Prussia economized on its army, replacing the regular standing army to a flexible army of 1.2 million of well-trained reservists, benefiting from its excellent educational system.

[3] As a rule, any major military defeat can be traced to destructive processes in the society. This article aims to show how technological innovations, which are first developed and refined in military situations, evolve as a societal response to shortages of resources against the background of worsening demographic and economic situations. This causes a cascade of dramatic societal changes.

daemonic connotations on the backgrounds of the two world wars of the 20th century. Meanwhile, a much more prosaic and pragmatic viewpoint may also be justified. While the attempts to grab the world supremacy did evolve in the future, the main heir of the German concept of the general staff might have been not Adolf Hitler, but rather Henry Ford, the creator of the conveyor system at the heart of the mass production economy, US-style. The appearance of a new style of business organization and its future dominance in the 20th century meant the entry of the mass worker, mass soldier *etc.* as parts of a uniform architecture fully run from the headquarters. After a short and well-designed training period, anyone could be placed as a cog into the system with expectations that this cog would function as designed. This called to life an extensive level of middle managers, a necessary part of the corporate style of the 20th century. The prosperous consumer society, US-style, rose as its highest achievement as soon as the related mass economy evolved enough to gain the ability to employ most of the population in its mass occupations.

These events could also be characterized through another simultaneous process – the entry of the mass steel, the new abundant material at the base of basically all important technologies of the approaching 20th century. It is a fact of life that military plans and dispositions can only work if there is an appropriate material environment for their realization, in this case, the telegraph, a dense grid of railroads, and, perhaps, most importantly, reliable weaponry. Moltke and his general staff could become so successful thanks to the breech-loading steel cannon developed by Krupp. These deadly, accurate and fast cannons created the logistical problem of deployment and efficient supply-lines. This, in turn, called to life a new managerial style, which evolved well ahead of the actual start of military operations. In this sense, the mass steel and the new managerial style of the Prussian general staff, at origins of mass production of the 20th century, were two faces of a single coin, which "needed" each other in order to fully function, even though, steel was known well before.[4] The crucial accomplishment of Krupp, who was among the most important innovators in the technological revolution of the 1860s, may look trivial from our vantage point – all he did was learning how to drill steel. This, however, started a revolution in steel working, which would produce, in the future, the car and all the other major accoutrements of the 20th century.

In our terms, Krupp created the point of imbalance by demonstrating the revolutionary possibilities of mass steel. As it is usual in history, he started with military applications, where cost does not present a problem. His technologies of steel working started the massive, worldwide rearmament. This sent investments into metallurgy, opening an important business opportunity. The impulse of disproportional investments into steel was thus created. Now, there was

[4] A steelmaking process resembling the one invented by Bessemer was known in China from the 2nd century CE.

a need in new applications, which were yet absent. At this stage, using economic motivators, the demand for steel, as an impulse creating a business opportunity was passed to Carnegie. On the cheap, during the recession of 1874, he created huge production facilities for manufacturing cheap mass steel. Even more importantly, he found first mass applications – in railroad bridges and steel rails. The business world was duly impressed, including such titans as J. P. Morgan, who bought Carnegie's business and sent in a surging flow of new investments. At this moment it became clear that the mass steel is the star technology of the coming era and has nowhere to go but up. This started the second railroad boom of the 1880s, which ended with fizzle. Considering the durability of new steel rails, there were no other massive uses. As we see, the point of disturbance or disequilibrium, created by Krupp, found thus its new life in economic applications. Since the latter got massive infusions of capital, it had to be returned whatever the means. As it became clear later, in the absence of new powerful economic applications, such means could also include a world war.

As things stand, at the start of the 20th century, the older known uses for steel were exhausted pretty soon. With steel rails already in, the dearth of new mass applications led to the depression of the 1890s. This highlighted the growing imbalance – while investments into new technologies were indeed huge there was a problem with obtaining returns. To survive, the new industries needed to pass the impulse further by introducing fundamentally new crucial applications taking advantage of the unique qualities of steel, such as its strength, springiness, elasticity *etc.*

This is exactly what happened – technologies of steel stamping and cold rolling were not possible with cast-iron, the main material of the previous, 19th century. As a consequence, the landscape of the 20th century would be formed by elegant steel bridges spanning miles, enormous skyscrapers *etc.,* none of which would materialize without mass affordable steel. The addition of the Heald's machine for steel-cutting in 1905 opened a new area, the advanced steel-working and machine-making, starting with producing the bike and ending with the mass car. This new tool could make thin uniform walls, a must for the internal combustion engine, which turned out to be the central invention of the 20th century. Meanwhile, the technological boom at the start of the 20th century ended with WWI. The latter, in its turn, allowed testing and refining of a large array of new steel machines, such as the lorry, the airplane, the cannon, the machine gun *etc.* At the heart of this all was the Killer App of the 20th century, the internal combustion engine.[5] Its development could thus proceed outside of economic limitations, which demands timely returns on its investments.

[5] During WWI 5–6 generations of airplanes were developed, bringing them from the level of Brothers Wright to nearly modern fighters, bombers, reconnaissance planes. The British army entered WWI with 60 lorries and ended it with 60 000 (Roberts 1989).

In this way, the initial point of imbalance, created by the technological revolution in the infrastructure of the 1860s (the Bessemer process, the mass steel, the steel working), ended by starting a technological revolution in production, since then associated with the name of Henry Ford. His famous Model-T was first made in 1908, and, as the first mass car of the 20th century, initiated the future axis of Texas-Detroit along with all the major features of the epoch – suburbia, highways, supermarkets *etc.*

1. Modeling domestication of a zone – as two technological revolutions

The story told above presents a persistent historical pattern. Transfer of imbalances creating technological revolutions in its wake is fairly typical in history and, perhaps, serves as its main engine. Below, we illustrate its persistence by using an example from an altogether different historical period, predating, by a century, our tale.

It is well-known that the British victory over Napoleonic France at the start of the 19th century was determined in a series of naval battles under Admiral Nelson.[6] In the same manner as Moltke's stratagems were enabled by Krupp's cannons, Nelson[7] could resort to his innovative tactic of "crossing the T"[8] thanks to the new gun – the carronade made by Carron Ironworks in Scotland. It was a light and extremely affordable gun for a close combat made out of cast iron, the direct opposite of the chief gun of the period made out of expensive bronze, which was precise with a long range, but also heavy and costly.[9] Foreshadowing the later Krupp's example, the main innovation of Carron's Ironworks consisted in inventing an appropriate method for drilling a solid cylinder cast out of iron. The similarity was further increased by the fact that exactly that method of drilling iron enabled the practical steam engine introduced by James Watt, which replaced the inefficient Newcomen's steam engine. Watt's engine started a new era, with the introduction of the steam-driven factory in 1814, and, in the future, the locomotive (1829).

Examples of disequilibrium as the main engine of history can be continued back to the past. Thus, the Age of Exploration was enabled by the gun-armed caravel.[10] However, the first crucial use of guns took place much earlier, during

[6] Learning about the necessity to fight at Trafalgar, the last and the most decisive of all these naval battles, the French admiral was sure of his coming defeat.

[7] This tactic was also used by the Japanese admiral Togo in 1905 leading to the Russian defeat at Tsushima.

[8] If, up to that time, the fleets used a parallel formation and the battle was reduced to duels of individual ships, Nelson's fleet charged on and, while passing an individual enemy's ship, the entire formation shot at it from a close distance.

[9] Such guns were preferred by Napoleon, a former artillery officer, who valued their precision.

[10] In Figure 3 below this event is named an infrastructural revolution related to the gun-armed sailboat.

the revolution in infrastructure, an indirect consequence of the Hundred Years War between France and England (1337–1453). After the elimination of the flower of the French chivalry by the lowly Welsh bowmen, France had to save itself through technological advance as it leapt to a new level of energy use. The effects of the prayers of Jeanne d'Arc were greatly strengthened by the fundamental rearmament of Dauphin's army (Hall 1997). Soon, gunpowder would foreshadow the role of steam and gasoline engines by opening access to the New World. The latter might have been reached before by many, including the Vikings and, perhaps, the Chinese treasure ships *etc.* However, lacking guns, the Vikings were easily repelled by the native Skraelings. Starting from the 1450s, the arrival of the gun-armed caravel (see gunboat economy at Figure 3) led to a huge economic boost, creating, sequentially, a number of powerful colonial empires: Portuguese, Spanish and Dutch. At the same time, gunpowder enabled new types of mining and opened access to massive amounts of iron ore, previously available in restricted quantities only. With availability of cut stone, it became possible to build larger, denser populated cities, which served as centers of industry. Such examples underscore of points of persistency of historic scenarios falling into stable recurring patterns.

This allows modeling of history as a passage of imbalances, which create impulses by starting logically-ordered technological revolutions. Each traditionally recognized historical epoch, from the Neolithic Revolution and up to the mass society, US-style, may thus be related to its specific geoclimatic zone, with its own well defined territory, specific domestic and wild plants and animals. The dominant energy resource, one per period, becomes useful and crucial for its epoch after the so-called Fundamental Invention of its era. The latter, in its turn, calls to life specific social institutions, which enable the domestication of the new rich zone, which formerly under-produced. This entity, uniting together the zone and the entirety of adaptations to its conditions, both technological and social, is further called a coenosis, meaning the interdependency of feeding chains realized through social institutions and technologies that sustain them by using the resources, which were made available by domesticating a new zone (Бадалян, Криворотов 2005, 2006; Badalian and Krivorotov 2006, 2008, 2009a, 2009b).

The exhaustion of the older zone pushed towards entry and domestication of the next zone. Starting at least from the dawn of the 13th century and up to the current day, this process can be traced through two waves of rising prices on inelastic resources, especially grain and energy (Fischer 1996: 4).[11]

[11] Among other proponents of "long waves" in history were Braudel (1984), Kitchin (1923), Kuznets (1930), Kondratieff (1984), La Roy Ladurie (1966). See also the work of Cameron (1989). The importance of geography in shaping the society was also researched by Diamond (2005).

In our model the domestication of the each of the distinctive historical geoclimatic zones[12] is traced to two technological revolutions: in production and infrastructure. The domestication of a new zone is predated by a revolution in infrastructure, which enables globalization and the corresponding transfer of advanced technologies developed by the extant dominant to its far periphery. This takes place still well within the old geoclimatic zone, albeit pushed to its far, usually seriously underproducing periphery. Globalization thus unfolds at the height of the power of the dominant, as soon as its inelastic domestic resources are nearly exhausted, pushing it OUT to reach for resources/labor of the far periphery, formerly considered wastelands. The revolution in infrastructure, which makes the globalization possible, is signaling thus of fast approaching overextension of the dominant infrastructure. Due to growing distances, the global extraction and distribution of the dominant energy resource of the epoch become increasingly expensive leading to the fall in its marginal utility and the related returns. This starts the search for its substitutions. For example, today, oil is extracted even in war zones in Africa, oil sands in Alberta and the Rocky Mountains of the US, where it must be extracted from the oil shale, perhaps, as an alternative source of energy, natural gas. Oil also comes from biofuel *etc.,* creating thus the variation much needed for starting the future evolution and creating the basis of evolutionary choice.

Similarly, in the Middle Ages the ploughing of virginal lands formerly covered with forests ended in the ecological catastrophe immediately predating the 1348 Black Death. The "wastelands" ploughed at that time of crisis hardly returned the effort and later were laid fallow as insufficiently fertile. However, the forest did not return. Instead, there came meadows, the foundation of the next landscape and the next economy of the early industrial era in Europe. This illustrates the unexpected consequences of forced decisions, which, summarily, lead to the next era.

Thus, the revolution of infrastructure predates globalization and creates the precondition for it by opening the resources of the far periphery for the use of the then dominant. The process of globalization unfolded at the end of all the known historical periods. It was as evident during the late Roman Empire just as it is today on the much larger territory of the current globalizing world. The revolution of infrastructure is based on the development of a new material, more adequate to the task: from the mass steel mentioned above to the bog iron of the German tribes, who could settle Europe and clear-off its forests after the fall of Rome. This also applies to the early blast furnace, the foundation of the "gunboat economy" at the Age of Exploration. However, as shown above, the revolution in infrastructure creates an unexpected new problem of finding

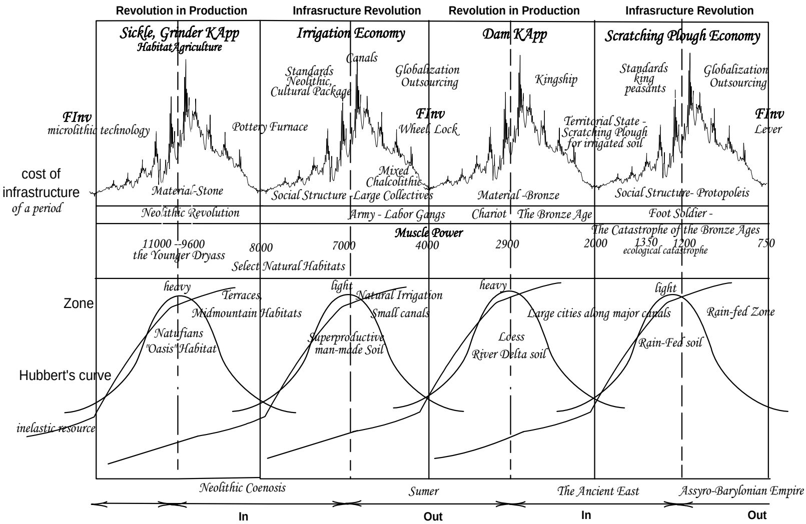
[12] Six such zones can be pinpointed, corresponding to the six historical periods traditionally accepted in history (Badalian and Krivorotov 2008).

novel applications for this revolutionary material (further material-enabler), able to fully use its unique features. Thus this material-enabler, originally designed mostly for military uses, which suddenly becomes available in quantity, creates a new point of imbalance. Its impulse is passed forth and the problem of brand new applications is eventually resolved. Usually, this happens in a new zone, through a fundamental invention, the basis of a brand new application, later called the Killer App, such as the internal combustion engine at the heart of the mass car, or the steam engine powering the locomotive a century earlier *etc.* continuing back into the past. The introduction of the Killer App starts a technological revolution in production, greatly raising the productivity of the new zone as its side effect. The latter would become the habitat for the next coenosis, thriving on the use of its riches, formerly of little if any use.

The start of the process of domesticating the next zone, immediately after the entry of the Killer App, pushes forth a new wave of imbalances and the related creative impulses. First, there must come a new domestic infrastructure necessary for the domestication of the new zone and creating a new type of geometry enabling the use of its riches. Among them, the entry and the efficiency of the mass car was co-dependent with the creation of the dense networks of highways, which followed, creating with the new geometry of suburbia, strung along them. Of course, this development, at its very inception, already carried the destructive seeds of the future Double Oil Shocks of 1971–1983 and many other problems of the contemporary US, which could not stop the maturing of its oil-based economy and the related infrastructure. Up to a point, the maturity of the mass production economy, dependent on oil was mitigated by the revolution in infrastructure started in the 1970s. The introduction of the chip led to the wave of computerization, including the system of barcodes and computerized inventories, which enabled the supermarket, the Internet and the modern globalizing economy.

If the old patterns continue to hold, simultaneously, this very revolution in infrastructure based on the chip must create the foundation for the revolution in production. The introduction of the next Killer App, still in the future, would then enable the domestication of the next zone, presumably in the current developing world, but on the new, currently unheard of, level of productivity. Technologically, this might bring to the forefront the robotics as the basis of the next economy of "small series" made "on demand". This scheme, which allows periodization of history, starting from the 1790s up to our days, was first presented by L. Badalian and V. Krivorotov (Бадалян, Криворотов 2006: 222). It is supplemented here with Figures 1–4. The latter extend this concept and show that its scenarios were applicable also far back to the past. Figures 1–4 delineate the sequence of the Fundamental Inventions of their epochs (FInv) and crucial technologies (Killer App or KApp) for 7 known historical coenoses, from the Neolithic Revolution and up to our days.

Figure 1. The Neolithic Revolution and the ancient Fertile Crescent



LEGEND: FInv stands for the Fundamental Invention. KApp stands for the Killer Application.

Figure 2. The classical antiquity and the Middle Ages

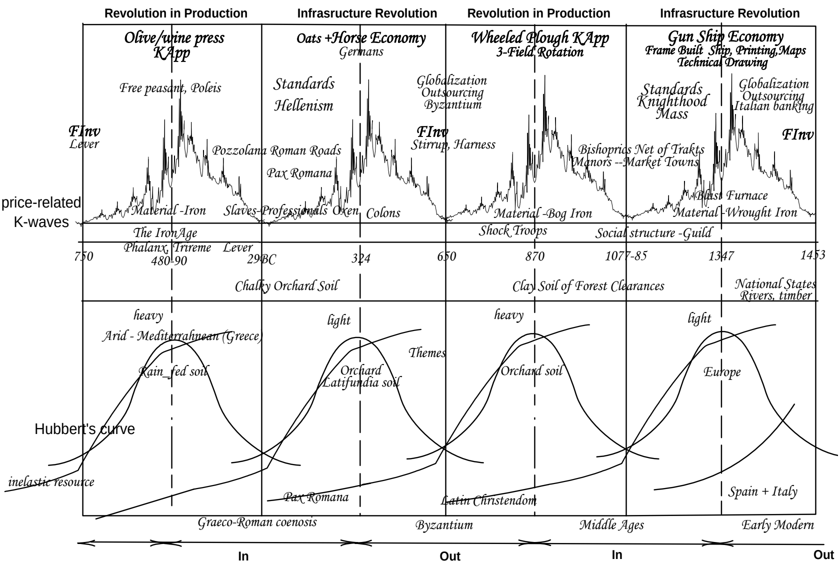


Figure 3. The Age of Exploration and the Industrial Revolution

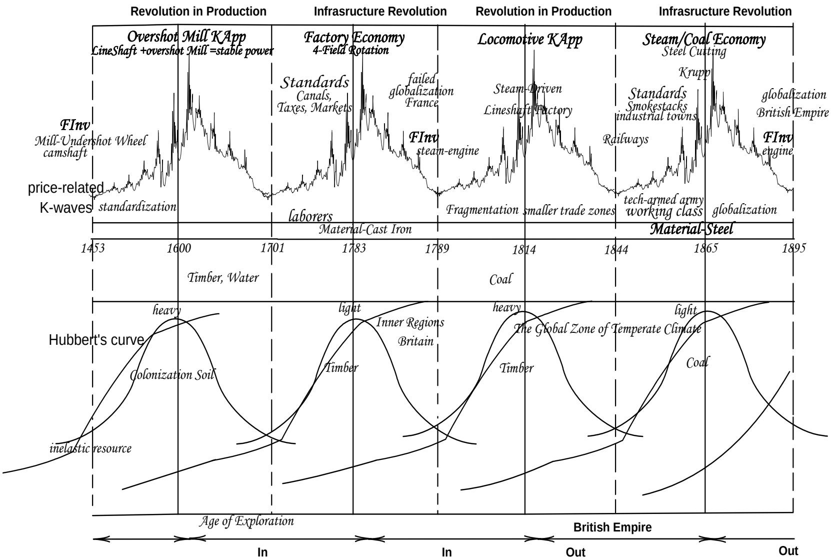
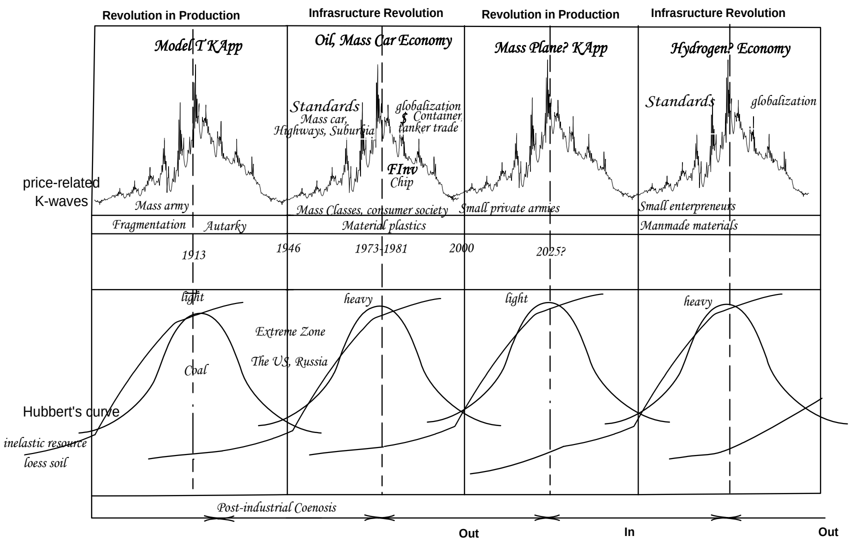


Figure 4. The mass society, US-style and the presumed future



2. The foundations of the mathematical model. Development as impulses of disequilibrium passed through historical time

The aforementioned scheme is expressed in a mathematical model below, showing the passage of an impulse within a Lagrangian mechanics. The non-classical Lagrangian model (first presented in Бадалян, Криворотов 2006: 226–240), describes a mechanics with a non-stationary mass, allowing also the case of the negative mass. This enables modeling of the entire investment process, starting from the expending the resource to build the related infrastructure and ending with the return on these expenditures from the working infrastructure. Below we show, as the laws of conservation applied both for energy and impulse can, under conditions of the stationary mass, produce the known equations of the classical mechanics (Бадалян, Криворотов 2006: 234). The Law of Energy Conservation thus serves as the mathematical framework for the passage of impulses created by disequilibria, which thus act as portions of potential energy (spent investments). They are thus converted into the kinetic energy, generated as the result of these investment flows, spent to build durable goods, including infrastructure, able to produce returns. Since returns are created as the result of the work of these flows they would be, in general, directly unrelated to the expenditures. This is due to a basic economic fact, which, by itself, makes it possible to model both investments and returns – namely, both particular enterprises and economies as a whole represent open systems. Thus, they may in fact return more than it was invested into them, or, in the case of misfortune, go bankrupt, failing to return the investment.

The conceptual economic basis for this model is provided by the interpretation, where the Lagrangian $L(x, \dot{x}, t)$ is an S-shaped function used to measure the utility of the main inelastic resource of a given zone as a parameter estimating its potential for economic growth.[13] Its first derivative, which measures the cost of the last unit of the resource sold on the market, represents thus the marginal utility and is expressed through a bell-curve.[14] The second derivative would meanwhile reflect the inelasticity of the said resource and the imbalances created by it. The introduction of the concept of the inelastic resource lets us explain a series of historical facts, including such as the rejection of a crucial resource of its era, such as coal, despite its huge known reserves, as soon as its marginal utility falls reflecting the rising prices of its production and delivery, due to the distance as the far periphery acquired growing economic importance. Our model forecasts the same outcome for oil in the midterm future (Бадалян, Криворотов 2006: 225).

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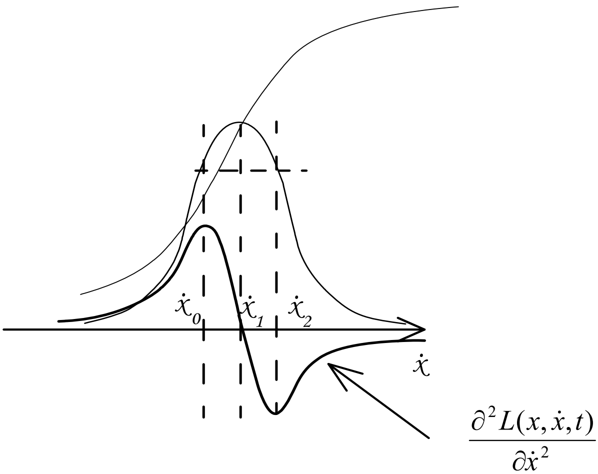
[13] This curve is drawn in Figures 1–4, where it is titled as the "inelastic resource". Let us imagine that the market needs 100 barrels of oil, half of which can be obtained sufficiently cheaply, with additional 45 barrels at twice the price, and the last 5 barrels at the ten times the price. Under conditions of complete inelasticity, with the market needing the entire 100 barrel portion for its infrastructure to fully function, the entire 100 barrels would be priced at the same level, reflecting the highest market price.

[14] In Figures 1–4 we named it Hubbert's curve following (Deffayes 2002).

In its turn, the Lagrangian $L(x,\dot{x},t)$ in the context of flows $\dot{x}$ – the first derivatives for the inelastic resource in question – presents an S-shaped curve, which has a special meaning in economics. It measures the utility of resources, which are needed to support the diverse institutions of the given society, which assure proper cycling from investments to returns. Within our terminology of evolutionary models of domesticating a zone (Badalian and Krivorotov 2006), these institutions are seen as unique feeding chains assuring the survival of its coenosis by uniting production and consumption into an indivisible, incessantly cycling whole. The second derivative of the S-shaped curve presented on Figure 5 describes thus the return per unit of such flows. Its positive part is related to expenses, while the negative part describes the return from the earlier investments, at the basis of durable goods, first and foremost, the infrastructure. In a Lagrangian mechanics as introduced below this is interpreted as an ability of the non-stationary mass to have either positive or negative values, depending on the situation and the phase in the cycle of investment-to-return.

Figure 5.



The Euler's equations for such a mechanics would bring us to uni- and multisectorial equations of economic dynamics (Бадалян, Криворотов 2006: 233–238). In the cited work, there are simple solutions of these equations (Бадалян, Криворотов 2006: 235–236), depicting the passage of an impulse (see the aforementioned examples of disequilibria, which create impulses of "potential" energy to be materialize through infrastructure understood as a repository of kinetic energy). It was shown that, for in a nearly linear case, while still safely far away from the boundaries of the zone, with its inelastic resources still plentiful and the production-consumption chains still in the more or less balanced condition, more or less approximable by an equilibrium, these equations much resemble the equations of the "Input-Output"-style, introduced by Leontieff (*Ibid.:* 237–238).

In the appendix below we describe a more complex case of an "Input-Output" dynamic model of economic growth. This model is based on balancing the economic growth through its pace, expressed through the second derivative of the resource $\ddot{x}$. By writing balance-style equations for second derivatives instead of the original functions, it becomes possible to model the process of passing disequilibrium as a linearized exchange of impulses as the basis of the concept of the proportional economic growth. Below, we show that irreducible non-linearities arise either due to the closeness to the boundaries of the zone (marked by inflationary peaks signaling of the approaching exhaustion of its inelastic resource) or within the induced sustained economic growth of the modern era, which is kept higher than the demographic growth and leads to life improvement. Under such conditions, as it is shown below, the proportionality of growth, presuming the constancy of life level disappears, and the economic growth is realized through a series of wavelike troughs and peaks. Starting from the industrial revolution, the latter are associated with the boom-bust cycles of the capitalist economy, usually accompanied with improvements in the lifestyle.

The mathematical equations below model the historical process as the passage of disequilibrium through a logically related series of technological revolutions depicted above on Figures 1–4. They can be used in the future for modeling modern economies by using standard statistics, such as available through the system of national accounts, data collected by the UN, OECD and other national and international bodies for the related economic indices. The goal is the estimation of the critical parameters warning about the approaching boundaries. The latter limit the possibilities for economic growth within a given zone as it comes closer to rejecting its dominant resource due to its gradual loss of the marginal utility – as soon as its extraction, distribution and use become too expensive to return the needed investments (see, for example, the process of rejection of coal as the dominant energy resource; Roberts [1989] considers it the underlying essence of processes between the two world wars).

3. Appendix. The mathematical foundations of the model

3.1. Economic growth modeled by a Lagrangian "input-output" mechanics

Below we illustrate the usage of the suggested Lagrangian model as a tool for estimating vital parameters of economic growth. The initial concept of a non-classical Lagrangian mechanics was presented by L. Badalian and V. Krivorotov (Бадалян, Криворотов 2006).

Let us consider a dynamic uni-sectorial model of an economy with inelastic resource x, its flow $\dot{x}$ and a standard Lagrangian $L(x, \dot{x})$, depicting an S – shaped curve of its utility. The standard Euler's equation for this case would be as follows:

$$\frac{\partial L(x,\dot{x})}{\partial x_t} = \frac{dp(x,\dot{x})}{dt}, \qquad (1)$$

where $p(x,\dot{x}) = \frac{\partial L(x,\dot{x},t)}{\partial \dot{x}}$ – generic impulse, $f(x,\dot{x}) = \frac{\partial L(x,\dot{x})}{\partial x}$ – generic force.

Calculating the partial derivative in (1) and denoting $\frac{\partial L^2(x,\dot{x})}{\partial^2 \dot{x}} = m(x,\dot{x}) = m_x(\dot{x})$, $\frac{\partial L^2(x,\dot{x})}{\partial^2 x} = k_{\dot{x}}(x)$, $\frac{\partial L^2(x,\dot{x})}{\partial x \partial \dot{x}} = K(x,\dot{x})$, $f_x(\dot{x}) = f(x,\dot{x})$, we derive

$$m_x(\dot{x})\ddot{x} + K(x,\dot{x})\dot{x} = f_{\dot{x}}(x) = \int k_{\dot{x}}(x)dx = \frac{\partial L(x,\dot{x})}{\partial x}. \qquad (2)$$

Disposing of the dissipative member $K(x,\dot{x})\dot{x}$ considered negligible, we derive the equation

$$\frac{\partial L(x,\dot{x})}{\partial \dot{x}} = m_x(\dot{x})\ddot{x}. \qquad (3)$$

Assuming that we are in the "productive" stage of the curve of return per unit of investments $m_x(\dot{x})$ (Бадалян, Криворотов 2006: 229–230), we obtain

$$-m_{ret} = m_x(\dot{x}) < 0. \qquad (4)$$

The generic force $f(x,\dot{x})$, which here is equalized with the marginal utility presented through the market price, is generated by the expenditures during the "spending" stage $f_-(x,\dot{x})$. In its turn, this is equal to all the expenses on production/distribution of this resource and the remnant $f_+(x,\dot{x})$ – the value created through these investments. Then

$$f(x,\dot{x}) = -f_-(x,\dot{x}) - f_+(x,\dot{x}), \qquad (5)$$

where

- $f_-(x,\dot{x})$ – function of marginal expenses. This is the part of the marginal utility of the given inelastic resource related to investments (materials, labor, amortization), which here represent the expenditures per unit of production.
- $f_+(x,\dot{x})$ – function of marginal added value. This is the part of the marginal utility of the resource, which is value-added during production per unit of resource.

The functions of aggregated value, costs and added values for the given resource X can be calculated using the formulae:

$$F(X) = \int_0^X f(x,\dot{x})dx, \qquad (6)$$

$$F_{-}(X)=\int_{0}^{X} f_{-}(x,\dot{x})dx\,, \tag{7}$$

$$F_{+}(X)=\int_{0}^{X} f_{+}(x,\dot{x})dx\,. \tag{8}$$

The minus sign in (4) means that the function $f(x,\dot{x})$ measuring value may, in general, have negative values. Note that $f(x,\dot{x})$ and $m_x(\dot{x})$ become negative for the mature economy, when $\dot{x},\ddot{x}>0$ means that forces start supporting the direction of movement, presenting the inertia of the system.

It would be natural to suggest that the return from investments m_{ret} is sufficiently large, so $f_{-}(x,\dot{x})<m_{ret}\ddot{x}$, and the added-value $f_{+}(x,\dot{x})$ remains positive. We also assume conditions of stable economic growth with a constant coefficient of return. Then, depending on the behavior of the complete function of value per unit of resource $f(x,\dot{x})$, which plays the role of the aggregate force in equation (2), we obtain the functions of economic growth below.

1. Conditions of constancy of value per unit of product $f(x,\dot{x})=-f_0=const<0$. It is easy to see that in this case we obtain conditions for constant economic growth $\ddot{x}=\dfrac{f_0}{m_{ret}}$ and production of resource in time is described by the quadratic curve $x(t)=\dfrac{f_0t^2}{2m_{ret}}$, where m_{ret} comes from equation (4). Further, we obtain $F(t)=\dfrac{(f_0t)^2}{2m_{ret}}$, with the pace of the economic growth determined by $\ddot{F}(t)=\dfrac{f_0^2}{m_{ret}}$.

2. Conditions of moderate linearized inflation (deflation). Situation described in p. 1 is, in general, preserved in the case of moderate, nearly linear inflation or deflation, linearly dependent growth. For example, for the Lagrangian we obtain

$$L(x,\dot{x})\;=\;-f_0\,x(1+\alpha\dot{x})-\frac{m_{ret}\,\dot{x}^2}{2}\,. \tag{9}$$

Under these conditions, the aggregate impulse $p(x,\dot{x})=\dfrac{\partial L(x,\dot{x})}{\partial\dot{x}}=-f_0\alpha x-m_{ret}\dot{x}$, thus, the dissipative core differs from zero $K(x,\dot{x})\neq 0$.

For this case, Lagrangian with inflation α and constant speed of growth f_0 works in the same way as the Lagrangian for constant growth lacking inflation (dissipation), thus, $L(x,\dot{x}) = -f_0 x - \frac{m\dot{x}^2}{2}$ since the dissipative members on the right and on the left compensate each other. This can be easily demonstrated, keeping in mind that the equation (2) under conditions of linear inflation transforms into $m_x(\dot{x})\ddot{x} = f_0 + (\alpha - K(x,\dot{x}))\dot{x}$ and then into $m_x(\dot{x})\ddot{x} = f_0$, since $\alpha - K(x,\dot{x}) = 0$.

3. Conditions of moderate inflation growing according the polynomial law. It is easy to see that for moderate inflation growing according the polynomial law and with the Lagrangian $L(x,\dot{x}) = f_0 x(1+\alpha\dot{x}^n) + \frac{m\dot{x}^2}{2}$ we obtain the formula

$$m_x(\dot{x})\ddot{x} = f_0(1-\alpha n\dot{x}^n)\,. \qquad (10)$$

This shows that, for the case of the moderate growth of the GDP, the growth remains polynomial, however, inflation quickly "eats" into it, reducing the growth to nearly zero and more or less constant GDP.

4. Conditions of moderate deflation. This creates the opposite conditions of Lagrangian $L(x,\dot{x}) = f_0 x(1-\alpha\dot{x}^n) + \frac{m\dot{x}^2}{2}$ and equation (11), where

$$m_x(\dot{x})\ddot{x} = f_0(1+\alpha n\dot{x}^n)\,. \qquad (11)$$

3.2. Closed economy

3.2.1. Input-output style equations depicting growth in multi-sectorial economy

3.2.1.1. Balancing pace of growth for production

A closed economy includes a full system of productive industries, which is balanced by the pace of growth of intermediary products which are exchanged among member-industries in the absence of imports or exports. The existence of a closed production system presumes its balance with two other systems: namely, consumption, represented through demography (the man), and extraction (the nature).

Let us assume that there is no dissipation and the vector of production is fully utilized, which means that all industries produce in a stable regime. Then, the resulting flow, despite its wavelike deviations, may be assumed constant.

x, y, z denote production in extractive, productive and consuming sectors, composing together a full-scale economy. Then $\dot{x}, \dot{y}, \dot{z}$ would denote the resulting flows, and $\ddot{x}, \ddot{y}, \ddot{z}$ – the related pace of growth for the products of the aforementioned sectors within a given economy.

From the point of view of balancing the resulting aggregate forces (2) the productive sector would generates two kinds of forces:

- The force generated by returns from an industry Ω. This is related to the constant negative mass $-m_{\Omega}$ (coming as return from the earlier investments into the infrastructure), and is denoted as $-m_{\Omega}\ddot{y}_{\Omega}$ in the right part of the balance equation (2).
- The force of inter-sector expenditures $-m_{\Omega j}\ddot{y}_j$, where $m_{\Omega j}$ are the inter-sector "input-output" Leontieff-style coefficients, whose applicability was researched by L. Badalian and V. Krivorotov (Бадалян, Криворотов 2006: 237–238).

3.2.1.2. Balancing the extractive sector through the pace of growth of productive sector

Among industries of the extractive sector we consider only those related to the dominant inelastic resource. In contrast, the extractive industries producing elastic resources are able to increase or reduce their output at will. In this sense, they are similar to the industries of production and may be disregarded, since their Leontieff-style coefficients can be kept sufficiently stable. However, as soon as the resource in question becomes inelastic, the related Leontieff-coefficients lose their stability, as economic imbalances grow. This is caused by increasing imbalances in supply-demand, which become observable through substantial movements of prices. This may cause significant changes in established ratios along with shifts in consumption of the given inelastic resource i in different industries Ω .

$f_i(x_k, \dot{x}_k)$ are the ratios of prices related to the consumption of the inelastic resource in the given industry per unit of time, usually, a year. In this way, such industries $i \in I = \{1,2,..., N_I\}$ which cannot avoid consumption of the inelastic resource would add non-linear, swiftly growing members into the equation. Then, for the given inelastic resource i we obtain the Euler's equation $f_i(x,\dot{x}) = \frac{dL(x,\dot{x})}{dx_i}$, where $f(x,\dot{x}) = f_i$ is the price of the inelastic resource i per unit of time, and x and $\dot{x}$ represent the aggregate vectors of resources for the given economy. Respectively, for a given industry-consumer of the said resources Ω, its ratio of expenses related to the consumption of this inelastic resource would equal $-e_{\Omega i} f_i$.

3.2.1.3. Creation of nonlinearities and labor as the end product of the productive industries

In its turn, the consumer sector uses products of the productive industries and produces labor. The latter, just as the inelastic resource produced by the extractive sector, is inelastic, at least to a degree, and tends to preserve its proportions, and respond to increases/falls in demand with a significant lag. This lag creates imbalances, since the demand for labor varies with business cycles, while its supply depends on demography, a much slower process, which generally correlates with the economic growth. Meanwhile, the overall level of consumption is inert, preserving its level, at least for a while, even after the real income went up or down.

This would mean that consumption, a relatively stable parameter, may respond to relentless pressure from outside forces by resisting them for a while and then rapidly shifting to a different level. Thus, it is characterized by a strong local non-linearity. This parameter is defined, just as the other essentially non-linear parameters above, by the ratio c_Ω of relative expenses C for consumption per unit of time. The same applies to savings – $S = A + I$ c – where the ratio is i_Ω.

Thus, for a closed economy we obtain a system of Ω equations, one per industry, be they in production, consumption or extraction.

$$-e_{\Omega i} f_i - m_{\Omega j} \ddot{y}_j - c_\Omega C - i_\Omega S = -m_\Omega \ddot{y}_\Omega, \qquad (12)$$

where

- Ω – the number of producing industries $-m_\Omega \ddot{y}_\Omega$ per industry Ω,
- j – index to measure the pace of investments $-m_{\Omega j} \ddot{y}_j$ for all producing industries providing an input for an industry Ω,
- i – index summarizing all expenses $-e_{\Omega i} f_i$ for all the extracting industries producing inelastic resources and serving as suppliers for the industry Ω,
- c_Ω – ratio of expenses for industry Ω from the aggregate C,
- i_Ω – ratio of expenses for industry Ω from aggregate savings S.

By denoting the total consumption as $K = C + S$ and as k_Ω its ratio for industry Ω the equation is simplified to

$$-e_{\Omega i} f_i - m_{\Omega j} \ddot{y}_j - k_\Omega K = -m_\Omega \ddot{y}_\Omega. \qquad (13)$$

Under conditions of a single inelastic resource the equation acquires the following form:

$$-e_{\Omega i} f_i - m_{\Omega j} \ddot{y}_j - k_\Omega K = -m_\Omega \ddot{y}_\Omega. \qquad (14)$$

3.2.1.4. Supporting economic growth by balancing the producing industries. Non-linearities and their role in the economic growth

We assume the relative stability of

$$g_\Omega G = e_\Omega f + k_\Omega K \qquad (15)$$

during the main productive period of a given economy. Its stability is based on the fact that the extracting industries and the producing industries which make the end-product are redistributing the rent, which, at the end, comes from the territory. The producing industries serve as the netto-buyers, while the extracting industries serve as the netto-sellers, who receive the natural rent. The aggregated sector G, with the addition of the non-linear members related to the extractive industries, production and consumption, is further called the sector of reproduction of the economic growth.

Under these conditions, the aggregate sector G of equation (15) holds all the non-linearities, which, at the end, are caused by economic growth, which thus acquires a cyclical form, typical for modern economies. If, at contrary, there are no non-linearities, then all industries, extracting, producing and consuming, would stabilize at some linear levels regarding each other. Then, instead of non-linear aggregate forces f, C, I, related to the expense of extracting the inelastic energy resource, consumption and production, we will get an aggregate inertial member $m^g_{\Omega j}\ddot{x}_j$, related to the exchange between industries causing a linear transfer to a given industry Ω ad infinitum

$$-m^g_{\Omega j}\ddot{x}_j - m_{\Omega j}\ddot{y}_j = -m_\Omega \ddot{y}_\Omega, \tag{16}$$

where $m^g_{\Omega j}$ are the respective linear input-output Leontieff-style coefficients and $\ddot{x}_j$ measures the pace of growth of the respective extracting, producing and consuming industries. By integrating both left and right sides of (16), we obtain the Leontieff input-output equations. This means that specific ratios of extraction, production and consumption may strike a nearly linear balance, with a slow economic growth proportional to the demographic increase. This implies the possibility of a nearly proportional growth, which, until it hits the territorial limits related to the loss of marginal utility of the main inelastic resource, can go on its own and does not require any special support. This conclusion is supported by the observable rhythms of economic history. In preindustrial societies the pace of growth was barely sufficient for stabilizing the life level and followed the demographic growth. The situation came out of control only upon approaching the resource limits of the related geoclimatic zone, where there were generated significant non-linear forces to compensate for both the inelasticity of the main resource and the inelasticity of consumption. Production, as always, remained the most elastic of all industries, a condition, which could be historically observed through fast increases in manufacturing during the time of agricultural shortages noted, for example, by Fischer (1996). In short, an established society could basically support itself, as long as it still had sufficient resources of its main inelastic resource. Thus, social upheavals and major wars usually signaled the approaching exhaustion of the natural resources of their zone. In this sense, the economic growth, which acquired a cyclical character in the West starting from the Industrial revolution, created a system of non-linear industries, which supported the accelerating growth through transfer of imbalances. Thus, there was created an impulse, passed, in a wavelike manner, while the boundaries of the zone were still safely far away, from the extractive industries to production via investments.

By grouping all the non-linearities into a special aggregate sector *G* devoted to the support of the economic growth, the equation (16) acquires the following look:

$$-g_{\Omega}G - m_{\Omega j}\ddot{y}_j = -m_{\Omega}\ddot{y}_j\,. \tag{17}$$

With linearity of coefficients $g_{\Omega}, m_{\Omega j}, m_{\Omega}$ and the expenses per sector G per unit of time, equation (17) becomes linear. The difference from the standard input-output Leontieff models consists in making it linear regarding the pace of growth, instead of production of industries as it was done in the original input-output models. This allows solving a basically non-linear equation by linearizing its derivatives. We thus balance not the flows of resources, which are fundamentally nonlinear, but the speed of growth, which, among other things, may acquire negative values.

3.2.2. The input-output equation for consumption

The sector of consumption works as any other industry in the sense that it also produces a resource, which is labor, and then exchanges it with other sectors for their products. From the point of view of input-output model as the balance of aggregate inter-industry forces (2) the sector of consumption creates and applies to other industries two types of forces:

- The recoil force coming from the sector of consumption, which is related to the constant negative mass $-m$ (this is the return from the earlier investments into infrastructure projects), and is defined as $-m\ddot{z}$ in the right part of the equation of balance (2), where the variable $\ddot{z}$ measures the pace of growth of the consumption sector. This means that workers, who were born at the time of economic expansion, as demographic response to the market stimuli, may be entering labor force even if it happens to be contracting.
- Forces related to expenses incurred by the supplier-industries $-m_{\Omega j}\ddot{y}_j$, where $m_{\Omega j}$ are the inter-industry Leontieff coefficients.

Then, the return from the consuming sector comes from the entire economy materializing as its end product, the society at large, which can reproduce on the basis of economic growth, while domesticating its territory. In its turn, the end product consists of pure consumption $C = C_{-} + C_{+}$ at the subsistence level and discretionary spending plus savings $S = A + I$ adding up to cover costs of amortization and investments

$$-C - I = -m\ddot{z}\,. \tag{18}$$

We should also keep in mind the linear forces of "recoil" from investments in regard to consumption – $m_j^c\ddot{y}_j$ and savings – coming from the producing industries. Namely,

$$-C = -m_j^c \ddot{y}_j\,, \tag{19}$$

$$-S = -m_j^s \ddot{y}_j\,. \tag{20}$$

Together, this adds up to

$$-m_j^c \ddot{y}_j - m_j^s \ddot{y}_j = -m\ddot{z}\,. \tag{19}$$

Equations (19) balance the pace of growth for the sector of consumption. Taken with equations (12) written for the sector of production they would complete the system, which now represents all sectors of an economy. The linear character of equations (19) does not change the results of 3.2.1.4.

In this way, the aggregate sector $G = f + C + S$ supports the economic growth by passing imbalances as an impulse for further changes within the entire system. This remains the source of nonlinearities for both producing and the consuming sector. It cannot be fully balanced and becomes the source of economic growth for modern economies while they are still stable and do not suffer from significant shortages of their main inelastic resource. Simultaneously, the existence of inelasticity, first and foremost, in

- inelastic energy sources;
- the inelasticity of consumption, which cannot be reduced below the minimal level for the given society;
- the inelasticity of savings, due to amortization and the need of minimal, irreducible level of investments to support the existing infrastructure, with additional investments needed for growth

explains the cyclical nature of modern economies. The latter grow while they still possess structural sources of growth within the sector $G = f + C + S$. The latter supports economic growth, while there is still the ability to pass along the initial impulse coming from the extractive sector of the given geoclimatic zone and create a new source of investments into its domestication. As soon as the resources of the given geoclimatic zone get nearly exhausted, its economic growth is curtailed starting a crisis, which pushes the dominant to go OUT to the far periphery, formerly considered wastelands. At the end of the day this pushes towards domesticating the next geoclimatic zone, first, by substituting the exhausted resource of the older zone with its virginal resources upon developing new technologies of using them. Meanwhile, the existence of a structurally embedded source of growth in the modern economies is usually associated with the sustained economic growth, which is faster than the pace of the demographic growth and thus leads to the improvement in the living conditions. The latter first appeared in modern economies after the 1850s, as a notable shift from subsistence economies predating the modern era. Meanwhile, nothing ever comes for free. The modern economic sustained growth has in its foundation a deep-seated instability. It substantially raises the level of associated risks, since it is cyclical in its very nature and presumes a sequence of booms and busts, some of these, perhaps, quite drastic and painful (see, for example, the two world wars, which were seen by John Roberts, a noted British historian, as the time of a societal switch from coal to oil [1989]).

In their turn, the planned economies of the countries of the former socialist block ignored the resource inelasticity of modern economies and their resulting cyclical nature. Even worse, their rigid distribution system further amplified the limitations of inelasticity by discouraging people from going OUT and looking for available alternatives in the search of personal gain. The economic planning became increasingly rigid as time went. This increased its inefficiency and the ability to self-balance. The best time of the planned economies coincided with the period of elastic and easily available resources. This was curtailed as shortages gradually amplified, and the inelasticities grew manifold in the rigid environment of the central planning closer to the end of the 1980s.

3.3. On Lagrangian mechanics related to the "input-output" model

Below we illustrate the family of Lagrangian mechanics related to the afore-mentioned dynamic model, which balances different sectors through linearizing their respective paces of growth. For this, we extend the family of Lagrangians, simultaneously formalizing the concept of a mechanics.

Definition

Let us assume that a stationary Lagrangian function $L(x,\dot{x})$ defines a global mechanics for all finite x and $\dot{x}$, if the following conditions are duly satisfied:

1. $L(x,\dot{x})$ is defined on all trajectories $x(t)$, $\dot{x}(t)$, where $t \in [0,\infty]$.
2. $L(x,\dot{x})$ is uninterrupted, monotone and has a limited measure for x and $\dot{x}$.
3. $L(x,\dot{x})$ has a single point of bend. Otherwise, its tangent becomes normal (vertical) when $t \to \infty$.

In the contrary case $L(x,\dot{x})$ defines a local mechanics as a limit of some global mechanics in the locality x or $\dot{x}$.

For economic interpretations of Lagrangian mechanics the two conditions of having a single point of bend or the existence of a normal tangent means that, for the second case, the mechanics is limited to positive – expense-driven values of the recoil (return) coefficients $\frac{\partial L^2(x,\dot{x})}{\partial \dot{x}^2}$ or to the friction caused by the increase in inelasticity $\frac{\partial L^2(x,\dot{x})}{\partial x^2}$.

Under conditions of definition 1 the Lagrangian $L(x,\dot{x})$, represented by an $S-$shaped curve of "Input-Output" type, is obviously a mechanics, since it is defined on all trajectories $t \in [0,\infty]$ and has a single point of bend. Meanwhile, a series of Lagrangians, which represent known physical mechanics, also satisfy the definition 1, even though they might not be distributed along an $S-$shaped curve and are, in accordance to p. 3 of definition 1, limited by a normal tangent.

Among them, the Lagrangian $L(x,\dot{x}) = -mc^2\sqrt{1-\frac{\dot{x}^2}{c^2}}$ represents the mechanics used in the special theory of relativity for a material point. On a closed interval $\dot{x} \in [0,c]$ the Lagrangian $L(x,\dot{x})$ presents the upward segment of an ellipse $\left(\frac{L}{mc}\right)^2 + \dot{x}^2 = c^2$ from the point $L = -mc^2, \dot{x} = 0$ to the point $L = 0, \dot{x} = c$, representing the ray $t \in [0,\infty]$ starting from $t = 0$. It is easy to see that $L(x,\dot{x})$ has a normal tangent for $L = 0, \dot{x} = c$ when $t \to \infty$. Regarding the classical mechanics, it, according to the definition 1, is local and is restricted to the area of classical speeds $\dot{x}$.

These examples provide a preliminary idea of the family of mechanics defined by 1 and related to S-shaped Lagrangians. Besides the economic applications, demonstrated above, these also include the known families of physical mechanics, including the classical mechanics along with the mechanics of the special theory of relativity. In our future works we will show the applicability of definition 1 to a much wider series of mechanics with applications in physics, economics and other sciences.

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Abstract

The article presents the concept of history as domestication of a sequence of nested geoclimatic zones. Each of these zones possesses clearly marked boundaries, its own unique package of domesticated animals and plants, its special dominant energy source *etc.* Its zones – specific social institutions – are organized into a system of feeding chains optimizing thus the use of its resources. The mathematical model of historical development presented in the article describes development as a fundamentally nonlinear process – imbalances are compensated by passing any impulses that they generate farther along the "chain". It is shown that the phase of globalization is compensatory and starts after all the crucial resources within the initial zone are nearly exhausted. This especially applies to the main energy source of the era, which, at the maturity of the system, has to be brought in from abroad to prevent its systemic shutdown. The periphery thus joins the cultural area of the then dominant, such as the US today. Since its conditions are substantially different, it has to compensate by developing its unique local adaptations. Wars, such as those currently unfolding in the Middle East, or, for example, the 1871 French-Prussian war signal of rising tensions due to growing shortages and of attempts to find brand new solutions. We use historical examples to showcase the compensatory process of passing imbalances along the chain. They function as impulses, which ignite development in new places as soon as the growth potential of the older zone is exhausted. The periodical nature of this process, which leads to the domestication of a new geoclimatic zone, is shown in attached pictures.

Keywords: long waves, dynamic models, general equilibrium, points of disequilibrium, market pendulum.