



THE UNIVERSAL LAW OF GRAVITATION AND THE DEATH OF DISTANCE

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Biographical note

Peter Nijkamp is Professor in Regional and Urban Economics and in Economic Geography at the Free University, Amsterdam. His main research interests cover plan evaluation, multicriteria analysis, regional and urban planning, transport systems analysis, mathematical modelling, technological innovation, and resource management. In the past years he has focused his research in particular on quantitative methods for policy analysis, as well as on behavioural analysis of economic agents. He has a broad expertise in the area of public policy, services planning, infrastructure management and environmental protection. In all these fields he has published many books and numerous articles. He is member of editorial boards of more than 30 journals. He has been visiting professor in many universities all over the world. He is past president of the European Regional Science Association and of the Regional Science Association International. He is also Fellow of the Royal Netherlands Academy of Sciences, and is immediate past vice-president of this organisation. Since June 2002 he serves as president of the governing board of the Netherlands Research Council (NWO). In addition, he is past president of the European Heads of Research Councils (EUROHORCs). In 1996, he was awarded the most prestigious scientific prize in the Netherlands, the Spinoza award.

Abstract

This paper addresses the validity of Newton's universal gravitation law in the emerging digital world. It is argued that the Newtonian gravity principle may also have a validity in cyberspace, but that Tobler's 'First Law of Geography' offers a more appropriate approach.

Keywords: Newton's law, spatial economy, Digital World

JEL Classification: R10, R12

1. Newton and Social Science

Novel scientific insights into the mechanism and dynamics of our world have often been induced by seemingly simple discoveries. In this thrilling book '*The Great Equations*', the author Robert P. Crease (2008) offers a fascinating record of universal equations that have decisively influenced the history of science. He mentions inter alia the equations ascribed to – or developed by – Pythagoras, Newton, Euler, Maxwell, Einstein, Schrödinger and Heisenberg.

Newton's *Law of Universal Gravitation*, sometimes coined the 'high point of the scientific revolution', is as simple as it can be in its pure form. It stipulates that gravity is a universal force among all bodies, while the gravitational strength between two bodies depends directly on their masses and inversely on the square of the distance between their centers. This law was not invented overnight; it took Newton almost four years (1684-1687) to conceptualize it as a full-proof truth in the form of a single mathematical equation.

The idea that all objects attract each other with a force that is proportional to the product of their masses and inversely proportional to their squared distance has been a center piece in the development of physics and astronomy; it brought more or less together terrestrial physics and celestial physics.

Clearly, Newton's law has decisively influenced the scientific progress in the natural sciences. However, there has been an ongoing complementary strand of literature in the social sciences, called *social physics*, which has also boosted a great popularity of the gravitational law in spatial interaction phenomena. In particular, in such disciplines as economics (e.g., international trade), demography (e.g., migration behaviour), transportation science (e.g., travel behaviour), geography (e.g., spatial allocation) or regional science (e.g., commuting), a great many conceptual and empirical studies on spatial interaction have been published. The present paper has two aims: (i) to provide a concise overview of some prominent and interesting applications of gravity theory in the social sciences ('*social physics*'), and (ii) to critically review the arguments that in a digital '*death of distance*' the Newtonian gravitational principle would no longer hold. We arrive at the conclusion that gravitational principles are likely to be valid also in a virtual reality, albeit in a modified way.

2. Newton in a Social Science Perspective

Newtonian physics was based on the identification of laws in a material world. But the space-economy is a mix of tangible and physical regions and often intangible human-behavioural constellations. The spatial economy is not a result of a random nor of a deterministic process, but emerges out of rational decisions and interactions of a multiplicity of actors. For example, the rise

of large industrial concentrations near accessible places and the growth in international trade of industrial goods are not separate developments, but two interlinked factors. The structure of the spatial economy may seemingly look rather complex, but has at the same time a deep underlying economic foundation. This can be exemplified by referring to the work of one of the founding fathers of structured land use analysis, Johann Heinrich von Thünen, who was able to combine locational market advantages with transport and production in order to derive a consistent relationship between land rent and a hierarchical ordering of industrial activities in geographical space.

The spatial economy does not only have a rational structure, but also a systematically organized interaction and flow system (transport, mobility, trade, telecommunications). The conceptual basis for a systematic analysis of spatial interactions in relation to centres of human activity and distance friction costs stems from Newtonian gravity theory. This theory has served as a conceptual and analytical framework for many flow analyses in the social and spatial sciences, e.g. in the analysis of migration, trade, tourism, and commuting flows. It has become a mainstream toolkit in regional and urban economics, in economic geography, and in trade and transport economics. A thorough analysis of the underlying principles of Newton's gravity concept reveals that the application of this concept to spatial interactions and flows is supported by two principles, viz. agglomeration advantages and distance friction costs. Consequently, the use of gravitational principles in quantitative spatial interaction analysis can be justified on theoretical-economic grounds (the so-called '*social physics*') (see also Nijkamp and Reggiani 1988).

It is not a widely known fact that one of the earliest fathers of '*social physics*' was a Polish scholar, Benon Janowski. In 1908 in Cracow, he published (in Polish) an important book, *On Distances as a Factor of Cultural Development. A Socio-natural Study*. After a hundred years this work has recently been translated into English, finally becoming available to an international audience (see Janowski 2013).

The permanent popularity of the gravity principle in the spatial sciences has also prompted the recognition of a hierarchical structure in the organization of space. This is not only reflected in central place theory à la Christaller or Lösch, but also in subsequent statistical regularities known as the Zipf law and its companion, the Gibrat law. Both laws have been the subject of intensive quantitative research in the past decade and have highlighted the existence of hierarchical systems in spatial economics and in industrial organization (see also Reggiani and Nijkamp 2013).

Another new trend which is noteworthy in the context of spatial interaction phenomena is the emergence of the digital world. This phenomenon has led to many speculative remarks on the future of the spatial economy, such as the '*death of distance*' hypothesis. In reality however, ICT

development has not yet led to the disappearance of the importance of space; the digital world is for the time being not a substitute for the material world, but reinforces existing physical patterns determined by cost frictions. Consequently, agglomeration formation and physical transport patterns have not yet shown a decline nor a fundamental shift. And it remains to be seen whether this will ever happen in the future. This intriguing phenomenon will be further discussed in Section 3.

There has been an ongoing debate over the past decade whether regional development is the result of autonomous forces which through centripetal and centrifugal impacts – in relation to size, scale and distance factors – determine the fate of a region (or system of regions), or whether regions are man-made geographical entities which through smart behaviour, self-organizing talents and effective policy interventions can decide on their actual and future fate.

In the recent literature we observe an increasing interest in the analysis of complex systems at the interface of Newton's principles and socio-behavioural systems. An interesting example is found in 'econophysics'. This methodological approach deals with complex systems where properties cannot simply be derived and predicted from the knowledge of initial states of these systems (see Schinckus 2013). This approach follows earlier new advances advocated by Stanley et al. (1996), in which physical science principles are brought in the domain of economics (e.g. financial systems). Agent-based models are to some extent based on such principles.

Clearly, in reality the regional force field has proven to be a mix of human action and exogenous physical forces. Physical distance plays no doubt an important role in material flows, but the smart use of interregional networks – through the use of intelligent logistics and spatial connectivity linkages – may mitigate the traditional barriers imposed by physical and geographical distances. And consequently, digital distance mechanisms become increasingly important, such as electronic orders (e.g., call centres), or advanced business services (e.g., electronic mail). If electronic technology assumes such an important place, the question arises what the impacts will be on trade or transport or – in a more extreme case – whether the friction role of physical distance will vanish in a virtual reality.

3. Isaac Newton versus Waldo Tobler

The universal gravitational principle holds for the material world. This was clearly articulated by Newton when he stated: "It is inconceivable that inanimate Matter should, *without the Mediation of Something else, which is not material*, operate upon and affect other matter without mutual Contact" (Isaac Newton, *Letters to Bentley*, 1692/93). Consequently, he drew the inevitable conclusion: "Gravity must be caused by an Agent acting constantly according to certain laws".

Newton's gravitational principle has laid the foundation for spatial interaction and spatial gravity models. The first application of the gravity model to population flows dates back to Ravenstein (1885). In the post WWII period many gravity model applications were made, amongst others by Isard (1960), Tinbergen (1962), and Linnemann (1966), in particular in the context of transport and trade studies.

It is noteworthy that in the 1970's, when gravity principles found their first entry into the social sciences – and in particular, the spatial sciences – a law was formulated by Tobler (1970), which had a great resemblance to Newton's gravitational principle and was sometimes even based on an almost identical formulation. This so-called '*First Law of Geography*' was specified as follows: "*Everything is related to everything else, but near things are more related than distant things*". This law is clearly broader than Newton's law, namely in two respects: (i) it is not taking for granted an inverse squared distance effect, but a much more general distance friction; (ii) it talks about 'everything', and not only about matter, so that also ideas, concepts or knowledge are encapsulated by this law. Especially the latter element is important in the context of our subsequent treatment of the digital world.

A new strand of literature can be found in the class of entropy models (see e.g. Wilson 1970), in which entropy principles were combined with distance frictions phenomena into the class of spatial interaction models. These models were mainly meso-macro in nature and depicted mainly systemic regularities, that were compatible with Newton's Law.

Another class of models closely linked to spatial interaction models is formed by discrete choice models (or random utility models), which were mainly based on micro-behavioural principles in space (see Tversky and Kahneman 1980). These models gained much popularity over the past decades, and laid the foundation for logit and probit analysis. Reggiani and Nijkamp (1988) were able to demonstrate the behavioural economic equivalence of gravity models, entropy models and discrete choice models.

More recently, Krugman (1995) argued that these spatial interaction concepts might be cast in the context of two main factors, namely agglomeration phenomena (masses in the Newtonian sense) and distance frictions costs. It is noteworthy that it seemed as though around the turn of century the class of spatial interaction models had reached a stage of maturity, leaving less scope for further innovative thinking. But then a challenging proposition was made by Cairncross (1997), when he formulated '*the death of distance*' hypothesis. This was a straightforward challenge to the validity of gravitation principles in a digital world. This will be further discussed in Section 4.

4. The Validity of the Gravity Law in a Digital World

The validity of the universal ‘principle of locality’ in physical space à la Newton may be questioned from the perspective of digital connectivity in virtual space. A seminal contribution to this issue has been provided by Castells (1996), who introduced the so-called ‘*space of flows*’. This notion has prompted new concepts, viz. ‘*virtual geography*’ (see Batty 1997) in which a distribution was made between cyberspace and cyberplace, and ‘*internet geography*’ (or ‘*cybergeography*’ (see Gorman and Malecki 2000), which stipulates that also the Internet is not a homogeneous system with an equal spread or access around geographical space. Kitchin (1998a, 1998b) has argued in this context that the cyberspace depends on real world’s fixities found in a concrete cyberplace. A review of the literature in this field can be found in Tranos and Nijkamp (2013), while a thorough treatment of this issue can be found in Tranos (2013).

The research on cybernetworks has centred on two flight paths, viz. (i) exploratory research on the complex nature of digital communication networks, with a particular view to the impact of distance factors (Reggiani et al. 2010; Tranos 2011), and (ii) explanatory research on the impact of physical distance – and broader relational proximities – on the formation of cyberspace in the context of gravity models à la Newton (see Barabasi 2012). Much of this recent research is undertaken in the spirit of the ‘*new network science*’, with a focus on large-scale real-world networks and their universal, structural and statistical properties (see e.g. Albert and Barabasi 2002, Newman 2003, and Watts 2004).

The above described two-step procedure has been extensively experimented and tested by Tranos and Nijkamp (2013) by investigating the traceroutes of the overall Internet use on the basis of inter-city digital (IP) links during the period 2005-2008. The results on the nodes degree distribution of the Internet offer interesting pictures of a power law distribution for the most connected nodes of the IP network, and an exponential law for the least connected nodes, while also a Tanner function has been tested. This result is largely in agreement with general – physically-based – networks in geography (see Reggiani and Nijkamp 2013).

The next – explanatory – step in the analysis of Tranos and Nijkamp (2013) specifies a Newtonian distance-decay model, complemented with various types of relational proximities (see Boschma 2004, and Torre and Gilly 2000). The analysis of these proximity impacts on cyberplaces is based on cognitive, organizational and institutional proximity indicators, as well as on Newtonian mass variables (e.g. population). On the basis of a panel-data random effects model, the authors come to the conclusion that in all cases the Newtonian distance friction effects and the population masses play a major role. In addition, various proximity indicators play a role as well. The IP

connectivity appears to be higher between neighbouring regions in terms of physical, technological, organizational and institutional distance.

Although the digital communication patterns are not necessarily subjected to Newton's universal gravitational principle in a physical world, it turns out that in practice they follow a similar principle. Consequently, it turns out that Tobler's '*First Law in Geography*' – referring to everything, and not only to physical matter – has a validity in a digital world. Thus, this generalized Newton principle reflects most likely a universal pattern. In conclusion, we may conclude, that in a digital world Newton is likely right, but Tobler is more right.

5. Is the Digital World a Flat World?

Our planet is full of high- and low-density settlement patterns and industrial agglomerations. IP links more or less mirror this pattern, even though technically the Internet world might be completely flat. But in the real world there are apparently centripetal forces that lead to a spatial concentration of IP links in specific locations, which act as magnets of a digital infrastructure. Similarly, there are also centrifugal forces that serve less connected regions and hence provide a base level of connectivity for dispersed locations. Apparently, as result of agglomeration benefits, core-periphery patterns can be identified in the global digital connectivity patterns.

In an interesting article by Rietveld and Vickerman (2004), the authors argue that the hypothesis of the '*death of distance*' is premature. They mention several reasons: (i) the assumption of travel as an inconvenience to be minimized may be false; (ii) increasing real incomes have induced a heterogeneous preference for the range of goods consumed and the range of activities undertaken; (iii) there is a long-range simultaneous optimality of a range of locations which is much wider than a traditional residential-workplace choice. Thus, the digital world has to be positioned in a much wider behavioural context (Hayes 1997; Tranos 2011).

The above observations prompt the question whether the ICT introduction has seriously affected the geographical-economic landscape (see Dreier et al. 2005). Several studies have shown the remarkable stability of geographical settlement patterns. On the one hand, there is an avalanche of literature on optimal city size (see Alonso 1971), while on the other hand there is an abundant strand of literature on scale and agglomeration advantages using total production factor analysis and data envelopment analysis (see Kourtit et al. 2013).

As mentioned above, the emergence of the digital world has prompted the challenging question whether near-to-zero distance friction costs would create a world with the '*death of distance*' (Cairncross 1997). This was further highlighted in a book by Friedman (2005) on '*The World is Flat*', where traditional disparities in terms of densities on wealth or income may vanish.

This has led to an interesting debate in the literature whether the world is 'flat' or 'spiky' (see McCann 2008).

The general conclusion from the recent literature on 'spiky worlds' is that there is a great deal of heterogeneity in the socio-economic geographic landscape of our world, that is not reduced by ICT access and use, but is sometimes reinforced by the unequal spatial benefits emerging from the digital world. Thus, our conclusion is warranted that there is not sufficient evidence for the hypothesis that in a digital world location and distance do not matter. Instead, in the spirit of Tobler's '*First Law of Geography*' it seems plausible that in a digital space-economy location and distance matter more than ever before.

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