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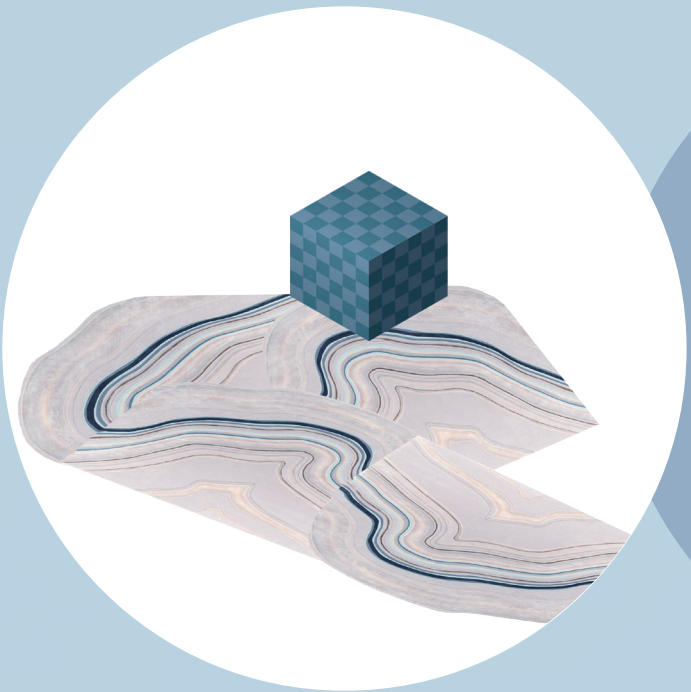

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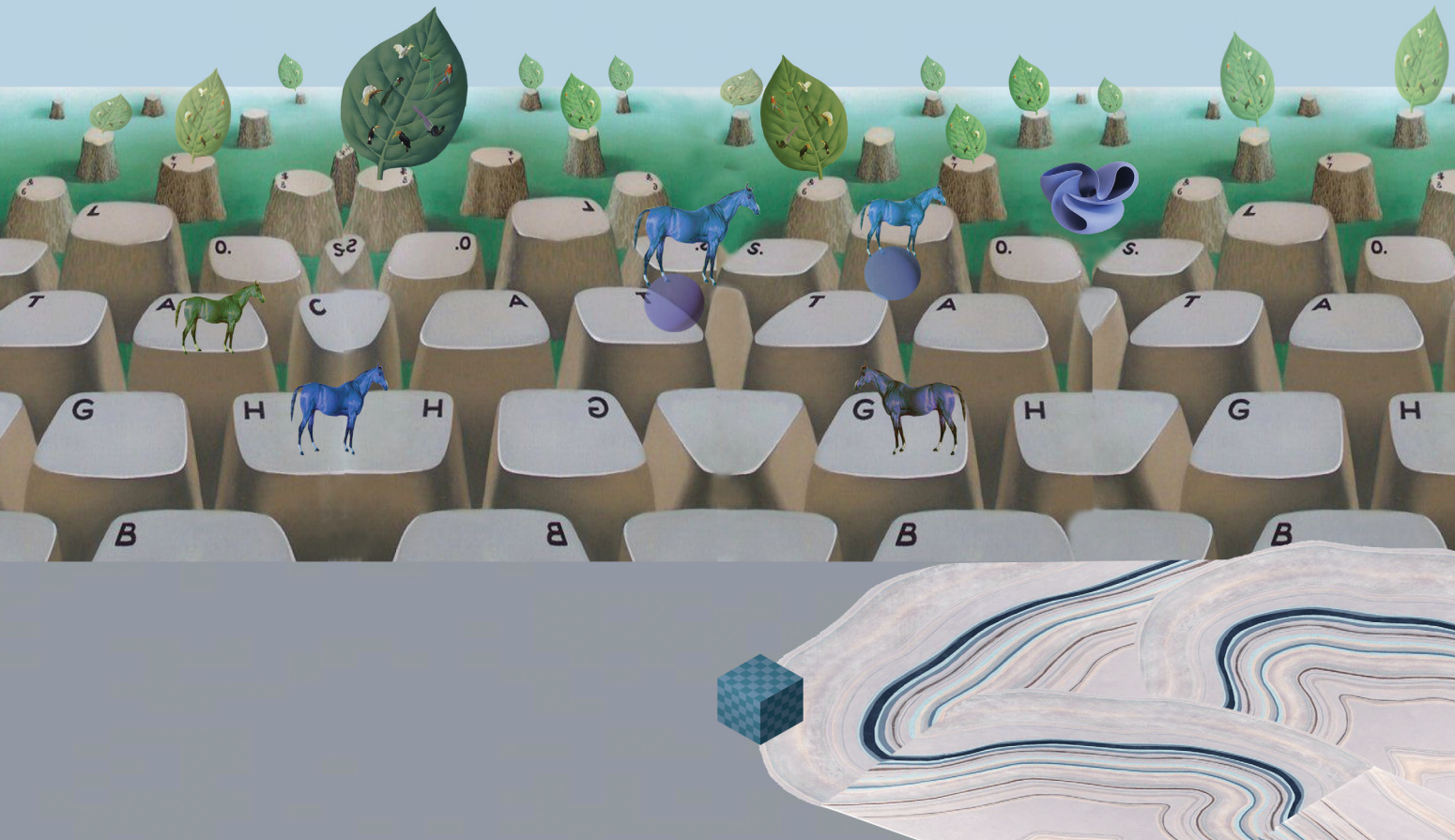

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Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

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- Corporate innovation management;
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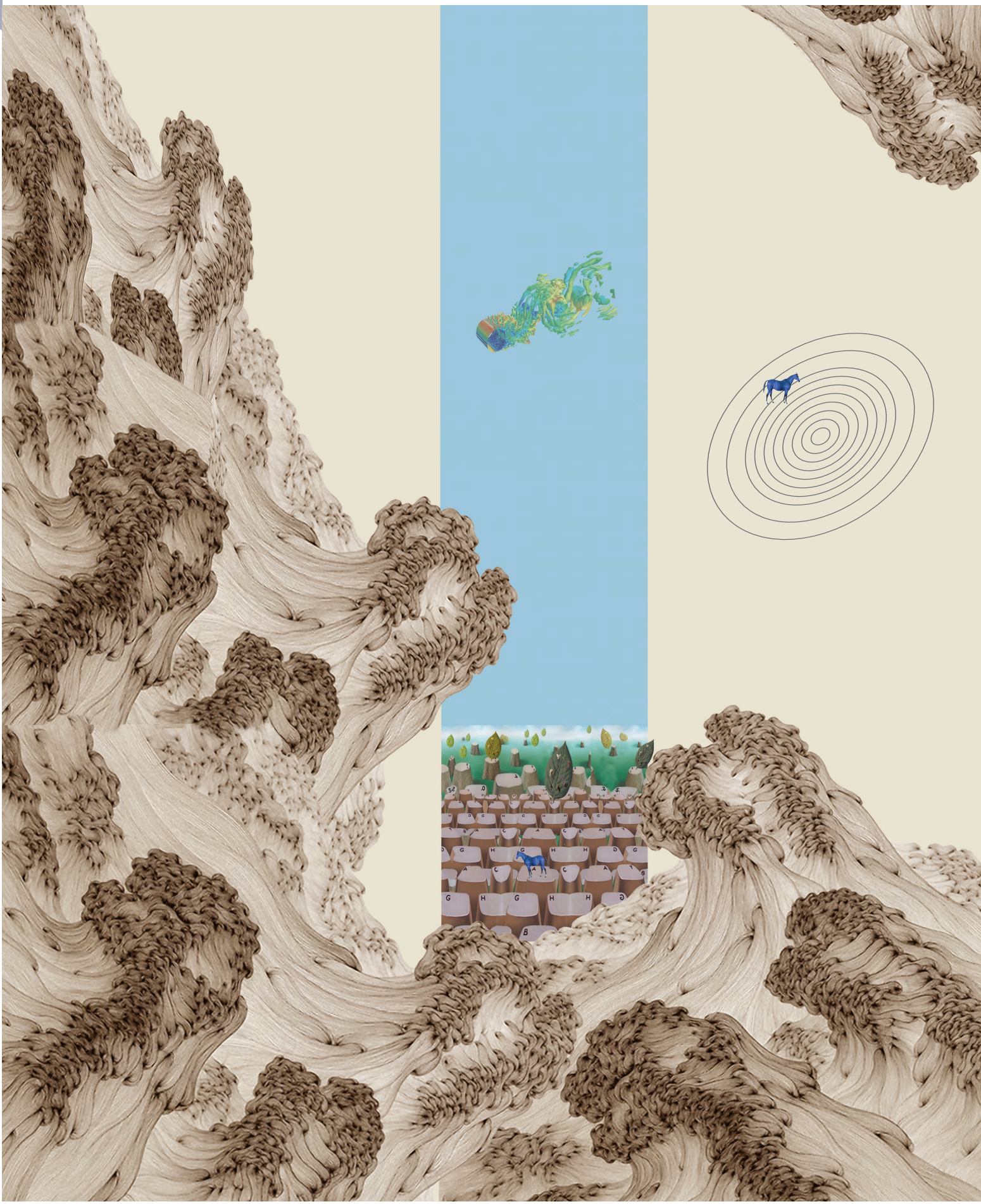

A Disrupted Future?

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Abstract

The tobacco industry worldwide has annual revenues of hundreds of billions of dollars and annual smoking-associated death rates in the millions. Electronic cigarettes designed as a less harmful alternative to traditional tobacco products allow users to inhale nicotine without consuming the products of burning tobacco, thus significantly lowering health risks. These and similar innovative solutions have a potentially disruptive impact on existing markets. Both newcomers and established cigarette firms have been active around these alternatives. However, the health implications of such products are still poorly studied and seemingly ambiguous. Moreover, there is an increasing number of reports on mass diseases associated with vaping. As a result, most countries and international institutions, including the World Health Organization, have adopted negative attitudes towards electronic cigarettes.

Do e-cigarettes represent a Trojan Horse that will undermine tobacco control efforts – or are they an effective way to wean users away from cigarettes thus opening the way towards a better future? This paper outlines estimates of the future health impacts of cigarette and e-cigarette use, and considers the broader issues surrounding this potentially disruptive innovation. It points to areas requiring further research and suggests how Foresight studies might address the topic.

Keywords: disruptive innovation; e-cigarettes; scenarios; alternative futures; foresight

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Introduction

"Disruptive Innovation" (see Box 1) has become a major theme in innovation studies (how can we explain the emergence and features of high-impact innovations?), and in Foresight exercises (how can we anticipate the implications of potential changes and prepare to make the most of them?). Most innovation studies rely on the comfortable assumption that successful innovations are necessarily ones that benefit humanity. Foresight work, in contrast, often explicitly considers questions of social as well as economic costs and benefits of change. Within innovation studies, climate change and related environmental issues have prompted more researchers to reappraise just what really constitutes a successful innovation.

Neither innovation nor Foresight researchers have paid much attention to one potentially disruptive set of innovations: electronic cigarettes (e-cigarettes). Some observers see these as preventing many millions of early deaths over the course of this century; but others oppose this innovation, even seeing them as making a high death toll more likely.

Many commentators suggest that e-cigarettes are indeed a disruptive innovation, with cigarette smoking patterns being disrupted by new electronic nicotine delivery systems (ENDS). The health consequences of inhaling smoke from tobacco have been exhaustively documented over the last half-century. The World Health Organization (WHO) estimates that there are currently over a billion cigarette smokers in the world today, leading to a huge premature death toll over the course of the century [WHO, 2008]. WHO, and most national public health authorities, have advocated and enacted policies aimed at restricting this toll. But even so, cigarette use is still growing in some regions of the world, though it is generally declining in most industrial countries.

Emerging early in this century, types of e-cigarettes have proliferated. Substantial markets have been created in some countries, though they remain prohibited in many places. ENDS allow smokers to inhale nicotine in a manner similar to smoking, while substantially reducing exposure to the harmful tars, gases, and other harmful substances in cigarette smoke. Forecasts for the USA alone indicate that a large shift to ENDS would avert millions of premature deaths over the coming decades. Unlike many supposedly disruptive innovations, this could be a matter of life or death.

While much of the analysis of disruptive innovations focuses on the challenges to, and responses of, incumbents, other stakeholders can play important roles. In this case, public health officials, the policymakers they advise and the various civil society and campaigning groups come to the fore. The reactions of these groups have been diverse and volatile. This has led to regulatory frameworks and market conditions varying widely across countries and over time. In some cases, the public health movement is resisting innovations that could reduce the harm associated with cigarette smoking. A "tobacco control" philosophy, with a strong distrust of the tobacco industry and aversion to nicotine drives this opposition. In contrast, a "harm reduction" philosophy sees ENDS as reducing preventable deaths well above the levels achieved by tobacco control, even if this means tolerating consumer choices as to whether or not to use nicotine. This essay examines the controversies and uncertainties surrounding this disruptive innovation, and the implications for innovation studies and Foresight activity.

No Smoke without Fire: The Troubled History of Tobacco

Numerous scholars and journalists have discussed the history of tobacco use, and of the cigarette industry. Thus we provide the briefest of summaries here.

Tobacco use spread from the Americas to the rest of the world from the 16th century on. Smoking has long been one of the most popular ways of using tobacco. Modern combustible cigarettes (with tobacco being rolled up in a paper cylinder) became commonplace in many countries in the nineteenth century, especially after mechanized cigarette rolling systems were introduced. In some developing countries, hand-rolled "cigarettes" remain very popular, e.g. the *bidis* of rural India. Combustibles became immensely popular by the mid-twentieth century. Marketing promoted their use by women and others for whom cigarette use had been regarded as inappropriate. Such marketing efforts extended beyond advertising: in films and elsewhere cigarettes frequently featured as ubiquitous, as adult and "cool". But in the 1950s, and especially the 1960s, public health organizations in Western countries began to systematically denounce smoking as a source of lung and other diseases.

It is now widely accepted that cigarette smoking is a leading (meanwhile preventable) cause of significant lung, cardiovascular, oncological, and other health-related mortality risks. Lung cancer, a relatively rare disease in the 19th century, has become the "most common form of cancer in the world … with only a 15% 5-year survival rate for all stages in the United States… Numerous elements have been attributed to the causation of lung cancer; however, none more strongly verified than cigarette smoking" [*Ruegg,* 2015]. Smoking also plays major roles in chronic obstructive pulmonary disease

(COPD — a set of diseases including emphysema and chronic bronchitis,) and cardiovascular disease (narrowing or blockage of blood vessels, liable to produce heart attacks, strokes, angina, etc.). The smoke that is created through the combustion of tobacco leaves (and other ingredients) in cigarettes contains a host of unhealthy components.[1] Smoking's health risks are largely by-products of the particular method of delivery of nicotine provided by cigarettes: nicotine itself is not a major factor.

The tobacco industry contested the evidence of health problems, commissioning studies that appeared to support its position and concealing results that contradicted its claims [*Bero,* 2013]. It argued that correlation did not prove causation, and that scientists were divided as to smoking's health consequences. Smoking was portrayed as an individual choice. If cigarettes were indeed dangerous, consumers had chosen to take risks (cf. [*Kyriakoudes,* 2006]). Since, the notion that nicotine was addictive might undermine the case about free individual choice, this was also contested. Such persistent obfuscations created widespread distrust of industry pronouncements, especially among public health officials whose anti-tobacco position hardened.

Health Impacts – Now and in the Future

When launching its MPOWER program of tobacco control in 2008, the WHO declared: "Tobacco kills a third to half of all people who use it, on average 15 years prematurely. Today, tobacco use causes 1 in 10 deaths among adults worldwide – more than five million people a year. By 2030, unless urgent action is taken, tobacco's annual death toll will rise to more than eight million. If current trends continue unchecked, according to various estimates, during this twenty-first century, tobacco could kill up around 500 million to one billion people …." [WHO, 2008, p. 1, footnotes removed].

More detailed descriptions and forecasts have been developed in the Global Burden of Disease (GBD) Study [*Mathers, Loncar,* 2006; GBD, 2017].[2] Almost a billion people (and one in four men) are currently smokers. If they continue to smoke, half of these can be expected to die prematurely as a result. The issue is shortening of life: GBD estimates an *annual* global loss of almost 150 million disability-adjusted life-years (DALYs).

The GBD model[3] takes into account demographic trends and forecasts of economic and social development[4]. (The latter are related to cause-specific mortality rates, estimated from a variety of statistical sources.) This enables a detailed analysis. The prevalence of smoking is declining in most population groups, in most industrialized countries. But 80% of smokers live in low-income and middle-income countries, in some of which smoking is on the rise. Population growth in some countries with a high level of smoking (China, India, etc.) may well mean that smoking and smoking-related deaths will grow.

The 2006 GBD study produced projections of deaths to 2030 [*Mathers, Loncar,* 2006]. Tobacco-attributable deaths were calculated,[5] and projected to grow, from 5.4 million in 2005 to 8.3 million in 2030. This is the baseline scenario estimate – more pessimistic and optimistic variants were also outlined, ranging from 7.4 million to 9.7 million deaths projected for 2030. A third of these are cancer-related, with slightly smaller shares accounted for by COPD and cardiovascular disease. Figure 1 graphically represents key projections for deaths attributed to tobacco. Striking differences emerge across world regions — a decline of 9% in high-income countries, but a 100% increase in low- and middle-income countries.

The more recent projections, up to to 2060, do not specifically pull out tobacco-related deaths, but Mathers [*Mathers*, 2018] draws on the recent GBD to provide projections of deaths from various causes to that date. Age-standardized death rates from most causes (including lung cancer) are forecast to decline. But population growth and ageing mean that total projected deaths are forecast to grow. Figure 2 presents the baseline scenario: here lung cancer grows steadily as a cause of death, to become the most common of the leading causes. Over the course of this century, around a billion lives are expected to end prematurely as a result of smoking. Using the 2015 ratio of deaths to DALYs suggests that some 25 billion years of life (disability-adjusted) will be lost. This is clearly a global

[1] Similar risks — notably mouth cancer — are associated with "smokeless tobacco" products such as chewing tobaccos and snuff. A detailed discussion of risks of both smoking and these other traditional products is provided in Chapter 10 of [*Stratton et al.,* 2001].

[2] Up-to-date information on GBD studies is available at https://www.thelancet.com/gbd (accessed 07.10.2019).

[3] See https://www.who.int/healthinfo/global_burden_disease/projections/en/ for data in spreadsheet format.

[4] Estimates of trends in years of schooling, for example. The passage of time was taken as a proxy for technological development and health interventions. Economic development was represented by per capita GDP adjusted for purchasing power parity, with World Bank forecasts used to project this.

[5] "Tobacco use was measured in terms of "smoking impact"— that component of observed lung cancer mortality attributable to tobacco smoking …This indirect measure of the accumulated hazards provides a better measure than do current smoking rates for the overall health impact of tobacco, taking into account lag times as well as important aspects of exposure such as duration, type, amount, and mode of smoking …Smoking impact was calculated for the historical mortality country–year observations by subtracting nonsmoker lung cancer rates from observed total lung cancer mortality rates in the data. …"" [GBD, 2017, p. 2014] Country-specific projections of smoking levels were produced from regional estimates developed in earlier studies, with some modeling of age-specific smoking levels.

Box 1. **What is Disruptive Innovation?**

While looking more at the extent to which new technologies involved novel ways of achieving effects, Freeman proposed a distinction between incremental, radical, and revolutionary technological innovations, in terms of their implications [*Freeman*, 1975]. In furtherance of these ideas, Christensen proposed the idea of "disruptive innovation" to put more emphasis on how far new ways of doing things disrupted markets [*Christensen*, 1997; *Christensen, Raynor*, 2003]. The concept of disruptive innovation was used extensively in studies of marketing, strategic management, new product development, and technology management [*Danneels*, 2004].

Changes in business models might not even require radical new technologies [*Christensen*, 2006]. When the airline industry was reshaped by the emergence of low-cost "budget" airlines, the new firms ("insurgents") reached less affluent markets, offering low prices with few of the "frills" (meals, hospitality, etc.) with which established airlines ("incumbents") competed. The newcomers did exploit opportunities for online marketing, booking, etc., but technology was not the main issue. The incumbents attempted to introduce their own low-cost brands, but these generally failed to counter the insurgents. Incumbents may find it difficult to restructure their practices in line with the new business models. Markets are reshaped, new firms rise, and the rules of the game are changed, by disruptive innovation. When change, even involving radically new technology, can be easily absorbed with existing business models, then it is seen as "sustaining innovation" rather than disruptive. It will only involve new markets if the innovation can substantially change the offer to consumers, for example by lowering prices.

Christensen argues that disruptive innovations generally offer users cheaper, simpler, and more reliable and convenient goods and/or services [*Christensen,* 1997]. They may at first find only a niche market, but in moving onto mainstream (mass) markets, they challenge established products and producers, rewriting the "rules of competition" and redefining the key aspects of performance valued by consumers. Incumbents, of course, are liable to fight back to retain their markets. They may try to improve their own product offerings (or at least their marketing), or to persuade regulators or actors in the value chain to limit the challenge from the insurgents.

Juma [*Juma*, 2016] vividly documents cases where incumbents deploy marketing campaigns and other tactics to portray the innovation as inferior or hinder its entry onto the market – for example, on grounds of threatening public health and safety. Taxes or regulations may be mobilized to limit the market acceptance of the innovation. One telling example is the case of margarine, where the dairy industry was able to persuade regulators in some US states to enforce rules specifying that margarine would have to be dyed an unsavory colour, or packaged in black paper. Recently, Mylan et al. [*Mylan et al.*, 2019] have discussed the opposition of the dairy industry to plant-based drinks, including rules preventing them being called "milk" (e.g. soya and almond milk).

Incumbents may alternatively "go with the flow" by acquiring the newcomers or imitating their innovations. If they can accomplish this without major revisions to their business models, they would have achieved sustaining innovations. The situation might well not be a black-and-white one; different business models, and even different markets, may coexist for long periods.

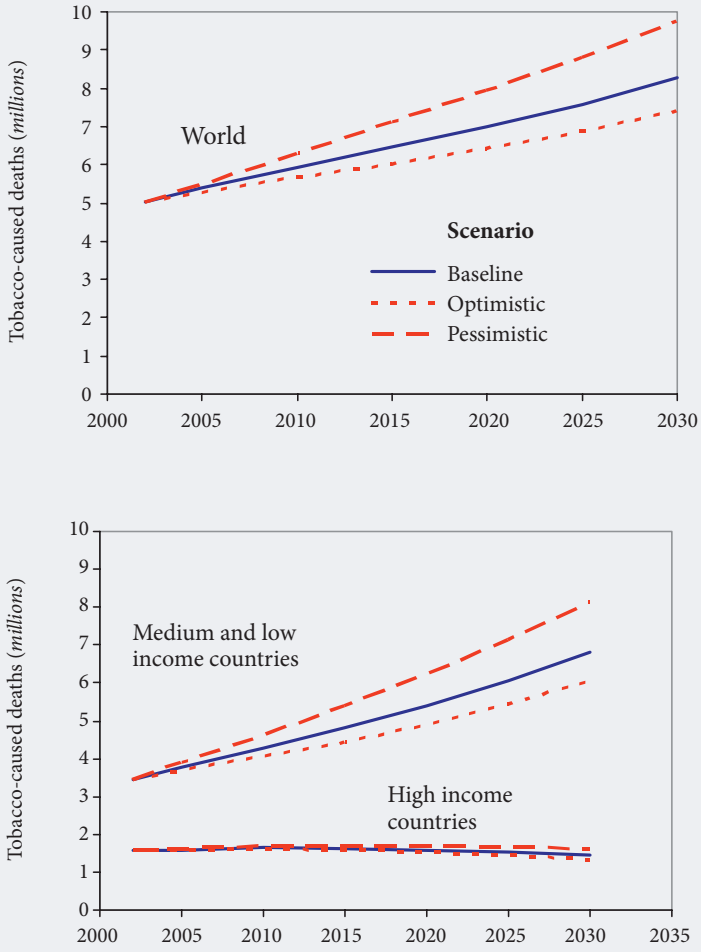
problem, even if it is less visible or dramatic than famines, fires, and floods.

Controlling Cigarettes

Public health authorities (and many other concerned stakeholders) have pursued a number of strategies aimed at reducing use. These include efforts to prevent people from becoming smokers and to aid them in quitting. Information campaigns aim to change awareness, taxes on tobacco products impose financial costs, laws and other regulations may restrict where smoking may take place and how (and to whom) cigarettes can be promoted and sold.

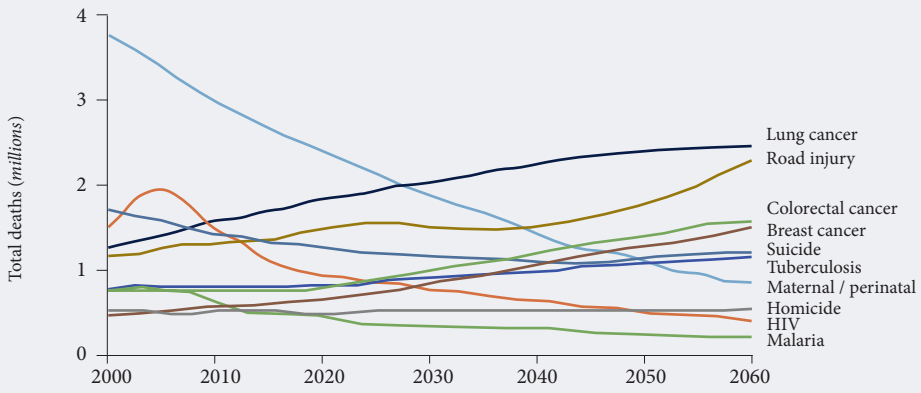
"Tobacco control" measures frequently involve banning smoking in places where others may be exposed to smoke, such as workplaces and public transport. Restrictions are often placed on the advertising and sale of cigarettes, especially to young people. Heavy taxes on cigarettes have become a source of revenue for governments, while initiatives such as helplines and other assistance for users hoping to quit require expenditure. Such

Figure 1. **Projections of Global Tobacco-Caused Deaths in 2002–2030 in Three Scenarios**



Source: [*Mathers, Loncar,* 2006].

Figure 2. **Projections of Global Deaths from Major Causes, 2000–2060**



Source: [*Mathers*, 2018].

Box 2. **The e-Cigarette**

Instead of using tobacco, ENDS devices supply nicotine in a liquid solution (commonly based on propylene glycol, and often including flavorings). This is vaporized, giving rise to the terms "vape" and "vaping". The idea is to achieve an experience similar to that of cigarette smoking, but with a huge reduction in the harmful substances produced by combustion. If this can be achieved, then ENDs can in principle disrupt markets, taking sales away from cigarettes to less harmful alternatives.

While there had been earlier patents and experiments, the successful commercial exploitation of this idea was first achieved in China. Industry lore has it that Hon Lik (who worked for Golden Dragon Holdings, a company producing ginseng products) was inspired to design a safer product than the combustible cigarette following his father's lung cancer. He patented an e-cigarette design in 2003 (internationally patented in 2007). His firm commercialized this in 2004 on the Chinese market, changing its name to Ruyan ("like smoke"), and exporting ENDS from 2007. According to the US Surgeon General [Surgeon General, 2016, p. 10], "In August 2013, Imperial Tobacco Group purchased the intellectual property behind the Ruyan e-cigarette for $75 million. As of 2014 an estimated 90% of the world's production of e-cigarette technology and products came from mainland China, mainly Guangdong Province and Zhejiang Province." Hon Lik himself joined the e-cigarette company Fontem Ventures, a subsidiary of the tobacco company Imperial, in 2013. Fontem is responsible for the e-vapor brand *blu*; according to *blu*'s website Hon Lik aims to continue development and innovation in the area.

Other manufacturers were quick to introduce copies of, and variants on, the design [Surgeon General, 2016]. The rapid evolution of ENDS' designs reflects, at least in part, the fast growth of markets for the products, and various dynamics within this market. Williams and Talbot [*Williams, Talbot,* 2019] identify four generations, differing in terms of the e-cigarette itself (its external form and appearance, e.g. whether it looks like a traditional cigarette or is more like an iPod or other device; and the battery characteristics, including "Mods" (consumers can vary voltage, wattage, and power via modified batteries) and on the atomizing units used in the ENDS. In common, they can deliver not only nicotine, but also much of the same experience as cigarette smoking, including the taste, ease of inhalation, and so on. The aerosols can be flavored in different ways. Different products have gained substantial footholds in different countries. Many new entrants are manufacturing vape liquids and devices, and retail outlets in the form of "vape stores" have proliferated in many countries.

measures have been instituted in many countries and are promoted by WHO's MPOWER program.[6] They are seen as having enabled the substantial long-term decline in the rates of smoking in most industrial countries (and some cases elsewhere, notably Brazil). But the decline in smoking is uneven globally. The GDB forecasts suggest that despite tobacco control measures, cigarettes will lead to massive mortality over the course of this century. WHO calls for a redoubling of efforts and denounces the tobacco industry's ongoing promotion of cigarettes (especially in low-income countries and to young people).

Facilitating cessation is the other part of the strategy. Many users are dependent on nicotine, finding it difficult to relinquish or even reduce the smoking habit. A variety of medical ways of addressing the problem have been attempted [*Aveyard, Raw,* 2012]. These include pharmaceutical treatment: drugs such as cystine and varenicline reduce the effect of nicotine on the brain, rendering smoking less pleasurable. To date, attempts to develop vaccines that counteract addiction (which have proven promising with some other drugs) appear to have been unsuccessful (for an interesting sociological study of these efforts see [*Wolters,* 2017]). Since the tars and other results of combusting tobacco are the main source of damage to the health of users (and others exposed to the smoke) nicotine replacement therapy (NRT) is widely used. NRT delivers nicotine through wearable patches, or sweets or gums.

[6] See https://www.who.int/tobacco/mpower/publications/en/ (accessed 09.10.2019) and related WHO resources for explication of tobacco control programs, success stories, statistics concerning the uptake of various measures, and so on.

A Disruption?

Many attempts have been made over the years to create cigarette products that involve or, at least, that appear to involve lower risks. Cigarette manufacturers have introduced and promoted, for instance, filters, and "mild" and "low tar" cigarettes. Some of these products, which can be seen as efforts to apply incremental innovation to preserve the established order, have been commercial successes. In general they do not substantially reduce risks — and in some cases increase them (e.g. by enabling smoke to penetrate further into the lungs) [*Song et al.,* 2017].[7]

Conventional cigarettes are "combustibles", burning tobacco and releasing nicotine in the smoke created — which also contains substances associated with health problems for users and passive smokers alike. Recognizing this, a more dramatic innovative effort involved the introduction of "Heat Not Burn" (HNB) products. These use batteries to heat tobacco (to temperatures well below those reached by burning it) so that nicotine vaporizes and can be inhaled.[8] Other substances are also vaporized. There has been controversy about the extent to which carcinogens are involved - something that is liable to vary across different HNB products. Tobacco companies introduced HNB devices in the 1980s, but these made little market impact. Users criticized their appearance, cumbersome features, and the taste and feel of the smoking experience. Marketing them as "safer" alternatives was also difficult, as it meant conceding that combustible cigarettes were unsafe, and raised issues with regulators.[9] HNB technology has recently been revived, as we shall see below.

The prospects for a disruptive technological innovation increased dramatically in the present century, with the emergence of e-cigarettes, ENDs. Unlike HNB (and, of course, traditional combustible cigarettes), ENDS do not use tobacco leaves (see Box 2), but still supply nicotine and an experience much like cigarette smoking.

During the 2010s, many voices suggested that ENDS could be disruptive to tobacco industries. For example, Citigroup presented e-cigarettes as a leading case in the very first issue of its annual series on disruptive innovations [*Spielman, Azer,* 2013]. More recently, Euromonitor took the e-cigarette firm Juul as a prime example of "Insurgent Brands". Juul Labs is described as follows:

> "the product of an independent nicotine delivery and vapourisation device start-up" that has "reconfigured the global nicotine landscape. It created a new category…[it] drove declines in the value of major tobacco company shares and provoked strategic revisions such that the USA's leading tobacco company jettisoned all its existing e-cigarette offerings. JUUL Labs raised US$1.2 billion in funding in June 2018, valuing the company at US$16 billion. Just 6 months later, Altria[10] bought 35% of JUUL Labs for around US$13 billion valuing it at US$38 billion…. Although the market for vapour products remains a fraction of that for cigarettes, the growth trajectory of both categories is very far apart. We expect to see 20.1% real growth in retail sales in value terms of vapour products in 2018, compared to 0.4% for cigarettes." [*Brehmer, Boumphrey,* 2019, p. 10].

The largest markets for ENDS are generally reported to be the USA and then the UK (e.g. WHO, 2016). According to BBC news reports [*Jones,* 2019], Euromonitor (a market research firm) estimated recently that the worldwide growth in the number of people vaping over the period 2011-2018 was from about seven million to some 41 million. They forecast 55 million users in 2021 – still only around 5% of the number of users of combustibles. The global market was estimated as being over $19bn, with the largest components being the USA (c$7bn), UK (c$3bn), followed by France, Germany, and China (each under $2bn). This compares with much larger figures for the global cigarette market size, where estimates involve hundreds of billions of dollars.[11] But Euromonitor's data do indicate that in terms of "value" (i.e. sales) vaping products in 2017 saw a growth of 50.7%, as opposed to 2.8% for combustible cigarettes, while in terms of "unit volume growth"[12] the respective figures were 36.8% and -1.4% [FSFW, 2018]. These radically different growth rates suggest that a disruption in the cigarette landscape may be underway.

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[7] These strategies, and other efforts to remove poisonous substances from tobacco, are discussed in detail in [*Parker-Pope,* 2001].

[8] There have been some concerns over the safety of the batteries used in these devices and a number of reports of explosions associated with these. For a discussion of injuries associated with such explosions see [*Rossheim et al.,* 2019].

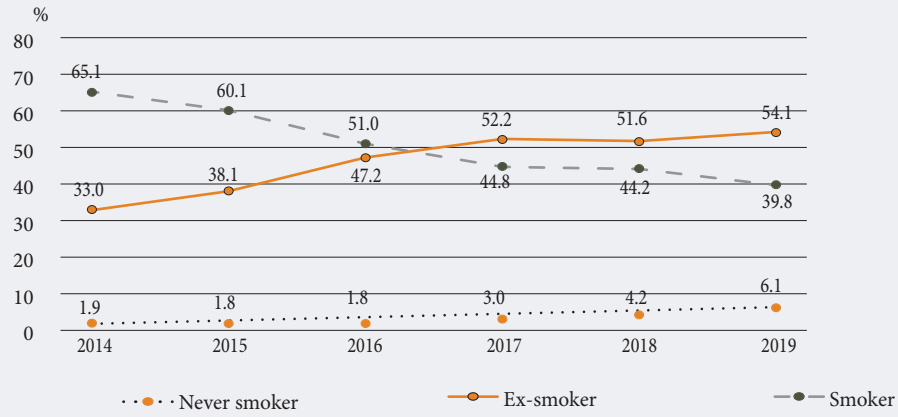
[9] For a discussion of the early HNB experience under the rubrics of "High-tech Cigarettes" and "Smokeless Smokes" see [*Parker-Pope,* 2001].

[10] Altria (formerly Philip Morris), with a revenue in 2018 of over $25 billion, is one of the world's largest tobacco companies, and currently holds a c50% market share of cigarettes in the USA.

[11] See for example the report at https://www.statista.com/statistics/259204/leading-10-tobacco-companies-worldwide-based-on-net-sales/ (accessed 13.10.2019), which also reports that the biggest firms in sales terms are Philip Morris International (2018 sales of nearly $30bn), British American Tobacco (over $26bn), Imperial Tobacco, Altria, and Japan Tobacco all around $20bn. It should be remembered that consumer prices for cigarettes vary considerably around the world, so some of the heaviest concentrations of smokers are based in countries that appear to have relatively small tobacco industries in terms of turnover; and some markets are served by artisanal production (e.g. of "bidis" rather than manufactured cigarettes in India).

[12] The individual "cigarette stick" and equivalents to this, were used as the unit.

Figure 3. **Structure of Adult e-Cigarette Use, Adults in Great Britain, 2014-2019**



Unweighted base: Current e-Cigarette Users (n)

Year	n
2014	498
2015	614
2016	667
2017	669
2018	738
2019	854

Note: Over this period the proportion of the adult population who are current ENDS users grew from 4.2% to 7.1%, 2.1m to 3.6m.

Source: [ASH, 2019].

The use of data from a market research company Euromonitor reflects in part the fact that only a few countries have accurate data on these phenomena. Especially valuable would be data that indicate whether people are shifting from combustible to electronic cigarettes, using the two as complements, or (most controversially) initiating nicotine consumption via ENDS.

The statistics for UK provide some relevant data. The Office for National Statistics [UK ONS, 2019] reports an ongoing decline in the number of UK adults who were current cigarette smokers, from 20.2% of the adult population in 2011 to 14.7% in 2018. Cigarette use has been monitored by the Opinions and Lifestyle Survey[13] from 1974, with e-cigarettes studied from 2014. Over 2014–2018, vapers rose from 3.7% to 6.3%. of the adult population. More than half of these said they vaped to help themselves quit smoking; just under a third because they saw vaping as less harmful than smoking. A detailed analysis of these and other survey data is presented by Public Health England [*McNeil et al.*, 2019], where among the points made are:

- The majority of adult vapers are ex-smokers.
- ENDS have not interrupted the downward trend in uptake of cigarettes.
- The prevalence of vaping does not seem to be on the rise since 2015 (some commentators relate this to widespread views that e-cigarettes are as unhealthy as combustibles[14]).
- Members of higher socioeconomic groups are less prone to smoke and are more likely to vape in order to quit smoking, while those from more disadvantaged groups are more likely to continue to smoke.
- The uptake of ENDS among non-smokers is very low – less than 5% of vapers are "never smokers", though there is a possibility that this figure is increasing (see the lowest trend line in Figure 3, which adds more recent data).

These conclusions suggest that ENDS are indeed potentially disruptive, in the sense of users actually moving away from combustibles. The ambition of many vapers is to move away from nicotine altogether. Some vapers, however, have become a subculture, holding annual conferences, competitions about being able to blow the most impressive "smoke" rings, and the like (a striking journalistic report is [*Usborne,* 2018]).[15]

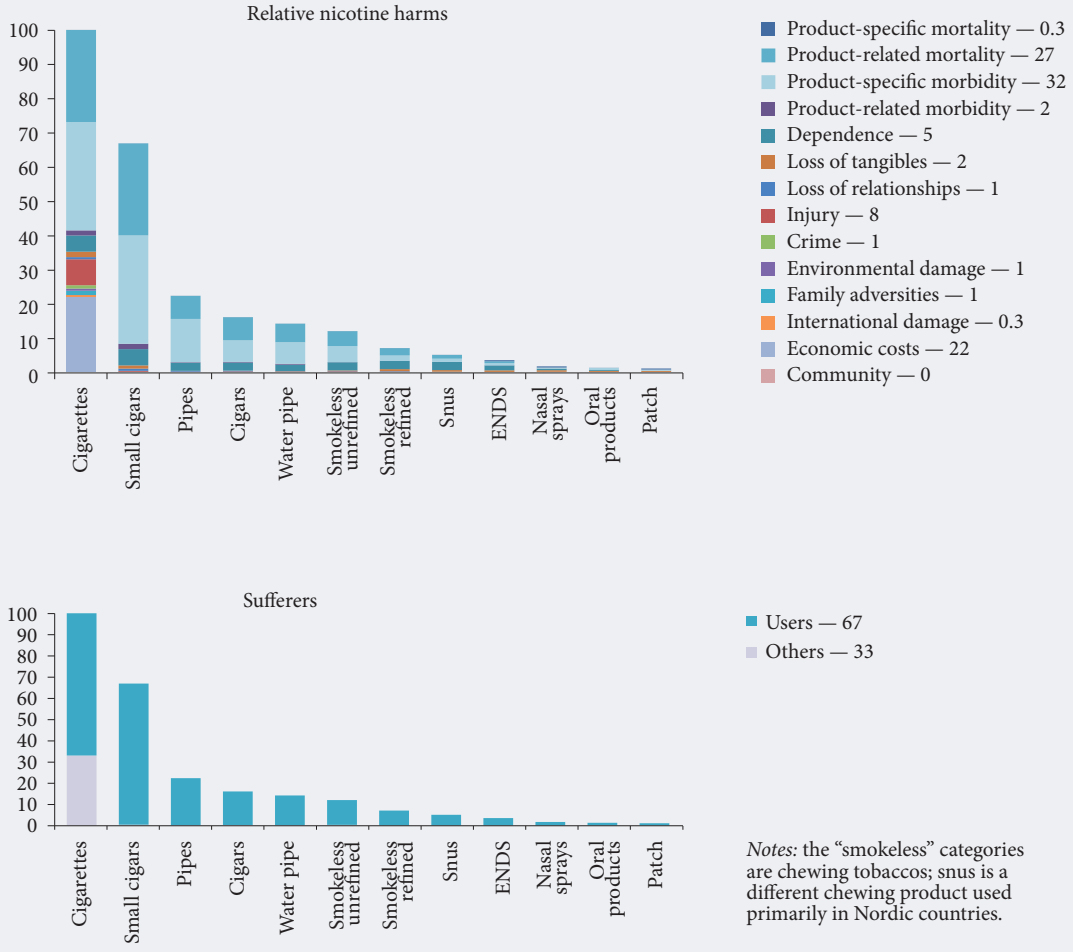
Consumers are expected to adopt disruptive innovations if these are felt to offer more benefits and/or fewer costs. If ENDS are to be more than a niche innovation, they have to provide the pleasure to the consumer (benefits), while reducing the costs (health risks). Consumer beliefs about health risks will be influenced by messages from credible sources, such as scientific authorities (though their messages are mediated through reporting in mass media, press releases, and the like). What do we know about health risks of ENDS?

[13] Of adults aged 16 years and above in Great Britain — this excludes Northern Ireland.

[14] ASH [ASH, 2019] present data showing an increase from 7% in 2013 to 25% in 2017 in the proportion of the adult population thinking that e-cigarettes are "more or equally harmful as smoking".

[15] For data on the situation concerning smoking, regulation, ENDS, and THR see https://gsthr.org/global-data/ (accessed 14.11.2019).

Figure 4. **MCA Appraisal of Different Ways of Acquiring Nicotine: Weighted Scores (%)**



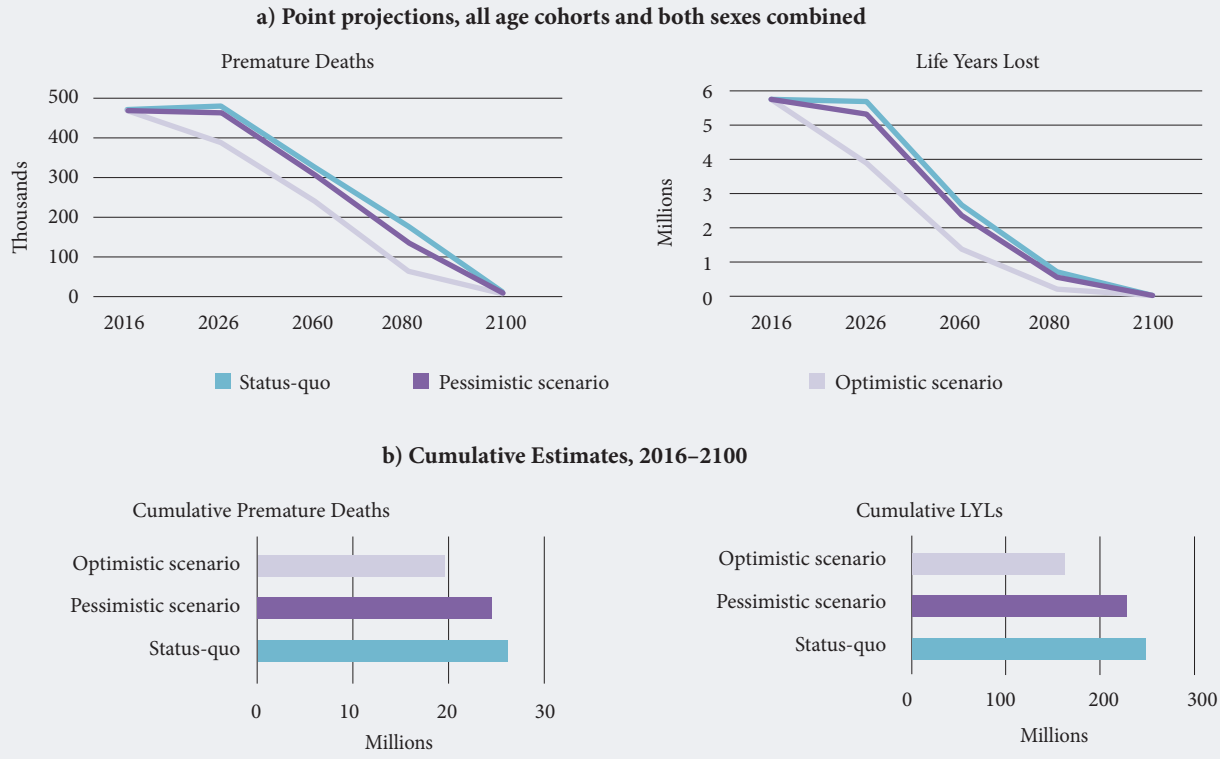
Health Risks and ENDS

Only a few studies directly compare ENDS use with smoking combustibles. Stephens [*Stephens,* 2017] examined the emissions from (one type of) ENDS, cigarettes, an HNB device, and a medical inhaler for nicotine. Stephens reported that while aerosols from ENDS contained various carcinogens, these were mostly at less than 1% of the potency of tobacco smoke. (When excessive power was delivered to the ENDS coil, high levels of some carcinogens would be released.) Medical inhalers were seen as posing least lifetime risk associated with carcinogens, followed by ENDS, then HNB, and finally combustibles. Note the implication that ENDS devices and applications may vary in health impacts — as designs proliferate, we may be less able to make generalizations.[16] Ideally, innovation would be directed towards lower health impacts: technological possibilities, regulations, and market demand all have roles here.

A second study, Chen et al [*Chen et al.,* 2017], compared ENDs with combustibles, using the U.S. Environmental Protection Agency's methodology for human health risk assessment. Twelve toxicants earlier identified as posing the greatest health risks were used as assessment criteria, and the estimates of exposure calculated, assuming similar usage patterns of ENDs and combustibles. Both practices

[16] This is confirmed by NASEM [NASEM, 2018, p. 6]: "Conclusion 5-2. There is conclusive evidence that, other than nicotine, the number, quantity, and characteristics of potentially toxic substances emitted from e-cigarettes are highly variable and depend on product characteristics (including device and e-liquid characteristics) and how the device is operated." Cf., "Conclusion 5-3. There is substantial evidence that except for nicotine, under typical conditions of use, exposure to potentially toxic substances from e-cigarettes is significantly lower compared with combustible tobacco cigarettes."

Figure 5. **Estimates of Impacts in the USA of a Shift (over 2016–2016) from Combustibles to ENDS**



Source: based on data presented in [*Levy et al.*, 2018].

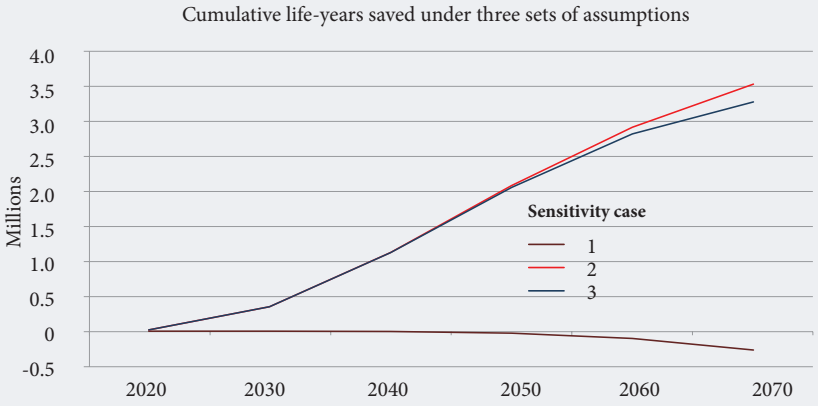
were found to have health risks, but combustibles posed much higher risks. Low quality ENDS were liable to be more problematic than devices with higher manufacturing and quality standards. These authors conclude that switching to high-quality e-cigarettes has the potential to save millions of lives.

A major review of evidence was undertaken by an expert group for the National Academies of Science, Engineering and Medicine. Its first conclusion as to harm reduction was "Conclusion 18-1. There is conclusive evidence that completely substituting e-cigarettes for combustible tobacco cigarettes reduces users' exposure to numerous toxicants and carcinogens present in combustible tobacco cigarettes." More explicitly "... across a range of studies and outcomes, e-cigarettes pose less risk to an individual than combustible tobacco cigarettes" [NASEM, 2018, p. 11].

In 2014, the UK-based Independent Scientific Committee on Drugs convened an international expert panel (spanning a range of disciplines) [*Nutt et al.*, 2014]. Multicriteria Analysis — a method familiar in Foresight studies — has been adopted to bring together expert opinion in order to address the likely health (and other negative) implications of different routes for nicotine delivery. The experts discussed various products and types of harm, and then assessed each of the 14 harms occasioned by 12 products. Both harms to the user and harms to others were addressed with seven items each. Each criterion was also assessed in terms of relative importance. Ratings were made on a 0–100 scale, with 100 referring to the most harmful product on a given criterion, and 0 defined as no harm. As Figure 4 indicates, cigarettes and small cigars were seen as far more potent sources of harm than other nicotine delivery systems. This study was employed in a widely cited reference point for assessment. In the subsequent debate concerning this study, the authors suggested that one simple way of interpreting the result is to see e-cigarettes as twenty times less harmful than combustibles [*Nutt et al.*, 2016].

What would it mean for health if the disruptive innovation actually were to prove successful? Clearly, in addition to the actual reduction in health risks, such factors as speed of diffusion/substitution, similarity of usage patterns, effects on rates of complete cessation of nicotine use, will need to be taken into account if forecasts are to have much grounding in plausible trends. Sophisticated mod-

Figure 6. **Scenarios for Impact on Life Years Lost in the USA**



Sensitivity case :

1 — vaping-induced initiation only;

2 — vaping-induced cessation only;

3 — both vaping-induced initiation and cessation.

Source: [*Warner, Mendez,* 2018, Table 1].

eling is undertaken within the tobacco industry (e.g. [*Lee et al.,* 2017; *Djurdjevic et al.,* 2018], which is evidently attentive to future market prospects. Steps toward assessing health impacts of a shift to ENDS are presented by [*Levy et al.,* 2018], who examine the US situation until 2100. Mortality and LYL (life years lost) are compared across a Status Quo scenario and Optimistic and Pessimistic scenarios. In the Status Quo scenario, smoking rates (from 2016) were projected forward, using data on rates of smoking initiation and cessation based on 1965–2012 data for different ages and sexes. The Optimistic and Pessimistic scenarios differ in three respects. First, residual cigarette smoking is merely 5% of the Status Quo value in the former, while in the latter it is 10%; the transition to these levels is assumed to take 10 years. Second, the initiation of uptake varies across scenarios; in the Optimistic scenario the initiation of e-cigarette use is assumed to be at the same rates (by groups) as is the initiation of cigarette use in the Status Quo Scenario, after reaching a 5% smoking prevalence. In the Pessimistic Scenario, it is assumed that nicotine use has become more "normalized" as a result of e-cigarettes; ENDS initiation is assumed to occur more rapidly (150% of the Status Quo scenario's smoking initiation rate). Third, the Optimistic Scenario, takes the excess risk of ENDS as being 5% that of cigarette use, while the Pessimistic scenario assumes it to be 40%.[17]

Figure 5 provides a visual representation of the overall implications of the scenarios. They converge in terms of premature deaths and life years lost by 2100. However, over the course of the 84 years the Pessimistic Scenario yields 1.6 million premature deaths averted, some 20.8 million fewer life years lost compared to the Status Quo. The Optimistic Scenario features 6.6 million fewer premature deaths and some 86.7 million fewer LYLs. These cumulative outcomes imply that a huge disease burden could be alleviated by a mass shift from combustibles to ENDS. (More detailed analysis, examining the relative experience of different age and sex groups, shows, for example, that the greatest impact of the shift to ENDS in the USA would be among younger cohorts).

A far wider range of assumptions for the modeling of LYL outcomes (to 2050 and 2070) was developed by [NASEM, 2018]. This compares various assumptions, many of them quite extreme, as to (a) the relative harm of e-cigarettes compared with combustibles (from 0 to 50% of the harm, (b) their potential effects on rates of initiation of combustible use (from neutral to a 50% increase), and (c) on cessation of combustible use (from a reduc-

[17] The model takes into account the effects of people moving from being smokers to becoming vapers, as well.

tion of -5% to increases of up to 15%). A total of 85 different combinations of these assumptions were explored. Some of these suggest major savings in LYLs, because ENDS offer only benefits. Others present far more threatening outlooks. For example, if ENDS substantially promotes initiation of smoking, then this leads to greater mortality and LYL in later years. (The benefits of increased net cessation emerge more immediately than the negative effects of increased initiation. Example: even if ENDS cause no harm directly, if they increase the rate of initiation of smoking by one-quarter, while increasing net cessation by 5 percent (to 4.57 percent) in 2015, a saving of nearly a million LYLs by 2050 would amount to a net loss of over half a million LYLs by 2070.) The conclusion that ENDS might be positive for public health over immediate decades, but negative in the longer term, achieved much publicity. But the NASEM's own summary states that "The modeling results suggest that, under likely scenarios, the use of e-cigarettes in the population will result in a net public health benefit....Under extreme adverse assumptions, the modeling projects a net public health loss."[18] Even under assumptions that ENDS present 10% of the risk of combustibles increasing the initiation of smoking by 10%, while that of cessation is only 5%, the worse of the scenarios thought likely, the reduction in LYLs from 2012-2017 was 1 million. In the best of these scenarios, the saving of LYLs was over six times this amount.

Warner and Mendez [*Warner, Mendez,* 2018] also consider also effects of ENDS on initiation and cessation of smoking of combustibles, in US scenarios to 2070. In a "Status Quo" scenario derived from historical data and assuming no introduction of ENDS, the background initiation rate falls from 20% in 2010 to 10% in 2028, and the background cessation rate increases from 4.18% in 2010 to 6% in 2028.[19] LYLs from this status quo are then compared with those for three scenarios — "sensitivity analyses". All of these feature assumptions that are "biased against finding a net benefit from vaping — to test the robustness of base-case findings" [*ibid.,* p. 43]. Sensitivity analysis 1 simply assumes that every smoker who quits smoking as a result of vaping loses 10% of the mortality reduction associated with quitting smoking outright. Analysis 2 assumes a vaping-induced initiation rate increase of 6%, three times what the authors estimated would be the most likely effect. Analysis 3 combines the increases of 6% in initiation rate and 5% in cessation rate, and the loss of 10% of the mortality reduction associated with quitting smoking without vaping. Figure 6 illustrates the results of these three analyses.

These scenarios indicate that benefits for public health of ENDS from helping cessation far outweigh the costs associated with vaping inducing additional young people to become smokers. Warner and Mendez see this conclusion as being consistent with those of most other published modeling studies. In contrast with [*Levy et al.,* 2018] — with a potential gain by 2100 of tens of millions life-years, Warner and Mendez estimate by 2070 a net gain of 3.3 million life-years. They see this as reflecting the former study having outlined scenarios in which vaping replaced smoking entirely within a decade — an immense disruption — while their study considered "evidence-based marginal vaping-induced changes in initiation and cessation" [*Warner, Mendez,* 2018, p. 44]. Though the estimated net benefits are only a small fraction of the huge toll of smoking-related LYLs, this small fraction remains a remarkably serious figure in terms of public health.

These modeling studies, furthermore, only consider the USA. Should analysis of this sort be extended to other countries and regions, the global figures would doubtless be enormous. In areas where cigarette use is not (yet?) declining, the impact of ENDS could be even more striking. However, the shift to ENDS use might be more problematic, since the current prices of the new devices are practically prohibitive for many consumers in some of these areas.

Responding to Disruption

Tobacco companies have not been complacent in the face of this threat. One strategy is illustrated by the cases of blu (Imperial) and Dragonite, as well as Altria and Juul, mentioned above. Some leading incumbents have acquired ownership, or partial ownership, of major insurgents. The Surgeon General's report [Surgeon General, 2016, Table 4.3] featured over 20 acquisitions or partnerships between established firms and ENDS newcomers before the end of 2015. Clearly, these incumbents perceived a realistic challenge from the disruptive innovation. A cover story published by *Newsweek* in May of that year highlights the British American Tobacco case [Newsweek, 2015].

Another strategy has been to develop their own alternative products. This would be in line with earlier efforts to overcome health-related concerns. Thus, Philip Morris International (PMI) is currently marketing IQOS, a novel Heat-Not-Burn product that has proven much more successful than ear-

[18] This formulation is on slide 40 of the presentation accompanying [NASEM, 2018], available at: https://www.nap.edu/resource/24952/NASEM-E-Cigs-Webinar-Slides.pdf (accessed 17.12.2019)

[19] Initiation and cessation rates stay at 2028 levels thereafter.

lier attempts at HNB. IQOS was launched in Japan in 2014 and now has a presence on several other markets, including the USA (where it launched in October 2019 having gained regulatory approval).[20] British American Tobacco (BAT) offers an HNB product, "*glo*": both IQOS and glo are permitted and on sale in shopping malls in Russia.

Parts of the established tobacco industry, then, have sought their own sustaining innovations (HNB). Parts have accommodated themselves to the disruptive technology, often partnering with the new competitors. The situation remains in flux, with different firms pursuing different (and sometimes multiple) strategies, while there is also much variety across different countries. China is an outstanding exception. China features a distinctive market situation. The tobacco industry is effectively a state-owned enterprise (cf. [*Li,* 2012]). Cigarette prices, and consumer awareness of the health risks of smoking, are low by international standards [ITC, 2017; *Horwitz,* 2019]. A comparison of web coverage on ENDS in China and the West notes a lack of online information from public health authorities in China (Chen et al, 2020). China has the world's largest smoking population: over 300 million smokers [ITC, 2017]. Over a million people die annually in China from smoking-related diseases; a figure forecast to treble by 2050 unless more substantial steps are taken to reduce that toll [ITC, 2017]. Ironically, given the "invention" of contemporary ENDS in China, and the presence of Chinese firms on international markets — the vaping population is low. Journalists report that China Tobacco is exploring HNB products, while e-cigarettes are coming under tighter regulation [*Horwitz,* 2019; *Kirton,* 2019].

Not only do industry and regulatory structures vary across countries, as do markets: the cost of ENDS or HNB systems may be problematic for poorer people, especially in poorer countries. Where ENDS are available, new firms and supply chains have arisen and continue to evolve. New complementary suppliers offer their own "mods"[21], as well as vaping liquids, flavors, and cartridges. One important element is that of "user innovation" (e.g. enthusiasts modifying battery features of ENDS devices). In some cases, there are illicit products and markets, including vapes whose critical ingredient is not nicotine, but substances derived from cannabis or "designer drugs".

An important role in the evolution of markets for combustibles and alternatives is played by regulators and public health organizations. In some instances, these bodies welcome a less harmful alternative to cigarettes and celebrate disruption. In many other cases, they are hostile.

There are several elements to this hostility. While many proponents of vaping have seen the innovation as a challenge to "Big Tobacco", champions of tobacco control see the growing ties between cigarette firms and the insurgents as evidence that "Big Tobacco" has found a new battlefront. Proponents of tobacco control have long been locked in verbal conflict with those opposed to regulation. Tobacco firms engage in various ploys, not least disputing the scientific evidence of strong links between smoking and ill-health and denying that nicotine was addictive. A visceral reaction to tobacco companies leads to suspicion about *anything* they advocate. It is hard enough to restore faith in an individual corporation, but practically an entire industry is tarred here (no pun intended).

A second set of reasons to resist the innovations portrays ENDS as a Trojan Horse. Vaping may be a "gateway drug", leading people (especially young people) towards cigarette use, via addiction to nicotine, and the normalization of smoking [*Chapman, Wakefield*, 2013].[22] These ideas are disputable; critical analyses of the "gateway theory" include [*Etter,* 2017; *Bell, Keane,* 2014; *Phillips,* 2015]). Evidence that ENDS use risks undermining the gains of tobacco control is ambiguous. In the USA, in particular, there has been considerable concern expressed about young people's adoption of e-cigarettes, with Juul portrayed as a major villain. In contrast, Public Health England concludes that vaping is often pursued as a route out of smoking and supports the UK's combination of strict product regulation and relatively liberal policy concerning sales to adults. [*McNeill et al.,* 2018] present the latest evidence review on the topic.[23]

A third set of reasons relate to the possible health hazards of ENDS. Since these are fairly new tech-

[20] According to https://www.pmiscience.com/our-products (accessed 15.11.2019) PMI is developing "four smoke-free product platforms, two of which are heated tobacco products and two are e-vapor products".

[21] Users modify ENDS devices so as to achieve different results (e.g. the production of visible vapor, the inhalation of different aerosols). An idea of the large range of "mods" that are available can be gained from the products featured at https://vaping360.com/best-vape-mods/ (accessed 02.11.2019).

[22] An echo of this viewpoint, which is bound to alarm public health officials and reinforce the view of tobacco industry intentions to profit from HNB and ENDS is provided by British American Tobacco in a guide for investors in March 2019 [British American Tobacco, 2019].

[23] The UK Government's position, in the section on e-cigarettes at https://www.gov.uk/government/publications/health-matters-stopping-smoking-what-works/health-matters-stopping-smoking-what-works (published 25.09.2018; accessed 21.11.2019), includes the statements: "Leading UK health and public health organisations … agree that although not risk-free, e-cigarettes are far less harmful than smoking. …E-cigarettes are currently the most popular stop smoking aid in England…. Over half (51%) have stopped smoking completely and of the 45% who still smoke, half say that they are vaping in order to stop smoking… There is growing evidence that e-cigarettes are helping many thousands of smokers in England to quit. The available evidence from research trials suggests that their effectiveness is broadly similar to prescribed stop smoking medicines and better than NRT products if these are used without any professional support…"

Box 3. **The "Mystery Vaping Illness"**

Over the course of 2019, reports began emerging – almost exclusively in the USA and later Canada — of users of vaping devices suffering serious lung problems (a condition called "popcorn lung", which can be fatal). The figure below indicates the emergence (and subsequent decline) of this phenomenon in the US. While numerous observers noted that it was unlikely that this could be a result of the use of e-cigarettes of the kind that had been safely used for years, and the likelihood was that the issue was to do with vaping substances other than nicotine and common flavorings, most public health authorities issued urgent warning about ENDS use in general — and this was picked up around the world.

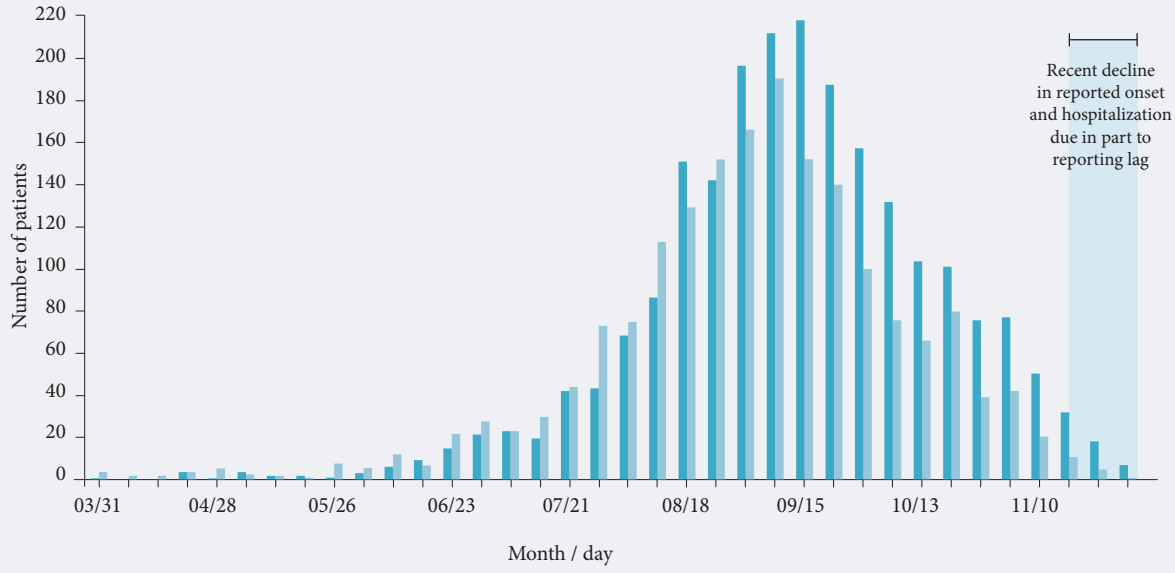
It took several months for US authorities to effectively confirm the suspicion that these cases were associated with use of vaping equipment to inhale THC (an active component of cannabis).

The Center for Disease Control and Prevention (CDC) [CDC, 2019] announced that they had "identified vitamin E acetate as a chemical of concern among people with e-cigarette, or vaping, product use associated lung injury ... laboratory testing of ...fluid samples collected from the lungs…[of] patients … found vitamin E acetate in all of the samples. Vitamin E acetate is used as an additive, most notably as a thickening agent in THC-containing e-cigarette, or vaping, products…"

By December 10, 2019, over 2,400 hospitalizations and over 50 deaths were reported by the CDC, with new cases still emerging (though at a decreasing rate). According to CDC: "THC-containing e-cigarette, or vaping, products, particularly from informal sources like friends, family, or in-person or online dealers, are linked to most of the cases and play a major role in the outbreak… Dank Vapes, a class of largely counterfeit THC-containing products of unknown origin, was the most commonly reported product brand used by patients nationwide."

Source: https://www.cdc.gov/tobacco/basic_information/e-cigarettes/severe-lung-disease.html#what-is-new (по состоянию на 15.12.2019).

Dates of symptom onset and hospital admission for patients with lung injury associated with e-cigarette use, or vaping in the United States, March 31–December 10, 2019



Source: https://www.cdc.gov/tobacco/basic_information/e-cigarettes/severe-lung-disease.html#epi-chart (as of 15.12.2019).

Box 4. **Prohibition versus Harm Reduction**

While the two key terms here are imperfect descriptors of the alternative philosophies, their use is ingrained and we will follow it below.

The **prohibitionist,** or abstentionist, point of view seeks to prevent the behavior that is associated with harm. Many cases concern a behavior with overtones of immorality – sexual promiscuity, drug abuse, driving above the speed limit. Risks associated with, for example, long-established sporting activities, are less often seen as requiring such an approach.

In the present case, prohibitionists stress the importance of tobacco control measures. They often see ENDS as a serious threat to the success of these measures (for reasons outlined in the body text). Some resistance to the disruptive innovation thus stems from quarters who are habitually aligned against the industries threatened with disruption. This is the mainstream position in many national and international public health bodies. Obstructive regulation could thus limit, or even suppress, the disruption.

The harm reduction point of view typically accepts that, even when discouraged (or even officially prohibited), many people will persist in undertaking risky practices. It highlights measures that can reduce the resulting harm.[I]

Though the approach has a long history (for example, mandating automobile seatbelts and motorcycle helmets), the terminology of "harm reduction" rose to prominence with the AIDS crisis in the 1980s. Condom use would reduce the risks of sexual intercourse; needle exchange and related approaches would restrict spread within (and from) communities of intravenous drug users (cf. [*Berridge*, 1999]). The harm reduction approach has found many adherents in controversial areas of social and health policy such as sexual behavior and drugs – for a review of evidence and criticisms see [*Hunt*, 2003]. Harm reduction approaches to ENDS are outlined by [*Polosa et al.*, 2013] (this paper also discusses *snus*, the innovative alternative to chewing tobacco).

An individual may well take a prohibitionist view of one topic, and a harm reduction view of another, and attitudes may be contingent upon the opportunities for enforcement of rules and for reduction of riskiness. However, tobacco control prohibitionists, such as Tobacco Tactics (an organization that investigates and documents the "strategies and tactics the tobacco industry uses to undermine public health") warn that:

"One of the reasons harm reduction is a sensitive topic is that it could involve engaging with the tobacco industry, which has a history of manipulating public debate and public health policy… To fully understand the harmfulness of potentially reduced risk products and their effectiveness for smoking cessation, tobacco industry investments and research into harm reduction and potentially reduced risk products should be carefully scrutinised… In fact, a number of scientists leading the debate on harm reduction and/or potentially reduced risk products are funded by the tobacco industry."[II]

Notes:

I Harm Reduction International hosts an annual conference on the field, and its website (https://www.hri.global/about) provides extensive documentation on the topic, with updates on the application of the approach (especially in relation to drug use) at https://www.hri.global/global-state-harm-reduction-2018 (accessed 24.11.2019). Much useful discussion on harm reduction in relation to ENDS is featured at the Nicotine Policy group at https://groups.google.com/forum/#!forum/nicotinepolicy (accessed 15/02/2020).

II Source: https://www.tobaccotactics.org/index.php?title=Harm_Reduction (accessed 23.11.2019).

nologies, long-term health consequences are yet to manifest themselves. Expert opinion on the relative risks of new products versus combustibles, discussed above, continues to be embedded into UK policies. However, debate has continued around the extent to which e-cigarettes may have dangers of their own. Especially where product quality has not been adequately regulated, it is likely that vapers may be inhaling unhealthy substances. A number of deaths and injuries have been caused by exploding batteries and user modification of this component of e-cigarettes is reportedly involved in several cases [*Equation,* 2019].[24] A number of hospitalizations have arisen in the UK when drug dealers sold e-liquids that were claimed to feature cannabis, but instead were packed with a dangerous designer drug [*Day,* 2019]. A "wild card" arose in the United States in the summer of 2019 — a "mys-

[24] For discussions in user communities see also: https://www.e-cigarette-forum.com/threads/exploding-vape.896751/ (accessed 25.11.2019).

tery vaping disease" resulted in thousands of cases of lung damage, and several deaths (see Box 3).

That third case against ENDS may apply less to HNB, where there is less of a technological break with combustibles. However, a fourth set of reasons to oppose ENDS will apply equally to HNB. This time, the subject of stigma is not the tobacco industry, but nicotine itself. One fear is that nicotine use may damage young peoples' development (Is this not detectable from decades of youth smoking cigarettes?). But what looms large is concern about addiction. Even if it may not lead to the use of combustibles, and even if nicotine itself carries few health risks at typical levels of consumption, the existence of a nicotine "habit" is seen as inherently unpalatable.

Numerous commentators frame these divergent reactions to ENDS among the public health community as reflecting the clash of prohibitionist and harm reduction philosophies (see Box 4.) Such prohibitionist and harm reduction viewpoints have come into conflict in many arenas and nicotine products is one of the latest. This conflict of viewpoints makes e-cigarettes a distinctive case of disruptive innovation. The situation varies a great deal across countries and has been heavily influenced by reactions to events such as the "mystery vaping illness", which, as mentioned above, has a great deal to do with secondary innovations spawned around the disruptive innovation. The incumbents have, in many cases, sought to accommodate themselves to the innovation, by offering their own new products. However, resistance to the innovation has been mobilized by stakeholders who have ongoing opposition to the suppliers of the established product, which the innovation was threatening to displace. The potential disruption has polarized the debate between the two philosophies about how best to deal with the health risks of smoking.

This makes e-cigarettes a highly distinctive attempt at disrupted innovation. An unusual configuration of interests and philosophies have lined up in many countries to forestall this disruption. It may even be that radical change will be associated with a sustaining (?) innovation: HNB.

The future prospects for tobacco harm are, as we have implied above, highly uncertain. We have seen estimates of the death toll, and life years lost, if current trends continue and the effects of more or less substantial shifts to use of ENDS. With the divergence in policies and regulations across countries, with numerous competing products emerging (not only ENDS, but also, for example, HNB and snus), and with competing viewpoints, this would seem to be an important topic for a Foresight study. What forms could such a study take?

Foresight[25]

Foresight exercises address alternative futures and uncertainties. They engage experts and stakeholders to examine these alternatives and the scope for human agency to shape patterns of development. They go beyond forecasting and thus beyond the sort of modeling discussed earlier. In our case, estimates such as those of loss of lives and life-years in different scenarios, provided by modeling can be important inputs to a Foresight exercise. They give a quantitative dimension to scenario analysis and policy targets. Analyses such as those concerning the impacts of a shift to ENDS in the USA alone, could be valuably extended, ideally to cover the whole world, and drawing on data concerning plausible rates of adoption and cessation. Such analyses can also be valuable for benchmarking the circumstances of different countries.

Focus

Any Foresight exercise has a focus. This could be the overall question of future tobacco use, its impacts, and strategies for limiting its toll on human health. Alternatively, in line with many technology foresight exercises, it could focus specifically on disruptive innovation, considering how innovative products and practices might emerge and reshape the smoking landscape. Here it would be particularly important to consider not just the disruption of ENDS, but also what may be seen as the "sustaining" innovation of Heat-not-Burn, where products such as IQOS and Glo have succeeded in making inroads onto several markets.[26] Though these have originated from big players in the tobacco industry, they radically differ from conventional combustibles, require change on the part of users as well as on the supply side, and may have considerable potential for harm reduction. Their social impacts are more significant than their attaining the status of "disruptive innovations".

The focus features a major topic and also has geographical and temporal dimensions: what locality, what time horizon? The focus usually reflects the sponsoring agency. Often these exercises are commissioned by national government agencies or by international bodies such as the European Com-

[25] The outline of Foresight activities presented here draws on the frameworks outlined in [*Georghiou et al.,* 2008; *Miles et al.,* 2016].

[26] Popular and user-oriented discussions of the different products and technologies are emerging online — see for example [*Koshelev,* 2019]. For a literature review on HNB use and health risks see [*Simonavicius et al.,* 2019].

Table 1. **Areas of Innovation Related to ENDS and ENDS Use**

Possible areas for technological and other types of innovation	• Conventional Cigarette products (e.g. novel additives, filters). • Production of Combustibles (and production, e.g., automation, 3-D printing). • ENDS designs and components (methods of vaporizing, sources of power, etc.) • The liquids used to make vapors (flavors, aerosols, other ingredients). • Alternative Recreational Products for Tobacco Users (new/improved noncombustible products such as e.g. snus, heat-not-burn (HNB)). • Alternatives to nicotine (e.g. new recreational drugs, or new practices that supplant nicotine use). • Medical techniques for managing nicotine dependency (e.g. Nicotine Replacement Systems such as patches). • Medical techniques for reducing nicotine dependency (pharmaceuticals, vaccination, new neuropsychology-based approaches, etc.). • Psychological approaches to reducing nicotine dependency (Cognitive-behavioral therapy, hypnotherapy, etc.; innovation here might include the use of new web-based support services, or wearable devices that support healthy lifestyles). • Tobacco Control Policies (new strategies and the use of new technology in public health campaigns, restrictions on smoking and advertising).
Downstream innovation	• Medical approaches (or other techniques?) that could limit or correct one or more of the major harms occasioned by tobacco use - and/or harm related to the use of new products for delivering nicotine. • Changing medical criteria concerning the treatment of diseases occasioned by practices known to be risky (e.g. restricting access to services for smokers).
Upstream innovation	• Tobacco agriculture (as impacted by climate change, new crop varieties, novel cultivation techniques) • Activities related to agriculture (including distribution, storage of tobacco crops). • Use of tobacco crops (use of other parts of the plant than are currently processed, applications for purposes other than nicotine/cigarette production). • Ways of producing nicotine (for example, large-scale, low-cost biosynthesis via modified yeast or bacteria).
Source: compiled by the author.	

mission or one of its directorates. In many ways a multinational study that encompassed major world regions would be ideal — it could include areas with high cigarette usage, such as China, and countries with very different approaches to tobacco control and to harm reduction alternatives. For example, Sweden has interesting experience with snus and Japan with HNB. (One difficulty is that many organizations, e.g. WHO, already have strong positions on such innovations.) The time horizon could feature a relatively short-term examination or aim to look generations ahead. Given that technological innovations often take a couple of decades to diffuse widely[27] and that the health impacts of cigarette smoking (and of ENDS?) unfold over an equally substantial period, it would make sense to cover at least the next twenty years.

Scenarios

Future prospects are highly uncertain, with numerous stakeholders are acting and reacting around the formulation and implementation of policies relating to tobacco control and to harm reduction (here we would include policies vis-à-vis ENDS, HNB, and similar new approaches to nicotine delivery). One way of exploring such ideas is to undertake scenario workshops. There are many different scenario approaches [*Miles et al.,* 2016] — one familiar approach would be to identify major drivers and uncertainties, and design scenarios around these. Another approach would start by identifying extreme (but plausible) outcomes, such as those in a 2-by-2 scenario framework, in which one dimension would involve extremes in the evolution of tobacco control aimed at cigarettes, one on extremes in the regulation of ENDS. The plausible extremes would be a matter for debate and resolution in the workshops that would examine what factors and forces might lead to such a pattern of development. Other workshop activities might involve attempting to simulate the responses of various stakeholders, with workshop members adopting "personas" representing different actors, how these might vary across countries and world regions, and in terms of outcomes for different social groups.

Horizon-Scanning

Scenario workshops are usefully informed by prior horizon-scanning activities. These might involve, literature reviews (State of the Science Reviews,

[27] Note that it is difficult to anticipate radical technological innovation more than a couple of decades hence, since this will often involve breakthroughs in knowledge that have yet to take place.

Bibliometric analyses, etc.) or more active elicitation of expert opinion by means, say, of Delphi surveys. One of the major purposes of such scanning is to examine the scope for technological (and social) innovations that could be important determinants of developments in the field. These might involve innovative products, production processes, social practices, regulations and regulatory systems, and new ways of measuring and monitoring activities and outcomes.

Table 1 illustrates the wide range of topics that could be examined here. Such a panoply of developments is exactly the sort of complex evolving landscape that we confront in many technology Foresight studies. A literature review may identify emerging possibilities for innovation in the various areas. Additionally, expert knowledge and creativity mobilized in, for example, brainstorming workshops and/or by the use of systematic creativity techniques could well pinpoint prospects that can be deduced from thinking about other lines of work. Once identified, key innovations can be addressed through workshops, Delphi surveys, and the like. For example, a Delphi survey could be organized to ask informed individuals about each innovation: how near it is to realization, when it might be launched, what the impacts would be (for example, health outcomes as well as other social and economic costs and benefits), what factors might facilitate or inhibit development, and so on.

Appraising future markets and regulations involves the analysis of key drivers, for example using STEEPV. Such factors may well vary across (and within): they include social trends (such as the conditions that may lead to a desire for stress relief, attitudes toward the use of psychotropic drugs, and levels of concern about health and lifestyle) as well as economic and political factors (among which the incomes governments derive from the tobacco tax may be important, while in some countries the links between tobacco industry and the state may be very strong — to the point where large cigarette manufacturers may be state-owned). Again, such developments can be addressed through media analysis, literature review, and the elicitation of expert opinions.

Wild Cards

Such enquiries would normally proceed before, and inform, scenario analysis. It will also be important in the course of such work to pay attention to wild cards — things that are not expected to have a probability of more than 1 in 10 of coming about, but that would have an immense impact if they did. The "mystery vaping illness" of the summer of 2019 (see Box 3) combines two topics where early warning signals were already apparent. First is the use of vaping systems for inhaling drugs other than nicotine. It is not uncommon for complementary and user innovations to be "wild cards" for the initial innovator, substantially changing the way in which their products may be used, and the cultural meanings they acquire. Second, is the emergence of unexpected health risks (apparently) linked to ENDS. The suddenly emerging wild card involved the fusion of these two topics. Mass media and politicians interpreted the damage done by illicit vaping activities as indicative of a danger in all e-cigarettes. Not only did it seemingly confirm fears about vaping being potentially harmful, but at the same time there was much media coverage about teenage vaping "epidemic". Concerns about the "mystery vaping illness" intersected with those about "a large increase in the proportion of high schoolers who reported any vaping in the past 30 days, from 11.7% in 2017 to 27.5% in 2019" in the USA [*Fairchild et al.,* 2019, p. 1319]. The response there and in several other countries has been restrictions on flavorings that are believed to appeal to young people in particular, and other moves to restrict ENDS use.[28] Ironically, it is plausible that potential users may have been motivated by the health scare to explore HNB devices instead of ENDS.

Further wild cards are likely to arise and hindsight will subsequently portray them as less "wild" than originally thought. Foresight discussions often throw up possible wild cards, but they can also be deliberately focused on. STEEPV can be used as a framework to brainstorm wild possibilities, and workshops can explore their implications. Experience suggests that, while we can often successfully identify wild card events, the specific manifestation of a wild card, and the cascading reactions of social actors, may take quite different forms from those envisaged. A whole pack of wild cards may ensue, leading to outcomes that can be highly dependent on the precise intensities and sequences of events.

These are among the most challenging aspects of Foresight studies – so much so that a distinct field of work on "risk assessment" has been developed to examine catastrophic wild cards, including also those phenomena believed likely to happen but with highly uncertain timing (extreme natural phenomena, from earthquakes to Carrington Event-type solar storms[29], are often of this type). Human

[28] Among recent press reports, one that discusses pressure on UK regulators is [*Waldie,* 2019].

[29] It is believed that a repeat of the Carrington Event of 1859, which created beautiful auroral displays but disrupted telegraph systems, would severely damage global electrical and communications networks. An approach to estimate the likelihood of such an event in coming decades is proposed by [*Morina et al.,* 2019].

history has been punctuated by wild cards. But it is impracticable to examine more than a fraction of the possible wild cards that can be anticipated in any detail – especially given that there are a myriad of ways in which any wild card might be realized. A few may be selected for risk assessment exercises. Others can be taken into account when developing early warning systems to monitor developments in the field over the following years.

Action

Later steps in Foresight exercises involve developing proposals for policies and strategies for stakeholders to purse, in order to achieve desirable futures. Various procedures can be implemented in order to generate and prioritize such options, with roadmapping techniques being useful for sequencing them. While roadmapping is generally used to identify steps towards a future whose desirability is a matter of some consensus, it is also possible to use such approaches to examine actions that might be required in the event that alternative scenarios materialize.

It is important to engage participants knowledgeable about such issues as the scheduling and phraseology of policies, the instruments available to different actors, and the extent to which stakeholders can be persuaded to deal with long-term prospects. In this controversial field it may be that it is difficult to achieve consensus, for example a prohibition/abstinence perspective and a harm reduction one may remain opposed even as concerns the longer term. Even so, dialogue between the opposing viewpoints – which may require a facilitator skilled in conflict — may be of value to all sides, in deepening their understanding of the relevant arguments, counterarguments, hopes, and fears.

A Foresight activity focused on tobacco futures and/or on the scope for disruptive innovation here, would seem to be well worthwhile. We are dealing with an activity involving expenditures of billions of dollars, and threats to many millions of lives. What would be important for such an exercise would be for it to be championed by an "honest broker", that is, one not seen as seeking to impose one or the other agenda on the process and who could engage those whose expertise is vital for the success of the process. Who will step up to this task?

The present article draws on outputs from the preliminary scoping of an envisaged multi-country Foresight exercise. Ian Miles was funded in late 2018-early 2019 by the Foundation for a Smoke-Free World (FSFW).30 FSFW received funding from a tobacco firm (Philip Morris International) and though it has documented its independence and governance,31 Tobacco Tactics considers it a "front organization" for the tobacco industry,32 and some correspondents to The Lancet recently proclaimed: "Now, more than ever, we must reinforce the hitherto successful calls from WHO and the public health community to reject collaboration with the Foundation" [Legg et al., 2019, p. 2478]. Preparatory work found that much wariness exists among potential collaborators in the Foresight study. The study got partial funding under the NRU HSE Basic Research Program and the "5-100" Program. The author is responsible for opinions presented in this essay.

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[31] See documents at https://www.smokefreeworld.org/governance/ (accessed 15.02.2020).

[32] https://www.tobaccotactics.org/index.php?title=Category:Front_Groups (accessed 17.12.2019).

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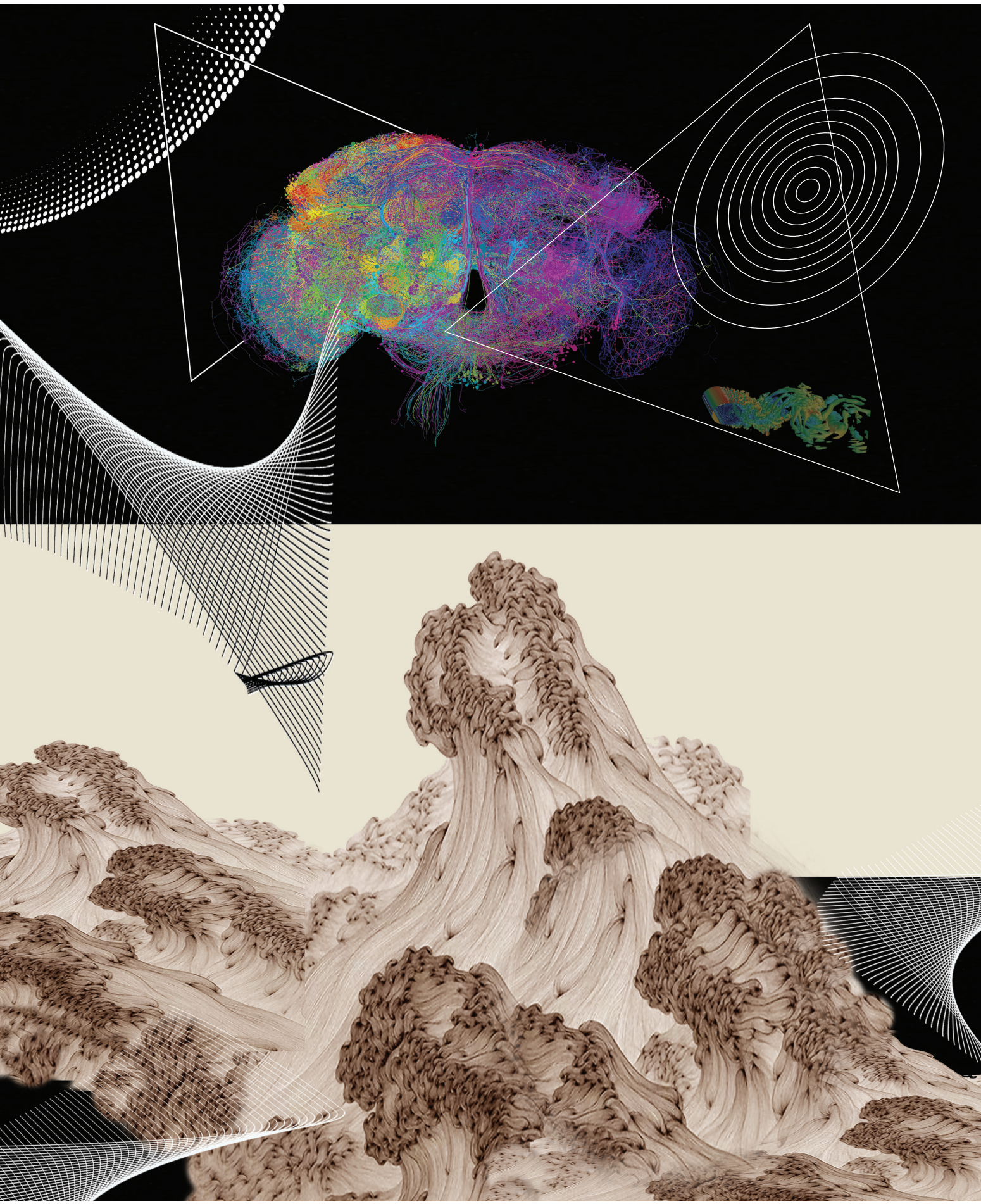
INNOVATION



Random Interaction Effect of Digital Transformation on General Price Level and Economic Growth

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Abstract

The paper attempts to evaluate the impact of digital transformation upon productivity using the multi-level structure model of a random interaction effect based on the Bayesian approach to cross-section data. Digital transformation significantly raised general price levels in Russia and has had consistently significant positive effects upon economic growth through the random interaction effect. Therefore, in Russia in 2018, digital transformation played a role as a driver of technological progress that prompted economic growth rather than economic stability.

Keywords: digital transformation; Bayesian theorem; MCMCglmm; random interaction effect

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Introduction

Digital transformations (DT) have been notable in business fields since 2010. Digital transformation is the intellectual process by which digital technologies are developed (in a similar way to general human development) in all social spheres.

This research suggests that digital transformation can be random and a technical shock, but it is also a phase of technological progress. Thus, at a given point, digital transformation could also be the start of a business cycle and may impact economic growth.

Considering the two-sided nature of digital transformation, this paper first researched what kind of effect it has on productivity, general price level, and economic growth in Russia. Second, this paper distinguishes between the impact of variations in price levels and rates economic growth determined by expert groups. Finally, this study aims to analyze the random interaction effect of digital transformation upon the general price level and economic growth.

Theoretical Background

To analyze the impact of digital transformation upon the economy, this paper will first consider its impact upon productivity. This is because digital transformation would act as a shock to productivity. This is to determine whether a digital transformation would reduce production costs and improve productivity in Russia in 2018.

Goldfarb et al. [*Goldfarb et al.,* 2015] evaluate the relationship between digitalization and production costs. This author also thinks that digital transformation may reduce operational costs including those related to searches for information and reservation costs. In addition, this paper suggest that digital transformation can reduce production costs including manufacturing, inventory, and management expenses, spending on trade including contract, distribution, and marketing costs. Furthermore, we can take the effect of information costs into consideration. Digital transformation can quickly and easily identify economic risks, thus reducing relevant expenses such as identification costs, moral hazard, and adverse selection. It is expected that deepening the digital transformation and the reduction in overall costs will affect general prices throughout the economy.

Draco et al. [*Draco et al.,* 2015] analyzed ICT's impact upon productivity on the basis of a theorem about the mutual interaction between costs and production. A decrease in the cost of production increases the productivity of a firm because it can produce more output from a given set of production factors. Moreover, this paper hypothesizes that increases in productivity from the digital transformation can directly affect real output on a national scale according to a production function. Thus, digital transformation at any given time indirectly affects economic growth through changes in productivity.

This paper is an attempt to create four latent variables. Each latent variable has respectively measured variables. The measured variables are the values that were observed during the research survey. Measured variables are selected by on the basis of economic theory. The variables were empirically tested over a long period.

Measured Variables of Economic Growth (PEG)

Charles I. Jones [*Jones,* 1995] tested the AK model using time series data. According to the AK growth model, the production function was set as follows:

$$y = Ak, \quad (1)$$

With y = Ak, A>0 representing the technical level, where, y =Y/L. k= K/L. Y, K, L respectively represent real output, capital stocks including human capital, and labor productivity.

The digital transformation at any point in time influences the value of A which represents the technology level in the production function (1). Then the changes in technology level (A) directly impact output level from equation (1).

This paper can use this concept as a latent variable, and the latent variable of economic growth (PEG) can be described by seven measured variables described in Table 1. The following can be thought of as the measured variables: the increase in R&D investment, population growth, the intensification of economic activity in networks, the reform of regulations and systems, the increase in the average number of years of education per person, the improvement of productivity, and finally, the increase in investments.

In the study by Caballé and Santos [*Caballé, Santos,* 1993], human capital and physical capital were determined endogenously and played a major role in determining economic growth. So, this paper uses human capital as one of the measured variables. The average number of years of education per person has been used as a proxy variable for human capital.

As we can see in [*Howitt,* 1999], there are arguments that population growth may affect the accumulation of human capital. Even if this is not the case, it can be argued that if there is a larger population, there would be a greater number of outstanding members of the workforce. Thus, population growth may determine economic growth. In addition to these variables, other measured variables include social security networks, the reform of regulations and systems, and economic activity networks. In endogenous growth theory, investment in R&D is considered a factor of optimization along with the supply of products on the market. R&D investment is included among the measured variables because it plays an important role in relation to human capital accumulation and innovation policies.

Table 1. **Latent Variables and Measured Variables**

Latent Variable[1]	Measured Variable	Nature of Measured Variable
Economic growth (PEG)	Increase in R&D investments	Endogenous
	Population growth	Endogenous
	Intensification of economic activity in networks	Endogenous
	Reform of regulations and systems	Endogenous
	Increase in the average number of years of education per person	Endogenous
	Improvement in productivity	Endogenous
	Increase in investments	Endogenous
Digital transformation (DT)	AI	Endogenous
	Mobile banking	Endogenous
	Sharing business	Endogenous
	Fintech	Endogenous
	IoT and smart factory	Endogenous
	Big data and cloud computing	Endogenous
	Navigation applications	Endogenous
	Mobile games	Endogenous
	Autonomous driving cars	Endogenous
Productivity (PRD)	Real wage	Endogenous
	Capital intensity	Endogenous
	Strengthening employee (re-)education	Endogenous
General price level (PRS)	Increase of money supply	Endogenous
	Increase of government expenditure	Endogenous
	Increase of import prices	Endogenous
	Increase of expected inflation rate	Endogenous
	Increase of exchange rate	Endogenous

[1] One out of the four latent variables, Digital transformation(DT), is exogenous. The rest latent variables, Economic growth(PEG), Productivity(PRD) and General price level(PRS), are endogenous.

Source: compiled by the author.

The above seven measured variables have been introduced as the fundamental factors that determine economic trends in economic growth theory. The measurement variables for economic growth are shown in Table 1.

There has been a long debate over whether an increase in the money supply can affect real national income. Lucas [*Lucas,* 1972] used a rational expectations theory to prove that money is neutral over the short and long term. In response, Ball and Romer [*Ball, Romer,* 1990] countered that even if the expectations are rational, the money supply may not be neutral if there is rigidity in the price structure. In this light, we further analyzed whether or not the increase in money supply affected economic growth.

Measured Variables of Digital Transformation(DT)

Digital transformation products, services, and technologies that are actively used on the market were selected as measured variables. On the basis of the classification of digital transformation technologies presented in Table 1, we attempted to select the variables for measurement, which adequately characterized the progress of digital transformation in Russia in 2018. The nine measured variables were as follows: (1) AI (Artificial intelligence), (2) Mobile Banking, (3) Sharing Economy, (4) Fintech, (5) IoT (Internet of Things) and Smart Factory, (6) Big Data and Cloud Computing, (7) Navigation Applications, (8) Mobile Games, and (9) Autonomous Self Driving Cars.

Measured Variables of Productivity (PRD)

In this study the three following measurable variables are used and are sufficient for describing the third latent variable, productivity: real wages, capital intensity ratio, and the training of personnel[1].

[1] One of reasons why productivity or economic growth is set as a latent variable, even though it can be measured is namely due to Solow's computer paradox. Solow said: «You can see the computer age everywhere except in the productivity statistics.» [*Solow*, 1987; *Triplett,* 1999].

First, Ackerloff [*Ackerloff,* 1984] presented the efficiency wage hypothesis. Amid asymmetric information, companies can increase their productivity by raising real wages to avoid adverse selection and reduce agent's moral hazard. This paper selected real wages as a measurement variable to account for productivity based on the efficiency wage hypothesis as shown in equation (2).

In the equation, *y, e, ω* mean real output, worker's work effort, and real wages, respectively.

$$y = f(e(\omega)), f'(\,) > 0, e'(\,) > 0, \quad (2)$$

Also, this paper selected the capital intensity ratio as the second measured variable. After the production function of Cobb-Douglas was derived, most production functions, such as CES (Constant elasticity of substitution), VES (Variable elasticity of substitution), and a translog function were derived from capital-labor ratio in equation (3). In other words, the capital intensitive ratio positively affects worker's average productivity.

In the equation, *Y/L, W/P,* and *K/L* represent average labor productivity, real wage, and the capital intensity ratio, respectively.

$$ln\left(\frac{Y}{L}\right) = a + b\, ln\left(\frac{W}{P}\right) + c\, ln\left(\frac{K}{L}\right), \quad (3)$$

where *b>0, c>0*

Finally, I used indicators of the level of education of workers and their participation in improving their qualifications and re-education programs. As a result of the accumulation of proficiency, it is possible to obtain a scale-up effect that increases the productivity of each factor of production [*Davis et al.,* 2017].

Measured Variables of General Price Level (PRS)

The fourth latent variable, general price level, can be measured by monetary growth, fiscal expenditure by the government, imported commodity prices, the foreign exchange rate of the Ruble, and the expected inflation rate in Table 1.

According to the money quantity theory [*Friedman,* 2017], the long term the growth rate of money is proportional to the inflation rate in equation (4). In the equation, M, V, P, T stands for money supply, velocity of money circulation, price level, and volume of transaction quantity, respectively. In the equation *m, v, π, t* stands for the rate of change of M, V, P, T with respect to time.

MV=PT

$m + v = \pi + t,$

In the long run, $v = t = 0$

$$\therefore m = \pi. \quad (4)$$

This paper makes an attempt to evaluate the general price level through government expenditure as the measured variable. According to Keynesian theory, if the government has increased fiscal spending, prices on the demand side would fluctuate at least in the long term. There have still been arguments about how much prices will rise when future expectations are introduced, but prices may rise in the middle and long term. This will prompt an increase in the general price level.

This paper also considers the prices of imported goods. If the price of imported goods goes up, it may increase wholesale or retail prices which subsequently pushes overall prices up in a country. Since Russia depends upon overseas imports of daily necessities, rising prices of imported goods are expected to impact Russia's general price level. Import prices are linked to the exchange rate of the Ruble. The exchange rate of the Ruble is being used as a measured variable representing the general price level in Russia.

Finally, this paper uses the expected inflation rate as an evaluation tool. The expected inflation rate was measured taking into account rational expectation theory. The rise in expected prices will raise actuual prices in the future. The level of the actual increase depends upon the time horizon (whether short or long term) and upon the type of expectations.

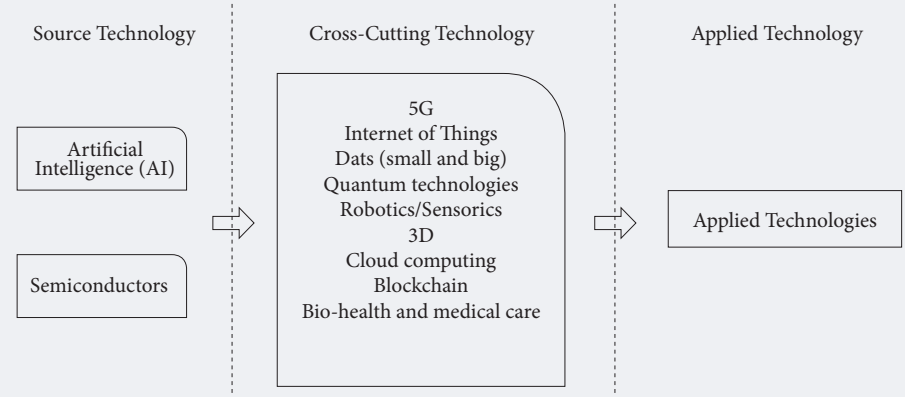
Qualitative Structure of the Research Survey

To conduct the analysis of digital transformation, the technology of digital transformation, its products, and its services are classified as shown in Figure 1. In Figure 1, digital transformation can be classified as base technologies, cross-cutting technologies, and applied technologies. Source technologies include artificial intelligence (AI) and semiconductors. Applied technology refers to the use of the two base technologies in the real world. Six technologies that have produced a wide variety of application technologies can be categorized as the cross-cutting technologies of digital transformation.

The research survey[2] was conducted face-to-face for about two months in November and December in 2018. The survey participants were a group of experts at the National Research University Higher School Economics (HSE) in Moscow. Respondents were divided into two groups, namely pivotal and non-pivotal. The survey was conducted through a multi-level

[2] The research survey was conducted by providing respondents with simple information according to the rational expectation theory. During the face-to-face survey, if there was a question, the respondent was provided with the necessary information. The questionnaire revolved around residents of the HSE guest house and HSE Moscow. The questionnaire consists of five sections, including digital transformation, productivity, general price level, potential economic growth, and the personal information of the respondents.

Figure 1. **Classification of Digital Transformation**



Source: compiled by the author.

model. Experts in each group responded to the four latent and 24 measured variables in Table 1. The collected questionnaire yielded 44 responses. Eight out of 44 surveys were considered pivotal, the other 36 surveys belong to the non-pivotal group. Each individual expert (1st stage) is nested once in the pivotal or non-pivotal group (2nd stage)[3].

The pivotal group included experts who are able to recommend policies to decision makers in the organization or make policy decisions by themselves. The positions held by those in the pivotal group include directors, deputy directors, members of the editorial committee of the journal, the heads of departments, and the deputy heads. Whether they were in a decision-making unit can be easily verified by the face-to-face surveys. Let us call the pivotal group type1, and the non-pivotal expert group type2.

A unilateral non-parametric Kruskal-Wallis test was conducted to see whether there are any differences between type1 and type2. Although whether one was pivotal was extracted from the survey according to the hierarchy of positions at the organization, this paper tries to confirm whether this distinction is economically and statistically meaningful. The Kruskal-Wallis test was conducted because, as shown in Figure 2, all four latent variables failed to meet the normality. This test was conducted on four latent variables. Those were digital transformation, productivity, general price level, and economic growth, respectively.

In the test, the null and alternative hypotheses are as follows:

Hn: The distribution of latent variables is the same regardless of the group.

Ha: At least in one group the distribution of values of the latent variable were distinguished from one another.

A dispersion analysis of the values yielded by the survey responses (independent of the group) was completed where in each of the four latent variables, the normality or equal-variance were considered. In Table 2 there is a statistically significant difference in the productivity variables. The general price level demonstrates a marginally significant difference. These variables rejected the null hypothesis and support the alternative. In addition, there is a difference, although only marginally significant, in the digital transformation variable. Economic growth has been shown to be consistent by supporting the null hypothesis. This analysis means that although the entire sample came from the Higher School of Economics (HSE) in Moscow, there were differences within the group[4].

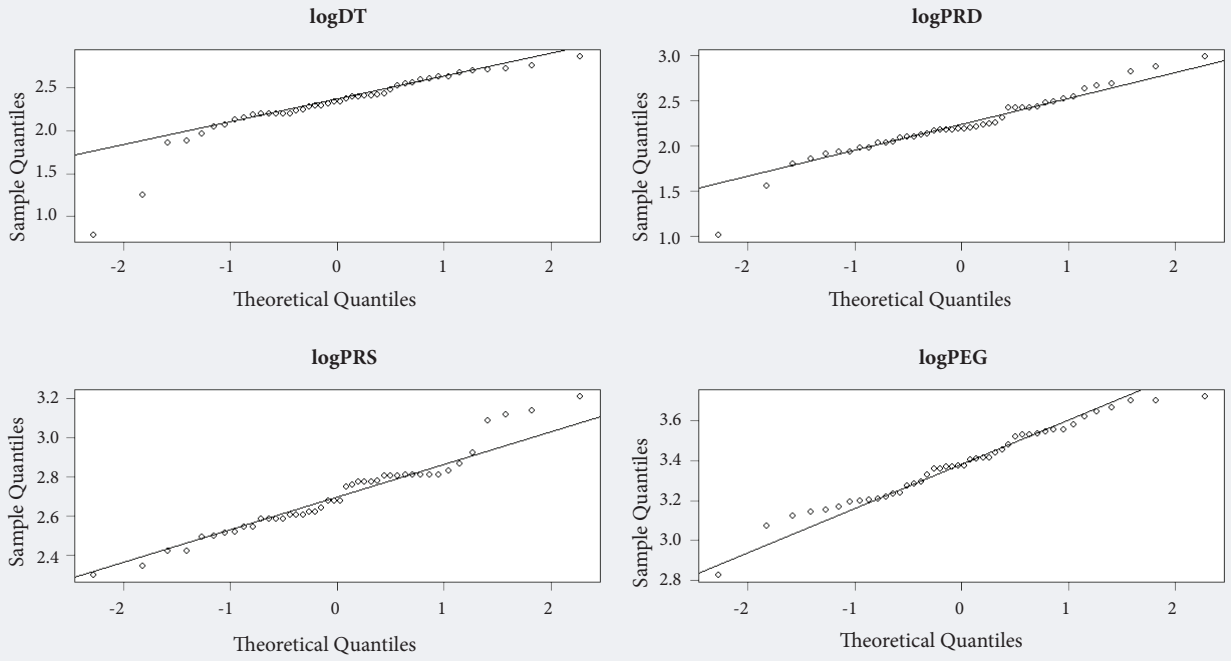
Analytical Model Building

The multi-level response model has two levels. Individual experts were included in either the pivotal group or the non-pivotal group. The model consists of four latent variables: DT, PRD, PEG, and PRS. Here, DT is the external latent variable, while PEG, PRD, and PRS are the internal latent variables that are affected by DT. All internal variables have their internal error respectively. Each latent variable has its respective measured variables. The measured variables are nine DTs, three PRDs, seven PEGs, and five PRSs, respectively as seen in Table 1. All measured variables have measurement errors, there are a total of 24 measurement errors. Thus, the two-level model consists of four latent variables, 24 measured

[3] Moulin [*Moulin*, 1986] proposed using the key mechanism with quasi-linear utility function to analyze decisions about public goods.

[4] After the pivotal group was also divided into two groups, the unilateral Kruskal-Wallis test was conducted for the three groups in the saturated model.

Figure 2. **QQ Normality Test**



Source: compiled by the author.

variables, three internal errors, and 24 measurement errors[5].

K Factor Model

There are several approaches to measuring latent variables [*Anderson, Rubin,* 1956; *Lawley, Maxwell,* 1962; *Bartholomew et al.,* 2011]. Joreskog made the Anderson and Rubin approach a statistical application called LISREL8.8 [*Joreskog,* 1990]. In addition, there are the R2WinBUGS and MCMCglmm instruments for the R program.

Among the several methods for calculating latent variables, this paper constructed a factor analysis model (5)[6]. In this way, it is constructed as follows:

$$Y = ZX + \xi, \text{ where } X \sim N(0, I), \xi \sim N(0, \varphi), \varphi = \\ = \text{diag}(\varphi_1, \varphi_2, \, , \, , \, \varphi_K). \quad (5)$$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad Z = \begin{bmatrix} \rho_{11} \cdots \rho_{1k} \\ \vdots \ddots \vdots \\ \rho_{n1} \cdots \rho_{nk} \end{bmatrix}, \quad X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_k \end{bmatrix}, \quad \xi = \begin{bmatrix} \xi_1 \\ \xi_2 \\ \vdots \\ \xi_n \end{bmatrix}.$$

In the multiple regression analysis equation (5), the measured variable becomes a dependent variable, and the latent variable is an independent variable. Here the regression coefficient is called factor loading. Factor loading has been used as latent variable value. In this paper, a significant latent variable has factor loading at the level 0.3. To derive theses values, we assumed that the residuals were not correlated, and X and ξ were independent of one another. Every X_i was assumed to be independent.

Mixed-Effect Model

As shown in equation (6), I had to confirm whether the intercept of logDT varies between the type1 and type2 groups. The estimated intercept (1.129) of the equation was substantial at a at a 95% significance level as seen in Table 3. The random effect was 1.114, which was also significant at the 95% confidence level (I-95%CI, U-95%CI) = (0.0002, 3.168).

Furthermore, this is also supported by the fact that ICC (Intraclass correlation coefficient) =0.1205 is not zero in formula (7). Because $\vartheta^2 \neq 0$, it is ICC ≠0. This means that there is variability between type1 and type2, so the random effect should be taken into account. Therefore, we intend to use the generalized linear mixed model (GLMM) to estimate the fixed and random effects of digital transformation in this model[7].

[5] There are many discussions about the size of the samples, including [Westland, 2010]. Experience shows that the ratio of analyzed situations to free parameters of 10:1 is considered sufficient. In this study, there are three parameters and 46 samples. Thus, this paper satisfies the 10:1 condition.

[6] After estimating the structural equation using the AMOS statistical package, the latent variables were calculated as the average of the estimated coefficients, but the factor analysis provided better results.

[7] The use of the Markov Monte Carlo Chain (MCMC) is intended to minimize the deviation bias between discrete values given that observations are discrete. Moreover, this method is more effective for taking insufficient variables into account.

Table 2. **Unilateral Kruskal –Wallis Test**

Variables \ Statistics	χ^2	Degree of freedom	P-value
Productivity (Logarithmic value)	4.9101	1	0.0415*
General price level	3.612	1	0.057(.)

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Source: compiled by the author.

$$DT_{ij} = \mu + TYPE_j + u_{ij},$$
$$TYPE_j \sim iid\ N(0, \vartheta^2),\ u_{ij} \sim iid\ N(0, \emptyset^2), \quad (6)$$

where μ mean.

ICC calculates as follows:

$$ICC = \frac{\vartheta^2}{(\vartheta^2 + \emptyset^2)} \quad (7)$$

The Bayesian Approach to the Linear Multi-Level Response Mixed Model

In the linear mixed structure with the multi-level response, the residuals calculated for the various groups during stage 2, were independent of each other. Also, it is assumed that during the first and second stages, the distribution of error is normal.

Here is an example of the latent digital transformation variable (DT), which we are trying to estimate, an average value (μ) and variance (σ^2), about which we know nothing. In the Bayesian approach, the posterior probability density function is proportional to the likelihood function multiplied by the priori probability density function according to the rules of the Bayesian approach as follows.

$$P(\mu,\sigma^2 \mid DT) \propto P(DT \mid \mu,\sigma^2)\ P(\mu,\sigma^2). \quad (8)$$

In this study, the a priori probability density function was derived using both the non informative priori probability distribution[8] and the inverse Wishart priori probability distribution. In the Wishart priori probability density function, the expected mean and variance were adjusted by looking at the convergence of each variable in the case of fixed and random effects. The initial values were a variance σ^2 of 1 and expected value μ = 0.002 in the Markov Monte Carlo model. Gibbs sampling was run from about 1,000,000 to 2,000,000 times and half was discarded to eliminate auto-correlations and dependencies from the initial value. At that time, the effective sample of about 100,000 was selected and the parameter value was estimated as the average value of the effective samples.

The Estimated Generalized Linear Mixed Model and Results

Generalized linear mixed models were specified at each stage to analyze the effects of the digital transformation (DT) upon productivity (PRD), general price level (PRS), and economic growth (PEG). In addition, a Bayesian approach was estimated by introducing the non informative priori probability distribution and inverse Wishart priori probability function in each equation for applying the MCMC (Markov Chain Monte Carlo).

The Effect of Digital Transformation upon Productivity

We analyzed the effects of digital transformation upon productivity.

$$PRD_{ij} = \alpha_{Oj} + \alpha_{1j} DT_{ij} + \epsilon_{ij},\ \ \epsilon_{ij} \sim iid\ N(0, \sigma^2), \quad (9)$$
$$\alpha_{Oj} = \alpha_0 + W_{0j},\ \ W_{0j} \sim iid\ N(0, \vartheta_0^2), \quad (10)$$
$$\alpha_{Oj} = \alpha_1 + W_{1j},\ \ W_{1j} \sim iid\ N(0, \vartheta_1^2), \quad (11)$$
$$PRD_{ij} = \alpha_O + \alpha_1 DT_{ij} + W_{0j} + W_{1j} DT_{ij} + \epsilon_{ij},$$
$$\epsilon_{ij} \sim iid\ N(0, \sigma^2) \quad (12)$$

We put equations (10) and (11) into equation (9), and yielded equation (12). In equation (12), *j* means type1 and type2, respectively. Moreover, *i* refers to individual experts in each type.

The first half of equation (12) $\alpha_O + \alpha_1 DT_{ij}$ represents the fixed effect. The second half, $W_{0j} + W_{1j} DT_{ij}$ represents the random effect. This section shows the size of the volatility of the intercept and the slope fluctuating around the α_0, α_1 depending on type1 or type2. Residual ϵ_{ij} refers to the total amount of variance that cannot be explained by DT. Also ϵ_{ij} represents total variability within the type. W_{0j} represents the variability of the intercept due to differences between types, and W_{1j} represents the variability of the slope due to differences between types.

There are three probability variables ϵ_{ij}, W_{0j}, W_{1j} in equation (12). Thus, there were two parameters and three probability variables to be estimated from the above model. That was α_O, α_1, W_{0j}, W_{1j}, ϵ_{ij}.

Table 3. **Location Effect: logDT~1**

Intercept \ Statistics	Post. mean	I-95% CI	u-95% CI	pMCMC
Intercept	1.129	0.216	2.066	0.038*

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Source: compiled by the author.

[8] In general, non informative priori probability distribution means a flat distribution function, but in this study the expected average value and variance are equal to zero.

Table 4. **The Effect of Digital Transformation upon Productivity**

Effect \ Statistics	Estimated parameter (probability variable)	Estimated value[1]	Credit Set (l-95%, U-95%)	P-value
Fixed effect	α_O	1.9334	–0.67307, 4.66381	0.0738
	α_1	0.0882	–0.24370, 0.41349	0.5886
Random effect	W_{0j}	292.2	0.01188, 19.11	
	W_{1j}	0.0603	0.01605, 0.119	
Variance of residual	ϵ_{ij}	0.1043	0.04851, 0.1705	
DIC		39.49293		

[1] Where estimates refer to the average value and variance of precise estimates of the effective sample from the marginal probability density function.

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DIC — Deviance information criterion [*Hadfield,* 2010]. DIC = 2D – D(∩), где D = –2log(Prob(y |∩)), ∩ is a set of parameters used in the model..

Source: compiled by the author.

These estimated values are summarized in Table 4. To estimate the expression (12), Gibbs sampling was repeated 2,000,000 times under the condition of the inverse Wishart probability density function. The results of Table 4 are estimated from the marginal posterior probability density function, which obtained 100,000 effective samples out of 1,000,000 left behind.

First, there was a positive relationship between digital transformation and productivity at a level of 0.0882 (fixed effect), but it was not significant. The random effect was significant and estimated at 0.0603. The total fixed effect was 2.0216. Therefore, the total effect of digital transformation upon productivity was positive and cyclical, but its statistical significance was weak.

Second, at the initial level of DT, the total random effect $W_{0j} + W_{1j} = 292.2603$. This value refers to the effect of DT upon PRD due to differences between groups.

Finally, the estimate of variance within the group was 0.1043. There was variability of each type was estimated at 292.2 for the intercept and 0.0603 for the slope. The dispersion in the difference between type1 and type2 should be considered significant because the dispersion figure between the groups was higher than that within groups.

The Effect of Digital Transformation upon the General Price Level

To analyze the effect of digital transformation upon the general price level, we created an equation system consisting of (13), (14), (15), (16), and (17). This equation system yielded random effects for all intercepts and slopes of DT and PRD by type1 and type2.

$$PRS_{ij} = \beta_{Oj} + \beta_{1j} DT_{ij} + \beta_{2j} PRD_{ij} + \varepsilon_{ij}, \varepsilon_{ij} \sim iid\ N(0, \rho^2), \quad (13)$$

$$\beta_{Oj} = \beta_0 + U_{0j}, \quad U_{0j} \sim iid\ N(0, \tau_0^2), \quad (14)$$

$$\beta_{1j} = \beta_1 + U_{1j}, \quad U_{1j} \sim iid\ N(0, \tau_1^2), \quad (15)$$

$$\beta_{2j} = \beta_2 + U_{2j}, \quad U_{2j} \sim iid\ N(0, \tau_2^2), \quad (16)$$

$$PRS_{ij} = \beta_O + \beta_1 DT_{ij} + \beta_2 PRD_{ij} + U_{0j} + U_{1j} DT_{ij} + \\ + U_{2j} PRD_{ij} + \varepsilon_{ij}, \ \varepsilon_{ij} \sim iid\ N(0, \rho^2). \quad (17)$$

Equations (14), (15), and (16) were put into equation (13), and then one obtains equation (17).

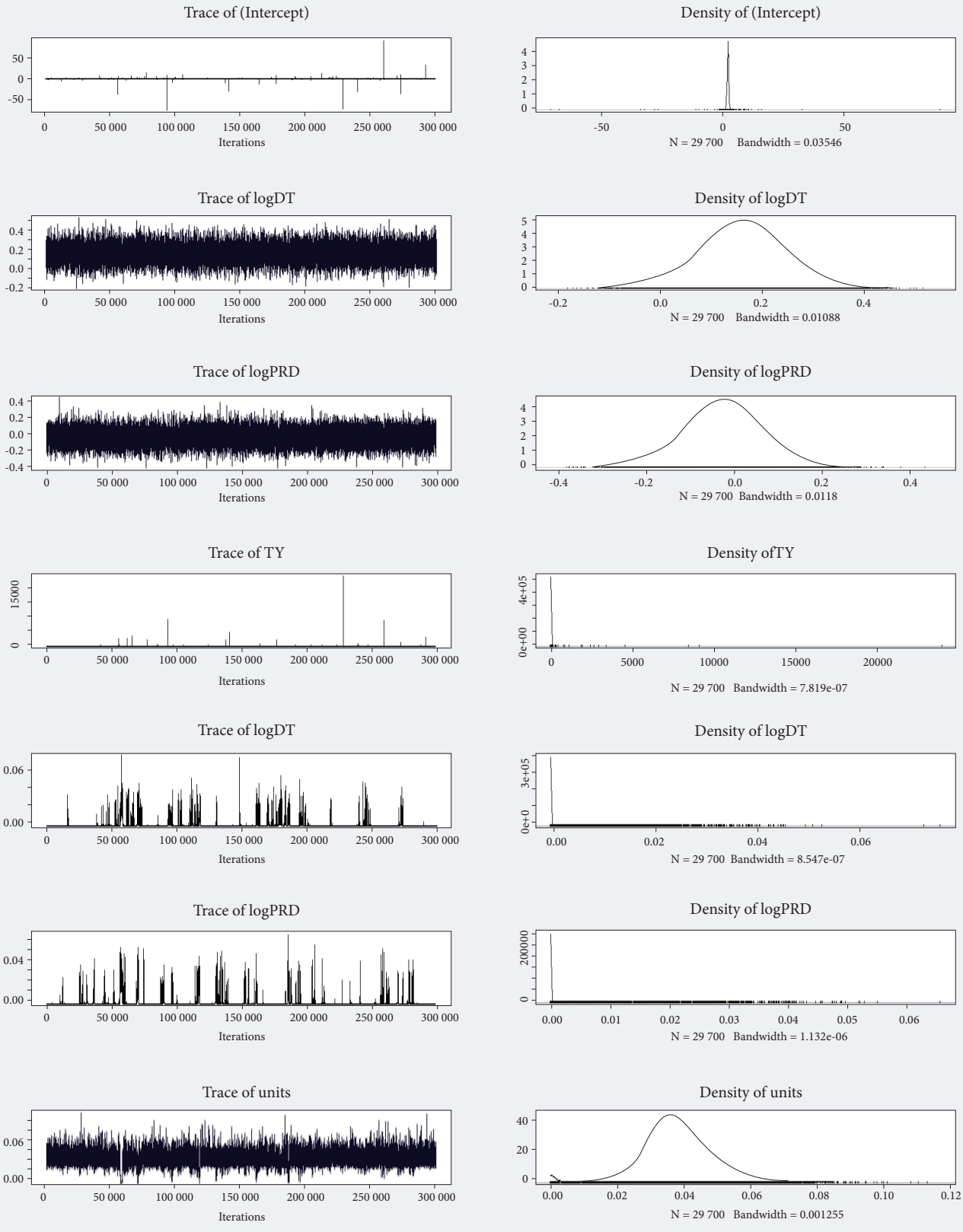
The first half in the equation (17) $\beta_{Oj} + \beta_{1j} DT_{ij} + \beta_2 PRD_{ij}$ describes the fixed effect and the second half $U_{0j} + U_{1j} DT_{ij} + U_{2j} PRD_{ij}$ represents the random effect. Residual ε_{ij} refers to the amount of variance that cannot be explained by DT and PRD. There are four probability variables ε_{ij}, U_{0j}, U_{1j}, U_{2j} in equation (17). Thus, there are three parameters and four probability variables to be estimated from the above model that were summarized in Table 5.

Equation (17) was estimated using the non informative priori probability density function and the inverse Wishart priori probability density function, respectively. When comparing the two models, the DIC value of the inverse Wishart priori model (-57.35371) is smaller than the non informative priori model (-18.47206). Therefore, the inverse Wishart priori model is superior to the non-informative priori model. Moreover, it is not possible to use the non-informative priori distribution because all the variables are unstable and not converging with the random effect as illustrated in Figure 3. On the other hand, each variable of the random effect derived under the inverse Wishart distribution is converging in Figure 4.[9] Therefore, the effect of digital transformation upon the general price level is to be analyzed with estimates obtained on the basis of the inverse Wishart probability distribution.

First, the effect of digital transformation upon the general price level in fixed effects was β_1=0.1609 at

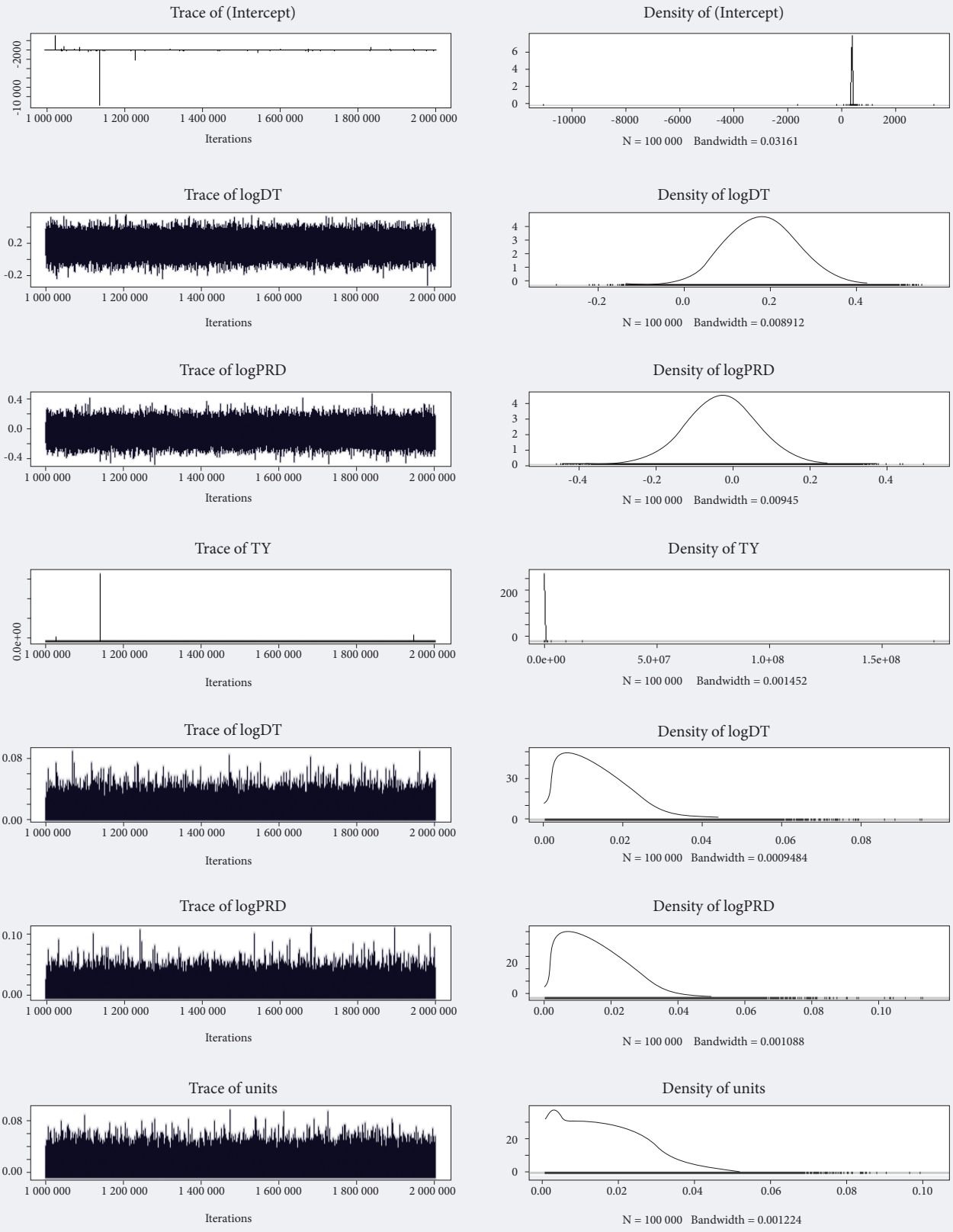
[9] All variables, regardless of the form of all priori information functions, were converged in the fixed effect.

Figure 3. **Marginal Posterior Probability Distribution Function with the Use of the Non-Informative Priori Probability Distribution Function in Equation (17)**



Source: compiled by the author.

Figure 4. **Marginal Posterior Probability Distribution Function under Inverse Wishart Priori Probability Distribution Function in Equation (17)**



Source: compiled by the author.

Table 5. **Effect of DT upon General Price Level**

Item		Non-Informative Priori Distribution			Inverse Non-Informative Priori Distribution		
Statistics / Effect	Estimate parameter (probability variable)	Average	Credit set (l-95%, U-95%)	P-value	Average	Credit set (l-95%, U-95%)	P-value
Fixed effect	β_O	2.3659	1.841143, 2.903513	0.00162 **	2.3312	1.732990, 3.108864	0.0085 **
	β_1	0.1652	0.001229, 0.321681	0.0421 *	0.1609	-0.005971, 0.326778	0.0571
	β_2	-0.0232	-0.196255, 0.150911	0.7878	-0.0438	-0.216958, 0.136778	0.6184
Random effect	U_{0j}	2.3750	1.784e-17, 0.009582		2018	1.149e-05, 0.5329	
	U_{1j}	0.0011	7.634e-17, 0.007833		0.0133	0.000652, 0.03041	
	U_{2j}	0.0012	8.439e-17, 0.007718		0.0159	0.0009982, 0.03512	
Variance of residual	ε_{ij}	0.0385	0.0184, 0.06123		0.0166	0.0002196, 0.03767	
DIC		-18.47206			-57.35371		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DIC — Deviance information criterion

Source: compiled by the author.

marginally statistical significance. Digital transformation significantly raised prices rather than lowered them. This means that digital transformation did not lead to productivity gains and a fall in prices, but increased costs. A similar effect has also been shown to raise prices in random effects that significantly reflect (U_{1j}=0.0133). Thus, digital transformation significantly increases prices for both fixed and random effects.

Second, the effect of productivity on prices is different for fixed effects and random effects. Fixed effects prompt an insignificant drop in prices, while random effects drive prices up (at a confidence level of 95%). The effect of productivity upon the price level was not clear.

Finally, the estimate of variance within the types is significant at 0.0166 at a confidence level of 95%. This is less than the dispersion between type1 and type2. This means that although the variation of general price level comes from within the group, one should also consider the variability resulting from the differences between type1 and type2. All the above estimated values are formed within a confidence level of 95%.

The Effect of Digital Transformation upon Economic Growth

Let us analyze the effect of digital transformation upon economic growth. To reflect the difference between type1 and type2, an equation reflecting random effects upon the intercept and the slope of DT and PRD was created as follows.

$$PEG_{ij} = \gamma_{Oj} + \gamma_{1j} DT_{ij} + \gamma_{2j} PRD_{ij} + \upsilon_{ij},\ \upsilon_{ij} \sim iid\ N(0, \phi^2), \quad (18)$$

$$\gamma_{Oj} = \gamma_0 + V_{0j},\ V_{0j} \sim iid\ N(0, \phi_0^2), \quad (19)$$

$$\gamma_{1j} = \gamma_1 + V_{1j},\ V_{1j} \sim iid\ N(0, \phi_1^2), \quad (20)$$

$$\gamma_{2j} = \gamma_2 + V_{2j},\ V_{2j} \sim iid\ N(0, \phi_2^2), \quad (21)$$

Let us put equations (19), (20), and (21) into equation (18), and then we can obtain equation (22).

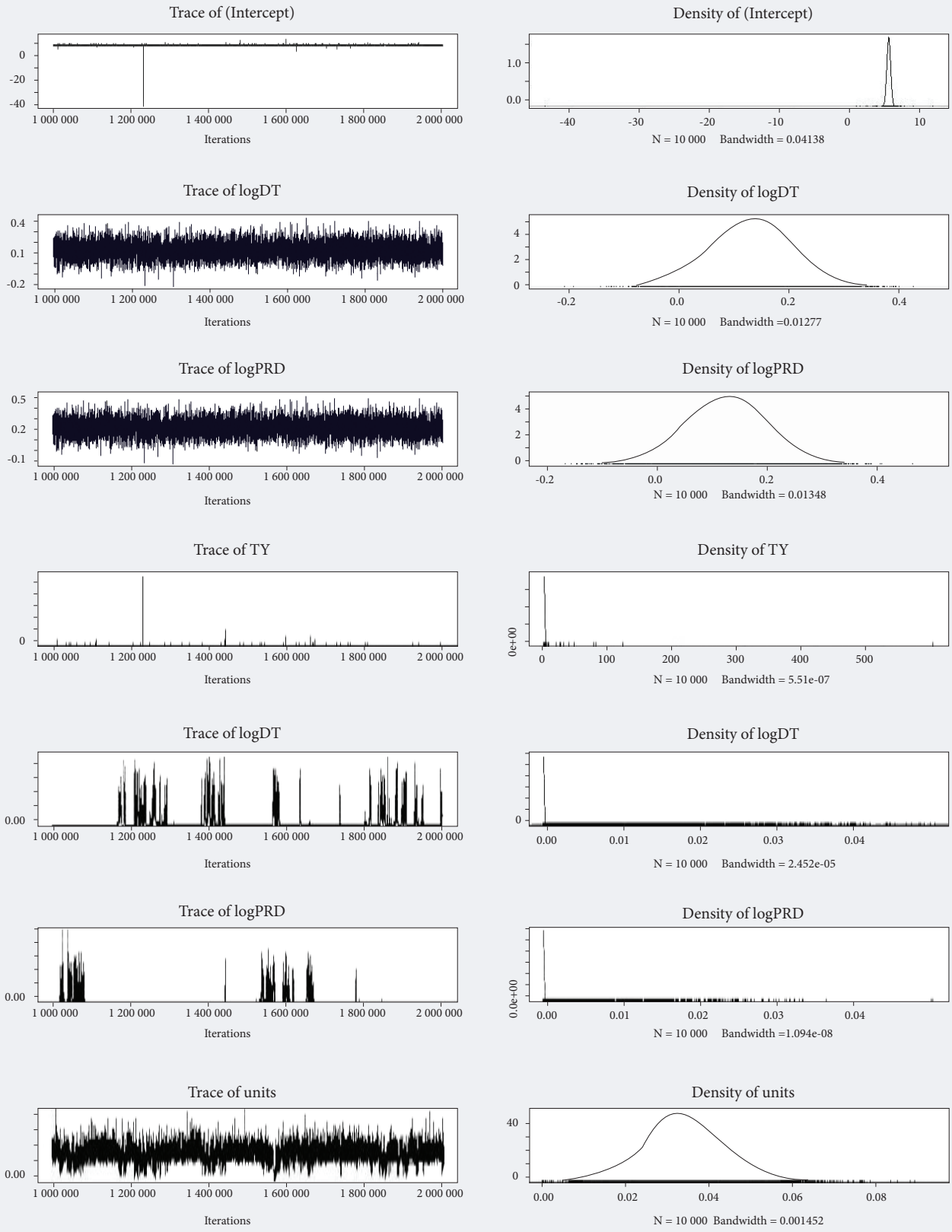
$$PEG_{ij} = \gamma_O + \gamma_1 DT_{ij} + \gamma_2 PRD_{ij} + V_{0j} + V_{1j} DT_{ij} + + V_{2j} PRD_{ij} + \upsilon_{ij},\ \upsilon_{ij} \sim iid\ N(0, \phi^2). \quad (22)$$

The first half of the equation (22) $\gamma_O + \gamma_1 DT_{ij} + \gamma_2 PRD_{ij}$ represents the fixed effect, and the second half $V_{0j} + V_{1j} DT_{ij} + V_{2j} PRD_{ij}$ describes the random effect. Residual υ_{ij} refers to the total amount of variance that cannot be explained by DT and PRD. There were four probability variables $\upsilon_{ij}, V_{0j}, V_{1j}$ and V_{2j} in the equation (22). Thus, there were three parameters and four probability variables to be estimated from equation (22). The results were summarized in Table 6.

Equation (22) was estimated using the non-informative priori probability density function and inverse Wishart priori probability density function. When comparing the two models, the DIC value of the inverse Wishart priori model (-94.69512) is smaller than the non-informative model (-23.1925) in Table 7. Therefore, the inverse Wishart model is superior to the non-informative priori model. Moreover, it is not possible to use the non-informative priori distribution each variable is unstable and does not converge with the random effect in Figure 5.[10] On the other hand, each variable of the random effect derived under the inverse Wishart priori distribution converges in Figure 6. Therefore, the effect

[10] All variables, regardless of the form of all prior information functions, converge with the fixed effect.

Figure 5. **Marginal Posterior Probability Distribution Function with the Use of a Non-Informative Priori Probability Distribution Function in Equation (22)**



Source: compiled by the author.

of digital transformation upon economic growth should be analyzed with estimates obtained on the basis of the inverse Wishart non-informative probability distribution.

First, digital transformation has a positive effect upon economic growth with fixed effects (γ_1 = 0.1379) at a marginally significant level. For random effects, there was a positive relationship (V_{1j} = 0.0176) at a 95% confidence level. Digital transformation demonstrates positive effects upon economic growth both in terms of fixed and random effects. This means that digital transformation can play a powerful role in driving economic growth in Russia.

Second, it can also be inferred that productivity has a marginally significant impact upon economic growth both in terms of the fixed effect (γ_2 = 0.1654) and random effect (V_{1j} = 0.0150) with a 95% confidence level. It can be thought that digital transformation has a positive effect upon economic growth via two channels. One manifests itself directly through technological advances and the other does so indirectly through productivity improvements.

Third, the estimate of the variance within the group is 0.0071 and the variation between groups is 699.4 for the intercept at a 95% confidence level. This means that the differences between the groups also have a significant effect.

Analysis of the Random Interaction Effect and Digital Transformation

The random interaction effect of digital transformation upon the general price level and economic growth is analyzed using a variance function. In order to analyze type1 and type2 by DT or PRD interaction, we use variance function as illustrated below in (23), (24)

$$V_{DT} = \begin{bmatrix} V_{1,1} & V_{1,2} \\ V_{2,1} & V_{2,2} \end{bmatrix} = \begin{bmatrix} \sigma^2_{type1} & \sigma_{type1,\ type2} \\ \sigma_{type2,\ type1} & \sigma^2_{type2} \end{bmatrix} \quad (23)$$

$$V_{PRD} = \begin{bmatrix} V_{1,1} & V_{1,2} \\ V_{2,1} & V_{2,2} \end{bmatrix} = \begin{bmatrix} \sigma^2_{type1} & \sigma_{type1,\ type2} \\ \sigma_{type2,\ type1} & \sigma^2_{type2} \end{bmatrix} \quad (24)$$

We assume that the different types in DT or PRD are independent, so variance function (23-1), (24-1), $V_{1,2} = V_{2,1}$ = is equal to zero, we could see no relationship between type1 and type2. On the basis of this, an attempt was made to evaluate the dispersion caused by the interactions of DT and PRD within type1 and type2, respectively [*Hadfield,* 2019].

$$V_{DT} = \begin{bmatrix} V_{1,1} & V_{1,2} \\ V_{2,1} & V_{2,2} \end{bmatrix} = \begin{bmatrix} \sigma^2_{type1} & 0 \\ 0 & \sigma^2_{type2} \end{bmatrix} \quad (23\text{-}1)$$

$$V_{PRD} = \begin{bmatrix} V_{1,1} & V_{1,2} \\ V_{2,1} & V_{2,2} \end{bmatrix} = \begin{bmatrix} \sigma^2_{type1} & 0 \\ 0 & \sigma^2_{type2} \end{bmatrix} \quad (24\text{-}1)$$

If the variance function is introduced in the random effect, the priori probability distribution should be set up differently than it has been in the analysis so far. This is because the variance function is obtained using a matrix, not by a scalar value. If the matrix in Equation (23-1) and (24-1) is reflected in the inverse Wishart priori probability distribution, then the posterior probability density function will be changed as the likelihood function is changed.

The Random Interaction Effect of Digital Transformation upon the General Price Level

The interaction effect of digital transformation in fact is the effect of a whole range of factors, so we

Table 6. **The Effect of DT upon Economic Growth**

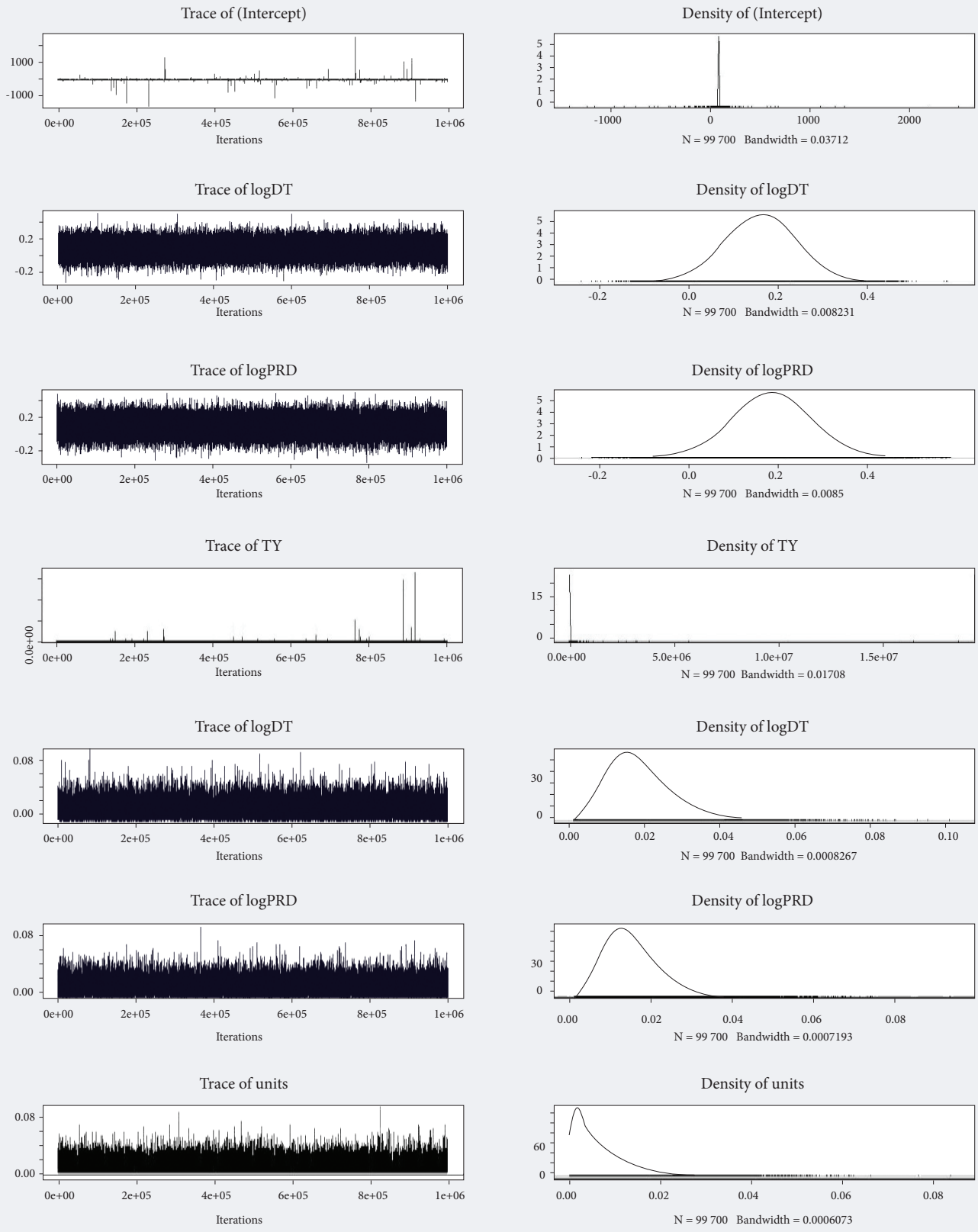
Item		Non-Informative Priori Distribution			Inverse Wishart Priori Distribution		
Statistics / Effects	Estimated parameter	Estimated value	Confidence level (l-95%, U-95%)	P- value	Estimated value	Confidence level (l-95%, U-95%)	P- value
Fixed effect	γ_O	2.7668	2.298004, 3.255209	0.001***	2.6861	1.352031, 4.119781	0.0249*
	γ_1	0.1388	–0.012589, 0.290072	0.0742(.)	0.1379	0.014989, 0.291980	0.0766(.)
	γ_2	0.1428	–0.007986, 0.309799	0.0780(.)	0.1654	0.004368, 0.324948	0.0434*
Random effect	V_{0j}	0.1201	2.295e-17, 0.006076		699.4	0.0009326, 5.569	
	V_{1j}	0.0022	1.206e-16, 0.01666		0.0176	0.003383, 0.03356	
	V_{2j}	0.0009	9.235e-17, 0.006303		0.0150	0.002911, 0.02884	
Variance of residual	υ_{ij}	0.0322	0.01144, 0.05125		0.0071	0.000173, 0.02024	
DIC		–23.1925			–94.69512		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DIC — Deviance information criterion

Source: compiled by the author.

Figure 6. **Marginal Posterior Probability Distribution Function Using the Inverse Wishart Priori Probability Distribution Function in Equation (22)**



Source: compiled by the author.

Table 7. **The Interaction Effect of DT upon General Price Level**

Effect \ Statistics	Estimated parameter	Post-mean	Credit Set (l-95%, U-95%)	P-value
Fixed effect	β_0	2.3022	1.63339, 2.97441	<1e-05***
	β_1	0.2094	0.01253, 0.41527	0.0431*
	β_2	–0.0552	–0.25718, 0.14320	0.5760
Random interaction effect	TY:TY.logDT	0.0070	0.003159, 0.01154	
	TY:TY.logPRD	0.0064	0.002962, 0.01076	
Variance of residual	Variance	0.0041	0.0001579, 0.0123	
Fitting degree of model	DIC	-113.17		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DIC — Deviance information criterion

Source: compiled by the author.

looked at the impact of logDT and logPRD in relation to general price level in the type1 and type2 groups. The variance function (23) describes the effect of the respective logDT (in type1 and type2) in the random effect. Another function (24) also describes the impact of the corresponding logPRD (also for type1 and type2) in the random effect. The results are summarized in Table 7.

In Table 7, DIC = -113.17 is so low that it is clear that it confirms the high degree of conformity of the model. In fact, in Figure 7, time traces representing MCMC (Markov Chain Monte Carlo) of each variable are well scattered up and down. The marginal posterior probability density function, which is drawn with effective samples is symmetrically shaped well

In relation to the fixed effect (0.2094), it was shown that digital transformation leads to a substantial rise in prices. Productivity growth (-0.0552) lowers prices but is not significant. This is a similar result to the previous analysis without considering the random interaction effect. Thus, one may postulate that digital transformation will lead to a rise in prices whether or not the random interaction effect is considered.

The variability (0.0070) of logDT in the type1 and type2 groups has been shown to significantly increase the price level. Productivity fluctuation (0.0064) has also been shown to significantly increase prices. There is little difference between the two values, but the variability caused by the interaction of logDT is greater than the variability caused by the interaction of logPRD.

Therefore, this suggests that in Russia, although in the early stages, digital transformation is linked to growing costs and prices rather than to investment and productivity improvements. All estimates except productivity have a 95 % confidence level.

Figure 7 shows the MCMC of the intercept, logDT, and logPRD respectively. The left-hand figure shows the 1,000,000 time traces of the parameters. The first 500,000 times are excluded to remove the influences of the initial value of the inverse Wishart probability distribution. The right-hand side shows the marginal posterior probability function of the estimated parameters from the effective samples. Estimates of each variable were derived from the stationary state of the picture on the right. The intercept fluctuates around about 2.3 and the scatter is not large, indicating that the estimated model is stable. The marginal posterior probability function of logDT and logPRD is also symmetrical to the left and right, so it can be seen to show an almost normal distribution. The logDT and logPRD also fluctuate around 0.2 or -0.05. It is symmetrical to the left and right, showing a similar approach to normal distribution.

In the graph, the random interaction effects of logDT and logPRD are also reliably converging. LogDT is centered around 0.0070 and logPRD shows a normal distribution of symmetry from left to right at 0.0064. The variance demonstrates some instability.

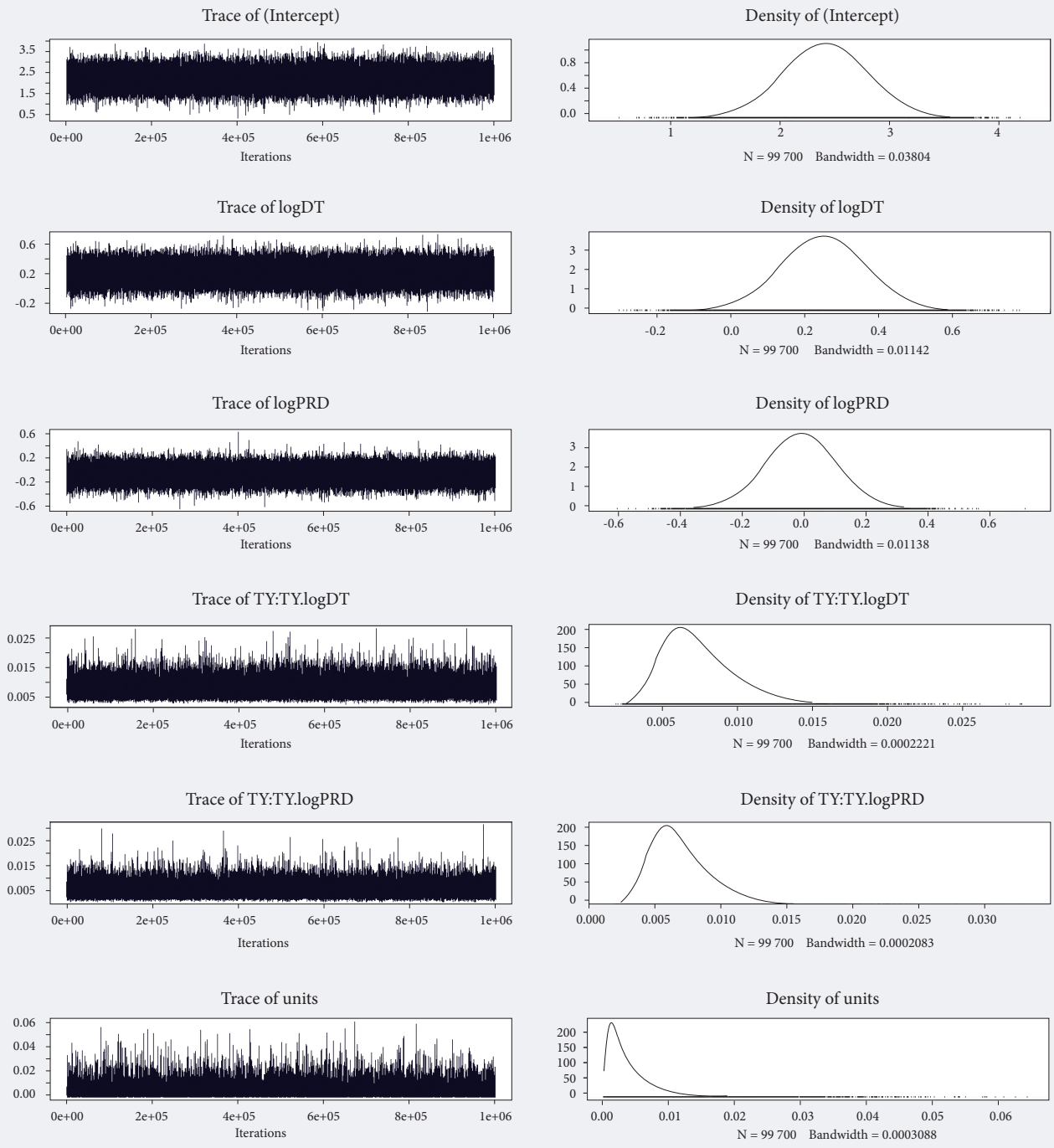
The Random Interaction Effect of Digital Transformation upon Economic Growth

The variance structure (23), (24) was substituted for the random effect equation (22) to see the random effect's interaction with economic growth.

In Table 8, the DIC is -31.07074 very low. Therefore, we can see that the model has a high level of conformity. In Figure 8, we can also see that all variables with fixed effects are converging. However, the marginal posterior probability function of both logDT and logPRD's random interaction effects skews to the left. This is due to the influences of the initial expected value. As we increase the number of repetitions, it is expected that we will approach a normal distribution.

The effect of logDT and logPRD upon economic growth for fixed effects is 0.1528 and 0.1355, respectively, with a marginally significant positive effect. The variability of logDT in the random interaction effect is 0.0015, which is greater than the variability (0.0010) of logPRD. Both values were significant at the 95% confidence level. In the equation, the vari-

Figure 7. **Marginal Posterior Distribution of the Random Interaction Effect on logPRS**



Source: compiled by the author.

ance estimate of residuals is 0.0207 and the function is steadily converging while the distribution of the marginal posterior probability is almost normal.

Conclusions

On the basis of the Bayesian approach to the analysis of a cross-section of latent variables (data for 2018) and the rational expectation theory, this paper draws the following conclusions.

First, the fixed effect of digital transformation upon productivity was not significant. However, in terms of the random effect, digital transformation had a significant positive impact. It is not easy to say that digital transformation has a positive effect upon productivity with a significant random effect but no fixed effect.

Second, both in terms of fixed and random effects, digital transformation has raised prices regardless of the form of the a priori probability distribution

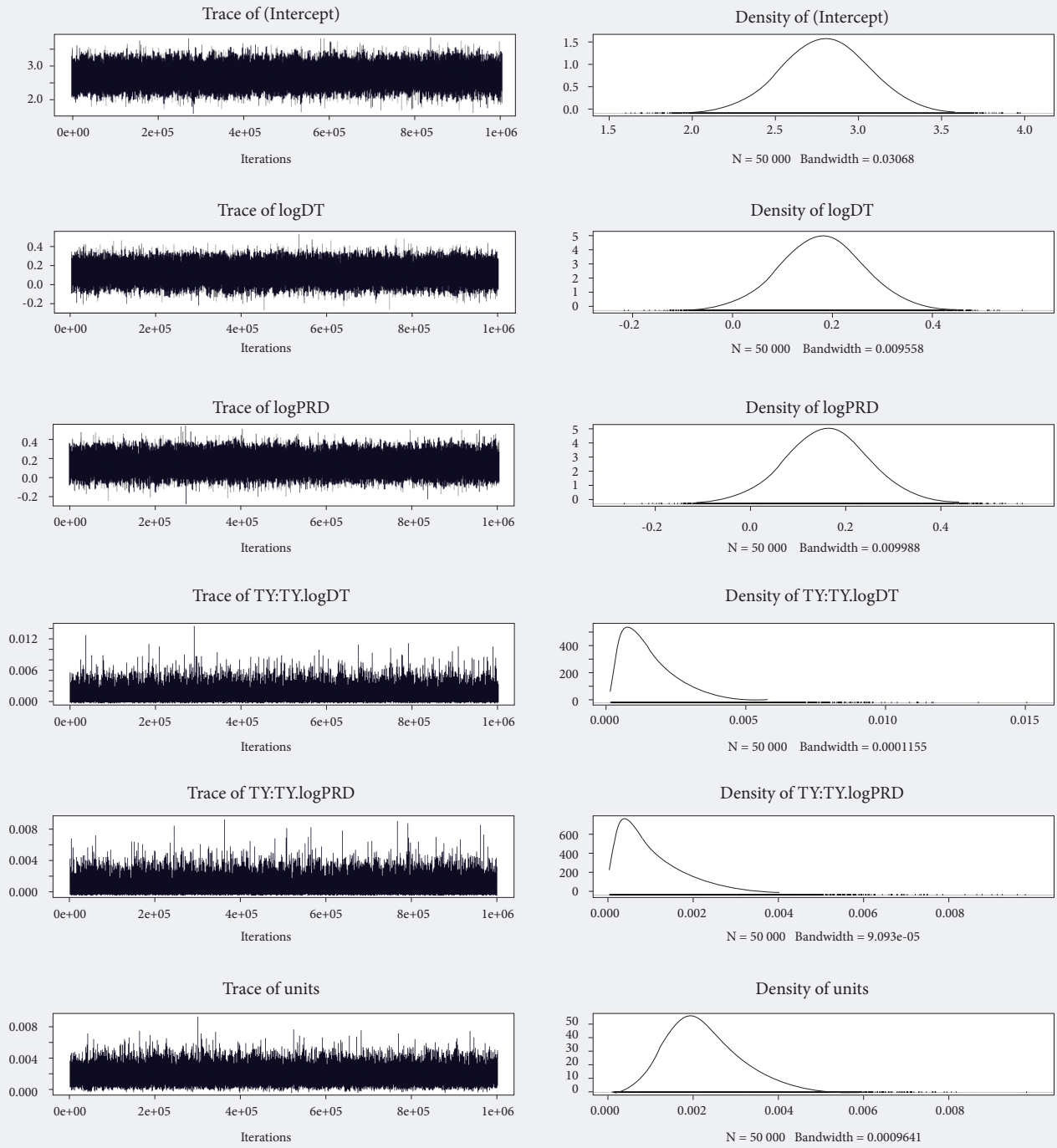
function. Digital transformation raises prices because its impact upon productivity remains unclear.

Third, when evaluating the effect of random interaction (with account of the variance function) fluctuations in the evaluation of this impact within groups was statistically meaningful, but generally digital transformation facilitates the increase of prices, These three results suggest that Russia needs to implement an innovation policy when pursuing digital transformation to stabilize prices through productivity improvement in the future.

Fourth, because the evaluations made by the pivotal and non-pivotal groups affected the variances of the general price level and economic growth, the differences between these groups should be considered

Fifth, digital transformation and productivity have demonstrated a statistically and consistently significant positive effect upon economic growth in terms

Figure 8. **Marginal Posterior Distribution of Random Interaction Effect on logPEG**



Source: compiled by the author.

Table 8. **Interaction Effect of DT upon Economic Growth**

Effect \ Statistics	Estimated parameter	Post-mean	Credit Set (l-95%, U-95%)	P-value
Fixed effect	γ_0	2.7641	2.264627, 3.267249	2e-05***
	γ_1	0.1528	0.004667, 0.307963	0.0561
	γ_2	0.1355	0.024912, 0.300192	0.0999
Random interaction effect	TY:TY.logDT	0.0015	0.000115, 0.003585	
	TY:TY.logPRD	0.0010	5.066e-05, 0.002675	
Variance of residual	Variance	0.0207	0.006324, 0.0373	
Fitting degree of model	DIC	-31.07074		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DIC — Deviance information criterion

Source: compiled by the author.

of both fixed and random effects. These results occurred regardless of the type of priori distribution, but when the inverse Wishart priori distribution was used, it was more stable as variables were converging, unlike the non-informative priori distribution.

Sixth, the random effect of digital transformation and productivity in relation to economic growth turned out to be substantial during the analysis of both groups. The random interaction effect of digital transformation and economic growth was more significant than that of the random interaction with productivity. One might conclude that the development of digital technologies directly impact economic growth. In addition, according to the respondents, digital transformation is thought to have a positive impact upon economic growth indirectly, through the improvement of productivity. This is clear evidence that in Russia the digital transformation is recognized as a technology shock affecting economic growth.

Therefore, in Russia in 2018, digital transformation has played a role in terms of technological progress that attracts economic growth rather than economic stability.

This paper has certain limitations. During the analysis with the use of the multi-level linear model and the Bayesian approach to variables of digital transformation, productivity, general price level, and economic growth were evaluated on the basis of measured variables, and not on actual data. In the future, these results must be empirically tested despite the difficulty of obtaining relevant real data.

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IT Governance Enablers

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Abstract

The pace of information technology evolution calls for governance. Control Objectives for Information and Related Technologies (COBIT) is the main framework for information technology governance (ITG) and defines the concept of IT governance enablers as a critical step for any governance decision or path. This investigation aims to clarify the enablers defined by COBIT to help organizations manage their information technology. Clarity on the meaning of enabler is still lacking in the literature. Enablers are somewhat described in COBIT, but space is left for confusion and contradictions among researchers and practitioners. The research question to be answered by this investigation concerns the definition for each enabler and how it is dictated by the COBIT framework. Further this study proposes a clarification concerning the definition of ITG enablers as addressed by COBIT and several filtration stages and criteria that were used to select high-quality studies. Given the aim of this research, the authors adopted a systematic literature review (SLR) methodology to analyze and synthesize the knowledge about the enablers from COBIT from the literature. Our findings may be used by future researchers to better define the scope of their definitions of enablers, to help future studies regarding the relationship of enablers with any technology or field, and to help future investigations concerning IT governance and its scope within an organization.

Keywords:
COBIT5; enablers; governance; IT;
IT governance; systematic literature review

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Introduction

IT governance (ITG) is high on the agenda at many organizations and high-level ITG models are being raised within the organizations [*de Haes, van Grembergen,* 2008; *Hardin-Ramanan et al.,* 2018].

ITG it is defined an important part of corporate governance, it is involved in leadership and organizational structures to ensure that an organization's IT sustains and extends its strategies and objectives [*Joshi et al.,* 2018]. ITG not only encourages desirable behavior in the use of information technology (IT) and has the capabilities to get the business operations aligned with IT [*Kude et al.,* 2017; *Hardin-Ramanan et al.,* 2018], it also defines the roles and responsibilities within information systems (IS) and related technologies to manage and support an organization's functions [*Higgins, Sinclair,* 2008]. ITG's purpose is to direct and manage IT initiatives to ensure that organization performance meets the goals established by management [*Selig,* 2018]. Some of the main objectives of ITG are the alignment of IT objectives with the overall business strategy, measures of IT performance, and competitive advantages provided by IT for the organization [*Higgins, Sinclair,* 2008].

Many ITG frameworks exist to assist organizations [*Bernroider, Ivanov,* 2011] and Control Objectives for Information and Related Technologies (COBIT) is one of the most complete and most often used ITG frameworks since it assists organizations in achieving their objectives for governance and the management of an organization's IT [ISACA, 2018]. Plus, the COBIT framework conceptually defines the role of enablers in the ITG field. Enablers are described as anything that can help achieve the objectives of the organization, they support the creation of business value through the use of IT and are an important step in achieving good ITG [ISACA, 2018]. However, little information exists about these enablers in COBIT documentation which confuses professionals. Therefore, this research aims to explore the literature and bring some clarity concerning ITG enablers.

Giving the nature of this research, a systematic literature review (SLR) methodology was employed to analyze the relevant literature, find gaps, synthesize findings, and use those findings in future research. SLR has great importance in fields where little or no consensus exists about a specific concept and helps one find the necessary information to support the research questions [*Tranfield,* 2003; *Okoli, Schabram,* 2010].

To sum up, this research aims to clarify and detail each ITG enabler and how they can be useful to an organization. Therefore, the main contribution of this research is to bring clarification on each ITG enabler and deliver a baseline for future research.

The following document is organized as follows, "Introduction", "Research Method", "Results", "Discussion and Insights," and "Conclusions".

Research Method

This research applied an SLR approach to identify and synthetize the literature published about ITG enablers. The SLR aims to identify, evaluate, and interpret all information about research relevant to a specific topic, where the individual studies in a SLR are called primary studies [*Kitchenham,* 2004]. This is performed in the following distinct stages which were revised following recommendations made by the author [*Kitchenham,* 2004] namely that the SLR include: the identification of the need for a review, the identification of the research, the selection of primary studies, an assessment of study quality, data extraction, and data synthesis. On this basis we created research stages to help us to deliver the most high-quality study by performing the selection according to our inclusion and exclusion criteria, filtration stages, and finally with an assessment of quality as illustrated by Figure 1.

Stage 1: Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for this review were guided by the following research questions to filter the articles chosen during the search:

RQ1: Was the article published in a journal with a classification of Q1 or Q2?

RQ2: Was the article published in conference proceedings with a classification of A or B?

Figure 1. **Research Stages**

Source: authors

These questions were used to guide our study to synthetize the material found in the journals and conferences via the internet, with the purpose of obtaining the correct information about ITG enablers. This review included only articles published in English published between 1999 and 2018. This window provided sufficient coverage to find an appropriate amount of literature on the topic at hand related to the terms that stand out as ITG enablers. The articles that did not provide information for addressing the identified research question(s) were excluded from this review.

Stage 2: Selection of Data Sources

This review included the following well-known four databases for searching the articles and the proceedings included in this review:

- Google Scholar (http://scholar.google.com)
- Elsevier Science Direct (www.sciencedirect.com)
- IEEE Xplore (https://ieeexplore.ieee.org)
- Taylor & Francis Online (https://www.tandfonline.com)

The selected data sources provided sufficient literature coverage for the review. The search for this review began on July 12, 2018. Data sources were systematically searched using the carefully selected search terms or keywords (see Table 1). For instance, the term IT governance was included along with enablers, as they were found to be complementary to one another. The search was separated by categories ("IT Governance", "IT Governance Enablers", "COBIT Enablers"). Inside these categories several keywords were included and combined using the Boolean term "AND", for example, "IT governance AND principles".

Stage 3: Search Strategy

During the research process a filtration process was used to find the 28 articles selected for this review. In Table 2 below, the filtration stages are described along with the various filters that were used. The first filtration stage filters the search terms described in Table 1 using "" in the academic databases mentioned above. The second filtration stage refines the search using keywords in the title of the articles. The third filtration stage checks the search terms in the abstracts from the search. In the final stage, the relevant articles for the review were chosen by checking the articles that correspond to the aforementioned research questions.

Table 3 shows the filtration stages for each term used to select the relevant articles for the review. Some of the search terms already yielded few results in the first filtration making it difficult to further refine the search, yielding zero results in the following stages, so those search terms were used for articles found in the first and second stages. One of the motivations of this research was to filter the search as much as possible, because the objective was to find only studies that provided useful information about ITG enablers. This is why during the third filtration stage in Table 3 there are some terms without any result, but in these cases, results were selected from the second filtration stage and then immediately went through the final stage where we obtained valuable information.

Quality Assessment

For the quality assessment, several questions were employed to ensure the relevance and quality of the selected articles. The assessment criteria were developed (Table 4) and applied to ensure the quality, relevance, and credibility of the articles included in this review. The first quality criteria question was used to select studies that were related to ITG so as not to use articles outside the scope of this investigation. The second quality criteria question was used to understand whether or not the article was chosen due to at least one of the ITG enablers being described. The third quality criteria question was applied to verify whether the study itself brings more value into our investigation with regard to useful information about at least one of the ITG enablers to guarantee more accuracy.

Table 5 shows which articles are aligned with the quality criteria questions applied in this literature review. This table shows that all articles were more concentrated on building concepts concerning each IT governance enabler and also shows that some articles are not necessarily related to ITG or to the information technology sector.

Results

This section presents the main findings elicited from the studies selected and reviewed through the SLR.

Table 6 presents the journal and conference each selected article belongs to as well as the respective classification. To increase the scientific rigor of our research study, only journals Q1 and Q2 (according the Scimago classification) were considered. Following the same logic, only conferences A and B (according to the Excellence in Research in Australia (ERA) criteria) were considered in this research.

This section presents the main findings elicited from the selected and reviewed studies through SLR.

Figure 2 shows the distribution of the 28 articles selected for the study according to the selection criteria, by year. The conclusions drawn from this distribution include the fact that in 2007, ITG enablers started to hold more interest for the scientific community.

Table 1. **Search Terms**

Search Category	Keywords
IT Governance	IT governance definition
IT Governance Enablers	IT governance principles, IT governance culture, IT governance ethics, IT governance information, IT governance people, Governance organizational structures, IT governance skills, IT governance competencies, IT governance applications, IT people
COBIT Enablers	COBIT processes, COBIT principles, COBIT frameworks.

Source: authors.

Table 7 provides more information about the selected articles. As one can see, there is a considerable number of Q1 journals in the final set, which is a promising indicator. Also, the sum of citations received by the articles for each classification is included. To classify the journals, the authors used the Scimago Journal & Country Rank (www.scimagojr.com) website. For the conferences, the authors used the ERA rank (www.conferenceranks.com).

Table 8 presents the selected articles allocated to each ITG enabler following the concept-centric approach proposed by [*Watson, Webster,* 2002]. Therefore, in this study we did not have an author-centric approach based on the point of view of researcher. It is interesting to find that the enabler "Information" is the least studied subject in the literature even though it currently considered one of the most (if not *the* most) important asset for organizations. On the other hand, "Principles, Policies, and Frameworks" are the more explored enablers among the selected articles.

Table 2. **Filtration Stages**

Filtration Stages	Description	Assessment criteria	Count
1st Filtration	Identification of relevant studies from the selected databases	Search Category and keywords using the filter ""	35559
2nd Filtration	Exclude studies based on titles	Title = Search terms Yes = Accepted No = Rejected	3327
3rd Filtration	Exclude studies based on abstracts	Keywords inside the abstract Yes= Accepted No = Rejected	359
Final Filtration	Obtain selected relevant articles	Address the research questions. Yes = Accepted No = Rejected	28

Source: authors.

Table 3. **Filtration Stages for Each Search Term**

Search Term	Filtration Stages			
	1st	2nd	3rd	Final
IT governance	33900	3230	342	2
IT governance behavior	7	4	1	1
IT governance enablers	17	2	0	1
IT governance principles	309	7	4	2
IT governance definition	180	6	1	1
IT governance culture	45	7	0	2
IT governance ethics	6	21	0	2
IT governance information	9	25	5	2
IT governance people	35	0	0	2
Governance organizational structures	125	0	0	2
IT governance skills	14	0	0	1
IT governance competencies	16	0	0	2
IT governance applications	13	0	0	2
COBIT processes	556	17	4	2
COBIT principles	82	2	0	2
COBIT frameworks	232	8	1	1
COBIT enablers	20	2	2	1
Total	35566	3331	360	28

Source: authors.

Discussion and Insights

After analyzing the selected articles and given the research objective of this study, it is important to detail what has been done and argued among the scientific community regarding each ITG enabler. Therefore, the following section presents a deeper description of each ITG enabler in the eyes of the scientific community.

Principles, Policies, and Frameworks

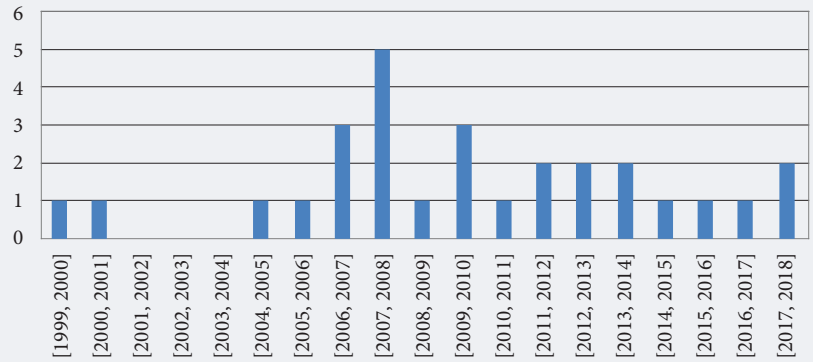
Principles are the channel to translate a desired behavior into practical guidance for day-to-day management [*Garsoux,* 2013] and they serve as the platform for developing governance monitoring and evaluation instruments [*Weill, Ross,* 2005]. Principles for [*Spremić,* 2009] and [*Bin-Abbas, Bakry,* 2014] consist of the high-level decisions

Table 4. **Quality Criteria**

Criteria	Definition
QC1	Is the context of the article related to IT governance?
QC2	Is the description of the article related to the context of the research?
QC3	Do the findings found in the articles bring value to the formulation of concepts?

Source: authors.

Figure 2. **Histogram of the Articles Selected by Year**



Source: authors

about the strategic role of IT in the business. ITG principles must emphasize the sharing and reuse of processes, systems, technologies, and data [*Spremić,* 2009]. Fink and Ploder [*Fink, Ploder,* 2008] say that principles may aim to provide an alignment between IT and business objectives. The application of principles demonstrates that governance and management are two separate subjects while ITG principles are based on common sense and goals [*Othman et al.*, 2014].

For Weill and Ross [*Weill, Ross,* 2005], the principles are normative statements that claim how governance or steering should happen and in which direction. When they refer to direction, they have in mind how governance actors should exercise their powers in meeting objectives. Another researcher [*Spremić,* 2009] says that principles are associated with six basic issues: "responsibility, strategy, acquisition, performance, conformance, and human behavior" and five main principles exist in ITG: "continuous development, integration of key requirements, simplification, knowledge management, and assessment measures".

A governance framework is designed to suit an organization's goal or mission, size, context, people, and traditions and therefore must emphasize the evaluation of needs, directing decision-making and monitoring performance-based organization business objectives [*Othman et al.,* 2014]. A good ITG framework helps manage IT controls [*Kerr, Murthy,* 2013], IT resources, and IT processes to achieve business-IT alignment [*Higgins, Sinclair,* 2008]. This framework must therefore be motivated by the content and context in which it is employed [*Othman et al.,* 2014]. Frameworks should be used as a guide for the formation of domains, objectives, processes, information resources, and decision-making rights [*Bernroider, Ivanov,* 2011].

According to [*Bernroider, Ivanov,* 2011], an ITG framework is driven by IT objectives which play an

Table 5. **References According the Quality Criteria**

Question	Article
QC 1	[*Garsoux,* 2013; ISACA, 2013; *De Haes, Van Grembergen,* 2008; *Kude et al.,* 2017; *Higgins, Sinclair,* 2008; *Othman et al.,* 2014; *Bernroider, Ivanov,* 2011; *Kerr, Murthy,* 2013; *Prasad et al.,* 2012; *Bowen et al.,* 2007; *Spremić,* 2009; *Bernroider,* 2008; *Tsoukas, Vladimirou,* 2001; *Heier et al.,* 2007; *Tallon et al.,* 2013; *Lockwood et al.,* 2010; *Bin-Abbas, Bakry,* 2014; *Simonsson et al.,* 2010; *Wu et al.,* 2015; *Beyer, Niñ,* 1999; *Heier et al.,* 2008; *Simonsson, Ekstedt,* 2006; *Huygh et al.,* 2018; *de Haes, van Grembergen,* 2008; *Fink, Ploder,* 2008]
QC 2	[*Garsoux*, 2013; ISACA, 2013; *de Haes, van Grembergen*, 2008; *Kude et al.,* 2017; *Higgins, Sinclair,* 2008; *Bernroider, Ivanov,* 2011; *Kerr, Murthy,* 2013; *Prasad et al.,* 2012; *Bowen et al.,* 2007; *Spremić,* 2009; *Bernroider,* 2008; *Tsoukas, Vladimirou,* 2001; *Heier et al.,* 2007; *Tallon et al.,* 2013; *Lockwood et al.,* 2010; *Bin-Abbas, Bakry,* 2014; *Simonsson et al.,* 2010; *Beyer, Niñ,* 1999; *Heier et al.,* 2008; *Simon et al.,* 2007; *Simonsson, Ekstedt,* 2006; *Huygh et al.,* 2018; *de Haes, van Grembergen,* 2008; *Fink, Ploder,* 2008]
QC 3	[*Garsoux,* 2013; ISACA, 2013; *Cram et al.,* 2016; *de Haes, van Grembergen*, 2008; *Kude et al.,* 2017; *Higgins, Sinclair,* 2008; *Othman et al.,* 2014; *Bernroider, Ivanov,* 2011; *Kerr, Murthy*, 2013; *Prasad et al.,* 2012; *Bowen et al.,* 2007; *Weill, Ross,* 2005; *Spremić,* 2009; *Bernroider,* 2008; *Tsoukas, Vladimirou,* 2001; *Heier et al.,* 2007; *Huang et al.,* 2010; *Tallon et al.,* 2013; *Lockwood et al.,* 2010; *Bin-Abbas, Bakry,* 2014; *Simonsson et al.,* 2010; *Wu et al.,* 2015; *Ali, Green,* 2012; *Beyer, Niñ,* 1999; *Heier et al.,* 2008; *Simon et al.,* 2007; *Queiroz et al.,* 2018; *Simonsson, Ekstedt,* 2006; *Huygh et al.,* 2018; *de Haes, van Grembergen,* 2008; *Fink, Ploder,* 2008]

Source: authors.

Table 6. **Selection of Journals and Conferences**

Journal & Conference	References	Classification
Information Systems	[*Cram et al.,* 2016; *Kude et al.,* 2017]	Q1
The Journal of Corporate Accounting & Finance	[*Higgins, Sinclair,* 2008]	Q1
International Journal of Disaster Risk Reduction	[*Othman et al.,* 2014]	Q1
International Journal of Project Management	[*Bernroider, Ivanov,* 2011]	Q1
Information and Management	[*Kerr, Murthy,* 2013; *Ali, Green,* 2012]	Q1
European Journal of Information Systems	[*Prasad et al.,* 2012]	Q1
Journal of Management Information Systems	[*Bowen et al.,* 2007]	Q1
Society and Natural Resources	[*Weill, Ross,* 2005]	Q1
Computers in Human Behavior	[*Spremić,* 2009]	Q1
Information Systems Management	[*Bernroider,* 2008; *Simon et al.,* 2007]	Q2
MIS Quaterly	[*Tsoukas, Vladimirou,* 2001]	Q1
Information Systems Frontiers	[*Heier et al.,* 2007]	Q1
Journal of Management Inquiry	[*Huang et al.,* 2010]	Q1
International Journal of Accounting Information Systems	[*Tallon et al.,* 2013; *Lockwood et al.,* 2010]	Q2
MIT Sloan Management Review	[*Bin-Abbas, Bakry,* 2014]	Q1
Corporate Governance	[*Simonsson et al.,* 2010]	Q1
Journal of Management Studies	[*Wu et al.,* 2015]	Q1
Hawaii International Conference on System Sciences	[*de Haes, van Grembergen,* 2008; *Beyer, Niñ,* 1999; *Heier et al.,* 2008; *Huygh et al.,* 2018; *Fink, Ploder,* 2008]	A
Strategic Information Systems	[*Queiroz et al.,* 2018]	Q1
Portland International Center for Management of Engineering and Technology Conference	[*Simonsson, Ekstedt,* 2006]	A
Communications of the Association for Information Systems	[*de Haes, van Grembergen,* 2008]	Q2

Source: authors.

Table 7. **Reference Classification and Citations**

References	Citations	Classification	Count
[*Ali, Green,* 2012; *Bernroider, Ivanov,* 2011; *Bin-Abbas, Bakry,* 2014; *Bowen et al.,* 2007; *Cram et al.,* 2016; *Heier et al.,* 2007; *Huang et al.,* 2010; *Kerr, Murthy*, 2013; *Kude et al.,* 2017; *Higgins, Sinclair,* 2008; *Othman et al., 2014*; *Prasad et al.,* 2012; *Queiroz et al.,* 2018; *Spremić,* 2009; *Simonsson et al.,* 2010; *Tsoukas, Vladimirou,* 2001; *Weill, Ross,* 2005; *Wu et al.,* 2015]	3507	Q1	18
[*Bernroider,* 2008; *Lockwood et al.,* 2010; *Tallon et al.,* 2013; *Simon et al.,* 2007]	516	Q2	4
[*Beyer, Niñ,* 1999; de Haes, *van Grembergen,* 2008; *Fink, Ploder,* 2008; *Heier et al.,* 2008; *Huygh et al.,* 2018; *Simonsson, Ekstedt,* 2006]	222	A	6
None	0	B	0

Source: authors.

Table 8. **References Selected for Each ITG Enabler**

IT Governance Enablers	References	Total
Principles, Policies, and Frameworks	[*Bernroider, Ivanov,* 2011; *Bin-Abbas, Bakry,* 2014; *Bowen et al.,* 2007; *Fink, Ploder,* 2008; *Garsoux,* 2013; *Kerr, Murthy,* 2013; *Kude et al.,* 2017; *Lockwood et al.,* 2010; *Higgins, Sinclair,* 2008; *Othman et al.,* 2014; *Prasad et al.*, 2012; *Spremić,* 2009; *Simonsson et al.,* 2010; *Weill, Ross,* 2005]	14
Processes	[*Bernroider,* 2008; *Cram et al.,* 2016; *Garsoux,* 2013; *Kude et al.,* 2017; *Higgins, Sinclair,* 2008; *Spremić,* 2009; *Tallon et al.,* 2013; *Tsoukas, Vladimirou*, 2001]	8
Culture, Ethics, and Behavior	[*Garsoux,* 2013; *Heier et al.,* 2007; *Huang et al.,* 2010; ISACA, 2013; *Higgins, Sinclair,* 2008; *Othman et al.,* 2014; *Tallon et al.,* 2013; *Tsoukas, Vladimirou,* 2001]	8
Services, Infrastructure, and Applications	[*Beyer, Niñ,* 1999; *Bin-Abbas, Bakry,* 2014; *Garsoux,* 2013; *Heier et al.,* 2008; ISACA, 2013; *Simonsson et al.,* 2010; *Wu et al.,* 2015]	7
People, Skills, and Competencies	[*Garsoux,* 2013; *Huygh et al.,* 2018; ISACA, 2013; *Kude et al.,* 2017; *Queiroz et al.,* 2018; *Simon et al.,* 2007; *Simonsson, Ekstedt,* 2006]	7
Organizational Structures	[*de Haes, van Grembergen,* 2008; *Garsoux,* 2013; *Higgins, Sinclair,* 2008; *Tallon et al.,* 2013; *Tsoukas, Vladimirou,* 2001]	5
Information	[*Ali, Green,* 2012; *Garsoux,* 2013; ISACA, 2013; *Higgins, Sinclair,* 2008]	4

Source: authors.

important role for the success of an IT project, but if an organization adopts frameworks without investing a substantial amount of time and resources to verify the validity of the constructs and dimensions, they may decrease the rate of success for the project. In the end, frameworks provide structures and metrics to measure the performance and control of the systems and provide information about the effectiveness and efficiency of management processes [*Bernroider, Ivanov,* 2011]. A framework should offer templates that can guide the people in designing ITG structures and processes, and they must rely upon industry practices and should not aim to explain antecedents or the implication of ITG [*Kude et al.,* 2017]. Finally, policies in ITG provide direction, stability, control, flexibility, and business alignment [*Lockwood et al.,* 2010].

Policy documents how information from the post-implementation review is passed on to decision makers while their feedback is essential for improving the business processes [*Lockwood et al.,* 2010]. For [*Prasad et al.,* 2012], policies must be put into place to guide the decision processes, while for [*Bowen et al.,* 2007] policies are viewed as a means to produce mutually agreeable outcomes. Lockwood et al. [*Lockwood et al.,* 2010] see policies as being used to implement specific applications and monitor the outcomes, since they provide a connection between corporate and business unit governance. According to [*Simonsson et al.,* 2010], policies also provide a method to calculate the IT risk level, which must be defined to help high-level staff approve it.

Processes

Processes are defined as a collection of practices influenced by the organization's policies and procedures where inputs are taken, manipulated, and outputs produced [*Cram et al.,* 2016] to achieve objectives [*Garsoux,* 2013] aimed at directing and controling an organization and helping it achieve its goals by adding value while balancing risks for IT and its processes [*Higgins, Sinclair,* 2008].

Another study [*Kude et al.,* 2017] considers processes the "formalization and institutionalization of strategic IT decision-making or monitoring procedures", since processes clarify accountability, decision rights, and decision procedures to encourage desirable behaviors in the use of IT. Yet, Higgins and Sinclair [*Higgins, Sinclair,* 2008] argue that processes must be consistent across applications, so they can be reused and should employ technologies that can meet growth demands.

The COBIT framework is a continuous development process and it associates its governance directions with the basic needs and management requirements [*Spremić,* 2009]. Bernroider [*Bernroider,* 2008] points out that a process contains a few ITG maturity indicators, such as activities, documents, metrics, and support for role and responsibility assignment. Processes are referred to as formal processes of strategic decision making, planning, and monitoring to ensure that IT policies are consistent with business needs [*Tsoukas, Vladimirou,* 2001]. Processes are factors that can help determine an organization's distinctive competence and dynamic capabilities as well as the internal process coordination that may contribute to firm-level business value [*Tallon et al., Ramirez, Short,* 2013].

Organizational Structures

Organizational structures are the key decision-making entities at an organization [*Garsoux,* 2013] that contribute to a standout performance through IT-related capabilities improving the effectiveness and efficiency of the internal business processes [*Tsoukas, Vladimirou,* 2001]. The implementation of these structures enables business and IT people to execute their responsibilities regarding the business-IT alignment and produce desirable behaviors that support the organization's strategy and objectives [*Tsoukas, Vladimirou,* 2001; *de Haes, van Grembergen,* 2005].

ITG organizational structures provide a better platform for understanding and the effective use of the acquired IT resources, in addition they define the roles, responsibilities, and a set of IT-business committees such as IT steering committees and business strategy committees [*Huang et al.,* 2010; *Tsoukas, Vladimirou,* 2001]. Organizational structures also contain formal structures and mechanisms to find and enable contacts between business and IT management functions [*de Haes, van Grembergen,* 2008]. Another study [*Higgins, Sinclair,* 2008] states that the organizational structures are forms of IT methods of governance to ensure that information flows well and establishes control objectives to promote business-IT strategy alignment. Such a statement is reinforced by [*Tallon et al.,* 2013].

Culture, Ethics, and Behavior

The culture of individuals and organizations is very often underestimated as a success factor in governance and management activities [*Garsoux,* 2013]. It holds great preponderance in the individual dimensions of ITG mechanisms [*Tsoukas, Vladimirou,* 2001] and should support the transparency concerning risk and risk awareness [ISACA, 2013]. Culture can shape ITG decisions in the form of IT function [*Bowen et al.,* 2007]. According to [*Bowen et al.,* 2007], the level of IT knowledge found in a culture has great significance during the exchange of IT visions or ideas, it is influential in making key decision and promoting IT use at an organization.

Having a culture that is transparent and participative is an important focal point in an organization [ISACA, 2013]. Bowen, Cheung and Rohde [*Bowen et al.,* 2007] also recommend that an IT culture should promote the strategic use of information to bring about the adoption of ITG at an organization. According to Huang et al. [*Huang et al.,* 2010] managers should not consciously shape cultures, but rather must instill a culture of ethics focusing on goals and values.

The acceptance of governance by managers and workers will enable the identification of threats and reduce risk, which can be a critical success factor for the organization thus making the adoption of a risk culture an asset [*Higgins, Sinclair,* 2008]. Ethics refers to the concepts of "all the beliefs, values, rituals, and behavior patterns that people in an organization share" [*Heier et al.,* 2007]. An organization that has a sustained pattern of ethical behavior engenders trust among employees and customers, which in turn leads to commitment, innovation, and business success in the long term [*Huang et al.,* 2010].

Organizations should promote ethical practices and managers must have ethical convictions and behave ethically [*Huang et al.,* 2010]. ITG tends to promote ethics or a culture of compliance within an organization to achieve a high level of governance effectiveness [*Heier et al.,* 2007]. That top management has a sense of leadership when promoting ethical awareness to achieve compliance requirements inside the organization is essential [*Heier et al.,* 2007]. The behavior may enhance the business-IT strategic alignment at an organization [*Tsoukas, Vladimirou,* 2001].

According to [*Bowen et al.,* 2007], behavior can inhibit or undermine the adoption of ITG practices as organizations may first need to educate their employees. Behavior is an important component for improving the relationship between IT and business and it promotes and executes continuous improvement in business and IT activities [ISACA, 2013]. For [*Tallon et al.,* 2013] behavior relates to the form of leadership that ensures that organization's IT sustains and extends its strategies and objectives. In that sense, ITG has the goal of encouraging a desirable use of IT within an organization [*Kude et al.,* 2017].

Information

Information is a key resource for all organizations [*Garsoux,* 2013]. According to [*Ali, Green,* 2012] information is a flow of messages and is a context-based arrangement of items whereby relations between them are shown (e.g. the subject index of a book). Information is created, used, retained, disclosed, and destroyed, but it is pervasive throughout any organization [*Garsoux,* 2013] (e.g.: deals with all information produced and used and information is required for keeping the organization running and well governed, but at the operational level, information is very often the key product of the organization itself).

In the ITG field, information items are essential for improving the relationship between IT and business, for example: documented requirements, documented change requests, business expectations, satisfaction analysis, and information strategy [ISACA, 2013]. The authors [*Higgins, Sinclair,* 2008] state that in COBIT, extending information is a necessary step for investments in IT assets and procedures and should be used to evaluate the benefits of these assets. Further, they say that information should hold predictive or feedback value regarding the organization's goals. Information contributes to achieving overall organization objectives using the information at every level of the organization for instance, at operational, management, and governance levels [ISACA, 2013].

Services, Infrastructures, and Applications

Services include the infrastructure, technology and applications that provide the organization with IT processing [*Garsoux,* 2013]. According to [ISACA, 2013] services are relevant in overcoming the mismatch between IT and business. The organizations for [*Simonsson et al.,* 2010] must actively identify the services where the customers need something and focus on planning and delivering those services to meet availability, performance, and security requirements.

IT infrastructure consists of hardware, software, databases, networks, and the people that perform operations within these layers [*Higgins, Sinclair,* 2008]. Infrastructure consists of coordinating and sharing IT services that provide the foundation of the organization's IT capability [*Bin-Abbas, Bakry,* 2014]. Infrastructure management is associated with maximizing return on computing assets and taking control of the infrastructure [*Simonsson et al.,* 2010]. For [*Higgins, Sinclair,* 2008], an organization must have an IT infrastructure with capabilities of planning, security, and risk control together with ITG to encourage diligence in the management of information resources.

ITG infrastructure must transform the services into a very well-defined business output to facilitate the future business models [*Wu et al.,* 2015]. To develop IT applications, there must be business application needs in place which are determined by the business requirements [*Bin-Abbas, Bakry,* 2014]. For [*Beyer, Niñ,* 1999], the applications have an effect upon ITG processes because they create busi-

Table 9. **ITG Enabler Definition**

IT Governance Enablers	Definition
Principles, Policies, and Frameworks	Principles are a tool to obtain the best practices to help high-level management make better decisions according to the business strategy. The principles are intended to share processes, systems, technologies, and data between the people at an organization and help guide people in meetings or steering sessions to follow the correct path for meeting business objectives. A framework provides a focus upon management and control of IT and provides standards for the organization. It uses IT resources to manage the processes in order to achieve business goals. Also, it provides a link between the other enablers and is driven by the content and context. Policies provide direction, control, and business alignment for the organization and documents how information should be delivered and transmitted to decision makers. Also, they provide guidance for process decisions and a connection between corporate and business unit governance.
Processes	Processes are a set of practices and activities to achieve objectives and they produce a set of outputs to support the achievement of IT goals. They direct and control an organization in the pursuit of business goals. The processes are used to monitor decision procedures and should be influenced by the policies and principles of the organization. Processes must verify whether or not IT policies meet business needs. They are also considered factors that help the organizations have dynamic capabilities and so achieve business value.
Organizational Structures	The organizational structures are a basis for decision-making entities at an organization and they improve the effectiveness and efficiency of internal processes. The organizational structures must be aligned to the organization's strategy and objectives, they define the roles, responsibilities, and set the IT-business committees. They must ensure that information flows smoothly inside an organization.
Culture, Ethics, and Behavior	Culture should establish a set of ideas and a vision to influence key decision-making and promote IT use. An organization should have a transparent and participative culture where one can promote the strategic use of the information to bring about the adoption of IT governance. Ethics are a set of concepts that include values, beliefs, and behavior patterns to increase the commitment, innovation, and business success of the organization. Ethics should promote good practices among the employees. Behavior enhances business-IT strategic alignment and the adoption of ITG practices at an organization. Behavior promotes and executes a continuous improvement of the business and encourages a desirable use of IT.
Information	Information is created, used, retained, destroyed, and passed on by a flow of messages. Information contains value and is one of the important assets of a business. Information should be predictive and provide feedback value about an organization's goals.
Services, Infrastructure, and Applications	Services include the infrastructure, technology, and applications that provide business value at an organization. They should focus on planning and delivering availability, performance, and security to customers. The infrastructure is all hardware, software, databases, networks, and the people that perform operations as part of these structures. Applications should meet business needs and they have the aim of enforcing ITG processes. Applications should focus on automation and digitization to deliver outcomes of strategic business value.
People, Skills, and Competencies	People at an organization have their own role and responsibilities and they are responsible for creating business value given that ITG people are at the tactical or strategic level of an organization. Skills are the capabilities used to create value and play an important role for people. There is a link between people skills and competencies, where organizations tend to pick people with a mix of business-centric and technical skills and an entrepreneurial, adaptive, and agile mindset.

Source: authors.

ness value through IT and their responsibilities are often split between IT domains. A business application in ITG is deployed by an individual business unit and these ITG applications have the aim of enforcing the ITG processes [*Beyer, Niñ,* 1999].

In ITG, the applications must offer automation and digitization. Further, they have an impact upon the operational processes and the outcomes of strategic business value [*Beyer, Niñ,* 1999]. According to [*Heier et al.,* 2008], the ITG applications offer monitoring features to ensure agreed-upon mechanisms are followed and the study suggests that ITG applications should be more investigated to decrease the rate of failure during implementation.

People, Skills and Competencies

People are required for the successful completion of an organization's activities, for making correct decisions, and taking corrective actions [*Garsoux,* 2013]. According to [*Simonsson, Ekstedt,* 2006], the people involved in ITG are included in the relational architecture (tactical or strategic level) of an organization where their roles and responsibilities are defined.

Nevertheless, people tend to receive less attention compared to processes and goals. Huygh et al. [*Huygh et al.,* 2018] also add that IT people execute their responsibilities in support of the business-IT alignment and they are responsible for the creation

of business value. On the other hand, skills are necessary to improve the relationship between IT and business [ISACA, 2013]. Kude et al. [*Kude et al.,* 2017] say that skills and capabilities are needed to make use of assets to create value. Moreover, Simon et al. [*Simon et al.,* 2007] add that skills in IT are essential to meet the needs of the organization and are critical to retain in-house. That is why most organizations tend to choose people with a mix of business-centric and technical skills [*Simon et al.,* 2007].

Finally, competencies tend to focus on the implementation success and use of ITG [*Beyer, Niñ,* 1999]. According to [*Queiroz et al.,* 2018], competencies in IT have an entrepreneurial, adaptive, and agility effect and they facilitate the relationship between agility and performance at an organization.

ITG Enabler Synthesis

To synthesize our findings regarding ITG enablers, Table 9 was built and presents a brief description of the definition of each enabler. It must be stated that this is not supposed to be a proposal of a formal definition for each ITG enabler, but a brief summarization of what the main literature understands about each ITG enabler. By doing so, the authors argue that this study adds some clarification about ITG enablers to the body of knowledge. This is something that was absent in the COBIT documentation and fairly improved in COBIT 2019 documentation.

Conclusion

This research presented a SLR regarding ITG enablers proposed by the COBIT framework. Along the SLR process, 28 high-quality articles were selected from scientific databases and analyzed. To improve the value of our research and the relevance of our findings, the concept-centric approach recommended by [*Watson, Webster,* 2002] was followed. From the analysis of the articles, several conclusions can be drawn:

- The enablers "processes, principles, frameworks, and policies" is the most investigated subject in the literature. This makes sense given that many researchers have focused their efforts on investigating and evolving the existing ITG frameworks as well as their possible variations within different organizational contexts.
- The enablers "people, skills, and competencies" and "information" are the least explored. Grounded on the fact that information is currently considered one of the main organizational assets and employees are one of the main sources of security breaches, this finding is worrisome.
- The body of knowledge about ITG is now enhanced by a more detailed description of each ITG enabler which may help future researchers and practitioners.

This study aimed to provide clarity about ITG enablers given the scarce information provided in the COBIT official documentation despite their relevance. The authors conclude that the research objective was achieved and ITG enablers are now easier to understand. During this study some limitations were uncovered that make it difficult for us provide stronger results, including the following: the lack of studies related to ITG enablers under the classification used for the study helped us draw the conclusion that this theme is not as often approached or talked about within the research community.

This identified research limitation also brought up the opportunity to start creating a basis for further research where our findings may help future researchers define their scope, problems, or even proposals in relation to ITG enablers.

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Trust-Based Determinants of Future Intention to Use Technology

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Abstract

It is widely recognized that one of the factors determining current and future socioeconomic development is the level of digitalization shaping a new type of society, the information society. One area of ICT application within information society is e-Government. A relatively low level of development of e-Government services in Poland was behind the search for the causes of this phenomenon. Among many technological, organizational, human, economic, social, and cultural factors determining the development of e-Government, many researchers indicated trust as one of the most critical factors. Mistrust is perceived as a basic limitation for the implementation of e-Government solutions. The author's object of interest was e-Declaration technology, which enables the electronic filling and sending of tax returns to the tax authorities. This article investigates the relationship between the features of technology users and their trust in the e-Declaration technology and their future intention to use the technology. The researched user traits refer to their general trust, overall trust in technology and science development, and their experience and trust in the internet. Data was collected with the use of the CATI (Computer Assisted Web Interview) technique. Altogether, 1,054 completed questionnaires were selected, containing 100% of the answers. The regression analysis was preceded by an analysis of correlations between variables. The hypotheses were confirmed using the Kruskal–Wallis non-parametric test. The obtained results confirmed positive relationships between Trust in e-Declaration (T) and all tested constructs: General Trust (GT), overall Trust in Science and Technology (TST), Trust in the Internet (TinI) and Internet Experience (IE). Results also confirmed the positive impact of Trust in e-Declaration (T) on the Future Intention (FI) to use the technology. In the adopted regression model, Trust in the Internet was recognized as a key factor in the success of e-Government development. Therefore, the Polish government, which offers solutions in the field of e-Government and wants to increase trust in the technology as well as extend future adaptations of the technology, should concentrate on building trust in the internet and the development of technology and science in general.

Keywords: user intentions; trust in technology; e-Government; general trust; Internet experience; trust in the Internet

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The dynamic development of technologies and their increasingly widespread applications always raise questions about the future scope of the use of a given technology [*Nazarko,* 2017; *Nazarko et al.,* 2017]. This question seems particularly important at the stage of implementation of new emerging technologies [*Hengstler et al.,* 2016]. The answer to the question "What will the future scope of technology use be?" will be of interest to the producers and users of technologies [*Halicka,* 2018]. To describe technology acceptance processes, many theoretical models have been developed, such as the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT) and D&M IT Success model. The most popular, the Technology Acceptance Model (TAM), was developed by Davis [*Davis,* 1985]. The main premise of the model was that the use of (technical) systems depended upon the motivation of their users, which was influenced by other external features and capabilities of the system [*Davis,* 1985]. Over the past 30 years, the original TAM model underwent many modifications, in which the authors added further variables. Many other researchers have introduced a variable of trust in technology into models explaining the current and future use of technology [*Gefen,* 2004; *Gefen et al.,* 2003; *Wu et al.,* 2011]. Also, *research* in the UTAUT model confirms that the most frequently considered external variables for the model include trust in technology [*Williams et al.,* 2015]. As proposed by Tams et al., trust in technology can be understood as beliefs about the desirable or beneficial features of a technology [*Tams et al.,* 2018].

Researchers have shown that trust in technology influences various technology acceptance levels, such as online recommendation agents, business information systems, mobile-commerce portals, and knowledge management systems [*Lankton et al.,* 2015]. Lack of trust is one of the most important barriers to e-service adoption, especially when personal or financial information is involved [*Pavlou, Fygenson,* 2006; *Belanger, Carter,* 2008].

Trust in technology can be considered at different stages of the technology acceptance process. Two types of trust can be remarked upon: *pre-use trust* before the application or implementation of the technology and *post-use trust* which is considered after the application or implementation of the technology [*Rousseau et al.,* 1998; *McKnight et al.,* 1998; *Komiak, Benbasat,* 2008; *Lin et al.,* 2014]. *Pre-use trust* influences the intentions of potential users to deploy the technology, while *post-use trust* influences the intentions of potential users to continue to use the technology. According to the research conducted by many authors, trust as a constructor in technology acceptance models was treated as a determinant of the attitude towards the use of the technology [*Gefen*, 2004; *Gefen et al.,* 2003; *Lean et al.,* 2009]. Research conducted by Wu et al. [*Wu et al.,* 2011] confirmed the existence of statistically important relationships between trust and attitudes.

Meng and his colleagues [*Meng et al.,* 2008] studied factors determining trust in technology in mobile-commerce. The model consisted of four categories of variables determining trust including general trust, trust in mobile technologies in general, trust in the seller measured by ability (competence), reliability, and friendliness, and institutional trust [*Meng et al.,* 2008]. The author's model was not subject to empirical verification.

Chen et al. were interested in a technological explanation in the field of e-Government. As factors determining trust in technology, the authors studied: general trust in technology, trust in the administration, trust in government websites, and previous user experience in using e-Government solutions [*Chen et al.,* 2015].

Alzahrani et al. [*Alzahrani et al.,* 2017] developed a theoretical model, in which, among the determinants of trust in e-Government, they indicated user experience, general trust, internet experience, and education.

Research related to the determinants of trust allowed the author to distinguish four groups of factors: (i) institutional-organizational factors, (ii) technological factors, (iii) factors related to user characteristics, and (iv) the environment. Authors are often interested in the determinants of trust that reflect the characteristics of technology users. The author of this article intends to limit the determinant without referring to the factors connected with the functionality and usefulness of technologies. Among the variables that are of interest to the author and which determine trust in a particular technology are general trust, trust in science and technology, and trust and experience in using the Internet. Moreover, the model includes relations between trust in technology and the future intentions of users.

The literature study carried out allowed for defining the following scientific questions: How do the characteristics of technology users determine the trust of Polish society toward e-Government and future the adoption of e-Government?

The aim of the article is to examine the relationship between the characteristics of technology users and their trust in technology and the future intention to use the technology. The researched features of the users refer to the general trust of the users and the general trust in the development of technology and science or trust in the Internet.

Literature Review and Theoretical Model

From a sociological point of view, general trust (social — the object of interest of sociologists) will affect trust in a specific technological solution. General trust is the belief that, as a rule, people are trustworthy. Research conducted by Chopra and Wallace

shows that every human being is characterized by a different level of general trust, conditioned by cultural and sociological factors [*Chopra, Wallace,* 2003]. Trust propensity (general trust) reflects an ability to rely upon others in different situations [*Kumar et al.,* 2017]. Zhou [*Zhou,* 2011] indicated that users with high general trust tend to have positive inclinations towards new technological solutions. Research conducted by Lee and Turban confirmed the moderating effect of individual general trust (individual trust propensity) on consumer trust towards internet shopping [*Lee, Turban,* 2001]. Lippert and Swiercz also included general trust as one of the characteristics that affect trust in technology [*Lippert, Swiercz,* 2005]. Agag and El-Masry tested relationships between general trust and consumer trust towards online travel websites [*Agag, El-Masry,* 2017], and proved the existence of positive relationships between the mentioned variables. Considering the above, the authors formulated the following hypothesis:

Hypothesis (H1). *General trust (GT) will positively influence the Trust in e-Declaration technology (T)*

In addition to general trust that reflects a person's willingness to rely upon others in a particular situation, the relationship between technology users and science and technology developments, in general, seems to be very important as well. Not always a high level of general trust coincides with a belief in the potential of technology development to improve human life. The results of the World Values Survey[1] confirm that societies with a relatively high level of general trust already have a much lower level of trust in the positive impact of technology and science on improving life and the world in general. For example, in the Scandinavian countries (Finland, Sweden, Norway), where the level of general social trust is very high (58.0%, 60.1%, and 73.7% of the population of these countries, respectively, believe that "Most people can be trusted"), the belief that "Science and technology are making our lives healthier, easier" is already much lower. A total of 36.0% of respondents in Finland, 33.5% in Norway and 38.0% in Sweden believe in this statement, which at the level of 8–10. In contrast, only 22.2% of the population in Poland positively reacted to the statement "Most people can be trusted" and as many as 61.2% of the population assessed the statement "Science and technology are making our lives healthier, easier" at the level of 8 to 10. Therefore, the author proposed an additional variable reflecting the belief of technology users in the very fact that science and technology can make our lives better, healthier, more comfortable, turning the world into a better place. Considering the above, the authors formulated the following hypothesis:

Hypothesis (H2). *General trust in science and technology (TST) will positively influence the Trust in e-Declaration technology (T)*

The internet — being the infrastructure of e-Government — is still a source of uncertainty for some users, and a lack of trust would affect the use of e-services [*Carter, Bélanger,* 2005]. Voutinioti [*Voutinioti,* 2013] also included the variable of Internet trust in the UTAUT model and demonstrated a statistically significant link between trust and user intentions in the use of e-Government solutions. Also, Lee and Turban [*Lee, Turban,* 2001], while building a model of trust in online shopping, considered the variable of internet trust and studied its impact upon trust in online shopping technology. Agag and El-Masry tested the relationships between consumer experience and consumer trust towards online travel websites [*Agag, El-Masry,* 2017]. Considering the above, the authors formulated the following two hypotheses:

Hypothesis (H3). *Trust in Internet (TinI) will positively influence the Trust in e-Declaration technology (T)*

Hypothesis (H4). *Internet experience (IE) will positively influence the Trust in e-Declaration technology (T)*

In the face of many studies on the factors shaping trust in technology, fewer research publications examine how and why trust determines subsequent adoption behaviors [*Tams et al.,* 2018]. From a psychological point of view, trust can help the user to exclude undesirable, unexpected technology performance and, thus, increase intentions to use the technology [*Gefen et al.,* 2003]. Developing their model for the adoption maturity of e-Government solutions, Joshi and Islam pointed out that trust was an important element for the sustainable adoption of e-Government solutions [*Joshi, Islam,* 2018]. Also, the research conducted by Hernandez-Ortega proved that trust in technology positively influences the intentions to continue using technology [*Hernandez-Ortega,* 2011]. Weerakkody et al. [*Weerakkody et al.,* 2013] confirmed the previous conclusions regarding the positive impact of trust upon the adoption and continued use of electronic government services. According to Agag and El-Masry, trust influences consumer intentions to purchase a trip online [*Agag, El-Masry,* 2017]. Similar results were obtained by Kumar et al. studying mobile banking technology [*Kumar et al.,* 2017]. Kaur and Rampersad indicated that trust in driverless cars played a crucial role in the adaptation process of such technology [*Kaur, Rampersad,* 2018]. Research conducted by Khalilzadeh et al. [*Khalilzadeh et al.,* 2017] in relation to near-field communication mobile pay-

[1] Available at: http://www.worldvaluessurvey.org/wvs.jsp, accessed 10.07.2017.

ment technologies did not show a statistically significant relationship between trust and intentions of user behavior [*Khalilzadeh et al.,* 2017]. Voutinioti [*Voutinioti,* 2013] demonstrated statistically significant links between trust and user intentions in the use of e-Government solutions. Different results concerning the relations between the studied constructs (trust and intentions) indicate that the type of technology determines the character of these relations. Considering the above, the author formulated the following hypothesis:

Hypothesis (H5). *Trust in e-Declaration technology (T) will positively influence the future intention to use e-Declarations (FI)*

Figure 1 presents the conceptual model that reflects links between all theoretical variables and hypotheses.

Research Methodology

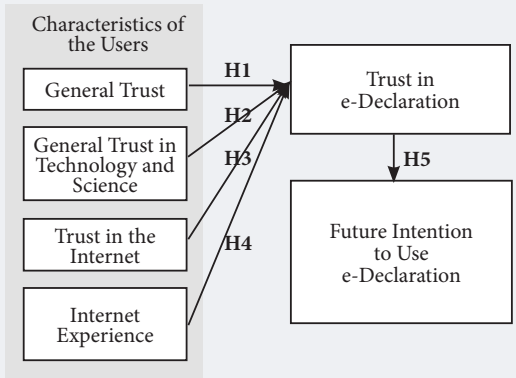
Data

The conducted research focuses on the e-Declaration - an electronic technology for submitting tax returns. This service and ICT tools were created by the Ministry of Finance. In 2018, the inhabitants of Poland filled more than 11 million tax returns electronically.

Research data was collected using a survey method. The conducted research was quantitative and allowed for verifying the accepted research hypotheses. The process of data collection was carried out with the use of the CAWI technique.

The survey respondents were Polish residents who had used the e-Declaration system within the last two years, i.e. sent their tax return via the Internet. The research process was carried out by employees of the Ministry of Finance (MF). As part of this collaboration, the author developed a research questionnaire, which was validated by employees of the Ministry of Finance. The task of the Ministry of Finance was to randomly send an e-mail message with a link to the electronic survey to taxpayers registered in the MF database.

Figure 1. **Conceptual Model**



Source: elaborated by the author.

The study assumed the acquisition of a representative sample, which allowed the results to be generalized for the entire population. The minimum sample size was 1,067, assuming a confidence level of 0.95 (1-α) and a maximum permissible error of 3% calculated for the general population of about 11 million taxpayers using the e-government system. The survey was conducted in May 2018. Successive (due to the technical limitations of the mailbox) lots of e-mails from the dedicated account ankietaPB@mf.gov.pl, allowed for the ongoing monitoring of the status of survey completion. As soon as 1,067 completed questionnaires were received, the e-mail dispatch was suspended. After the analysis of the returned questionnaires and the elimination of forms with data gaps, 1,054 completed questionnaires containing 100% of answers were selected.

Of the 1,054 respondents, 484 (45.9%) were women, and 570 (54.1%) were men. The share of respondents aged 26–40 was 52.1% (549 persons), followed by 29.5% (311 persons) aged 41–60. The number of respondents in the age groups of 18–25 and over 61 years of age constituted about 9% of the respondents each (9.1% — 96 persons and 9.3% — 98 persons).

Measures

Since some constructs could not be directly observed, a series of measures were used in each case. Based on the literature study, four items have been identified for measuring Trust in the e-Declaration, and two for the Future Intention to Use (Table 1). To measure the general trust and trust in science and technology, questions included in the research carried out by the Institute for Comparative Survey Research as part of the World Values Survey were used. All constructs were measured using a seven-point Likert scale to access the degree to which a respondent agreed or disagreed with each of the items (1 = totally disagree; 7 = totally agree). Cronbach's alpha coefficients of the constructs were used to verify the reliability of the scale and proved the acceptable reliability of the scale ranging from 0.738 to 0.926 (Table 1). Descriptive statistics and composite reliability for the constructs and items are presented in Table 1.

The mean value of the indicated constructs is shown in Figure 2. The low evaluation of general (social) trust coincides with the results of global research, according to which Polish society belongs to countries characterized by a relatively low level of social trust (World Values Survey).

Table 1. **Constructs and Items**

Constructs (source)	Abbr.	Observed variables (Items)	Mean	Cronbach's alpha
General Trust (World Values Survey)	GT	Most people can be trusted	3.83	
General Trust in Science and Technology (World Values Survey)	TST1	Science and technology are making our lives healthier, easier, and more comfortable	6.27	0.760
	TST2	The world is better off because of science and technology	5.78	
Trust in the Internet	TinI	I generally trust the solutions offered by the Internet	4.70	
Internet Experience	IE	I have extensive experience in using the Internet	6.47	
Trust in e-Declaration [*Al-Hujran et al.*, 2015; *Colesca*, 2009; *Lippert*, 2007]	T1	The e-Declaration system works according to my expectations	5.49	0.926
	T2	I am convinced that the e-Declaration system will function properly when I need it	5.38	
	T3	I can rely on the e-Declaration system	5.69	
	T4	The e-Declaration system is predictable and unchanged	5.42	
Future Intention to Use e-Declaration [*Kurfal et al.*, 2017; *Al-Hujran et al.*, 2015; *Venkatesh et al.*, 2012; *Bélanger, Carter*, 2008; *Carter, Bélanger*, 2005]	FI1	I intend to make greater use of the e-Declarations system	5.13	0.738
	FI2	I intend to make greater use of e-Government services	5.61	

Source: elaborated by the author.

The structure of the assessments of the variables is presented in Figure 3.

In the case of the variable Internet Experience (IE), as many as 94.5% of respondents answered on a scale of 5 to 7, thus assessing their experience in this area very highly. Compared to the other observed variables, the respondent assessments of the variable Trust in the Internet (TinI) indicates a slightly lower level of trust among respondents. Almost one in four respondents (23.6%) rated their trust in the internet from 1 to 3 on a 7-degree scale. The phenomenon observed during the research is a relatively lower level of trust in relation to a specific technology (e-Declaration: variables T1–T4) than the general trust in science and technology (TST1, TST).

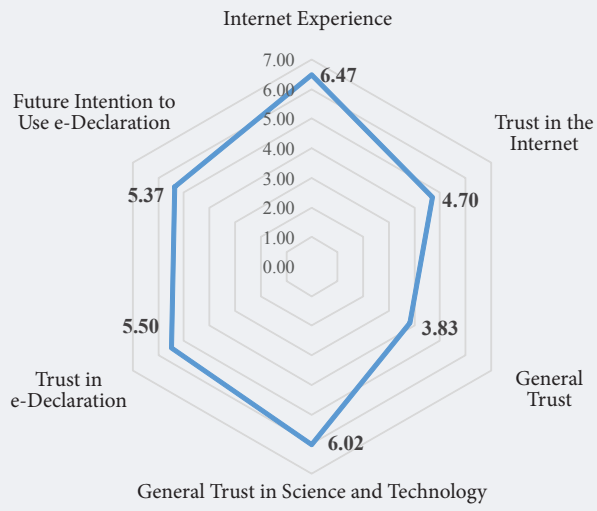
Research Results

Table 2 shows variables of the Spearman's correlation coefficients. Between all constructs and Trust in the e-Declaration significant correlations were found, but the strength of the relationship was weak or moderate.

The hypotheses were confirmed using the Kruskal-Wallis non-parametric test. The results of the test are presented in Table 3. The results of testing the relationships between constructs showed that all tested relationships were statistically significant. Trust in the e-Declaration (T) was statistically significant due to the General Trust (GT), general Trust in Science and Technology (TST), Trust in the Internet (TinI), and Internet Experience (IE) as well. Thus, the relations reflected in hypotheses H1–H4 were confirmed. The research also confirmed that Trust in the e-Declaration (T) had a statistically significant impact on the Future Intentions (FI) of users, which allowed for supporting hypothesis H5

Correlation analysis which confirmed statistically significant relationships between the variables General

Figure 2. **Mean Value of the Construct Assessments**



Source: elaborated by the author.

Table 2. **Spearman's Correlation Coefficients**

Constructs	Trust in e-Declaration Construct
General Trust	0.229**
General Trust in Science and Technology	0.372**
Trust in the Internet	0.456**
Internet Experience	0.167**
Future Intention to Use the e-Declaration	0.434**

Source: elaborated by the author.

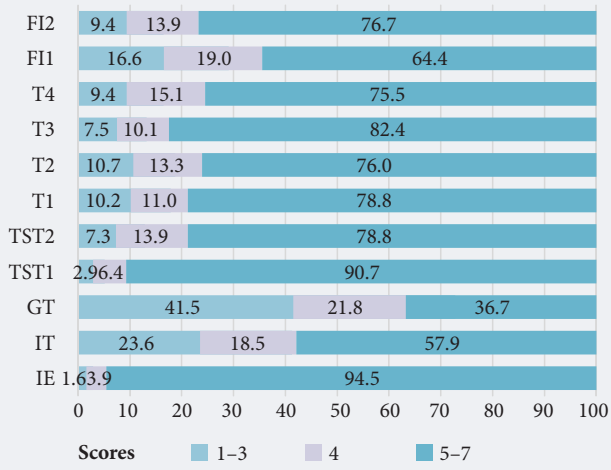
Trust, general Trust in Science and Technology, Trust in the Internet, Internet Experience, and Trust in the e-Declaration allowed for conducting a multiple regression analysis. The constructed regression model turned out to be statistically significant ($F = 78.373$; $p<0.001$) and all predictive factors explained 23% of the dependent variable ($R2=0.23$). Trust in the Internet ($\beta=0.25$; $t=9.897$; $p<0.001$) and general Trust in Science and Technology ($\beta=0.23$; $t=6.641$; $p<0.001$) have a significant positive impact upon the Trust in the e-Declaration.

Discussion

The correlation analysis confirmed statistically significant relationships between the Trust in the e-Declaration (T) and all the examined variables General Trust (GT), general Trust in Science and Technology (TST), Trust in the Internet (TinI), and Internet Experience (IE). At the same time, a statistically significant relationship between Trust in the e-Declaration (T) and Future Intentions to Use the e-Declaration (FI) was confirmed.

The obtained research results allowed for verifying the hypothesis H5 indicating a relationship between Future Intentions to use the e-Declaration and Trust in the e-Declaration. Similar results were obtained by many other researchers [*Weerakkody et al.,* 2013; *Voutinioti,* 2013; *Kumar et al.,* 2017; *Kaur, Rampersad,* 2018; *Ejdys, Halicka,* 2018].

Figure 3. **Mean of Construct Assessments** (%)



Source: elaborated by the author.

The conducted research confirmed that the variable General Trust (GT) has a statistically significant impact on Trust in the e-Declaration (T), which allowed one to support the hypothesis H1, which is consistent with the results of other authors [*Lippert, Swiercz,* 2005; *Agag, El-Masry,* 2017]. To some extent, this relationship may explain the relatively low level of digitalization of public services in Poland. Polish society has one of the lowest levels of social trust. In Poland, only 22.2% of the population positively reacted to the statement "Most people can be trusted", which is very low when compared to other countries such as Finland, Sweden, and Norway where the level of general social trust is very high (58.0%, 60.1%, and 73.7% of the population of these countries, respectively, believe that most people can be trusted) (World Values Survey). Therefore, the process of building trust in technologies determining the scope of their future use is largely determined by the general level of social trust.

The results obtained by the author confirmed a statistically significant relationship between general Trust in Science and Technology (TST) and the Trust in the e-Declaration and, thus, substantiated hypothesis H2. Despite the relatively low level of general trust, Polish society is characterized by a high level of trust in science and technology development as a factor that makes our lives better, healthier and more comfortable. This level of trust in science and technology also determines the trust in a specific technological solution, in this case, the e-Declaration.

In the model, two important relationships were studied between Trust in the Internet and Trust in the e-Declaration and between Internet Experience and Trust in the e-Declaration. Hypotheses H3 and H4, reflecting these relationships, were supported. The obtained results were consistent with the results of other authors. According to other researchers [*Carter, Bélanger,* 2005; *Voutinioti,* 2013], the Internet, as a new medium of technological applications, is an important factor determining trust in specific solutions, and the decisive factor is Trust in the Internet and Internet Experience possessed by its users.

The conducted regression analysis allowed for answering the question "What factors should be considered to increase the level of trust in a technology?" The highest B coefficients in the regression equation, and, thus, statistically significant dependencies were recorded for two variables, namely, Trust in the Internet (TinI) and general Trust in Science and Technology (TST). Therefore, the Polish government, which offers solutions in the field of e-Government and wants to increase trust in such solutions, should concen-

Table 3. **Results of the Test Hypotheses**

Relation between Constructs	Test statistic Chi-Square	P	Hypothesis Testing
H1: General Trust vs. Trust in the e-Declaration	114.64	***	Support
H2: General Trust in Science and Technology vs. Trust in the e-Declaration	158.20	***	Support
H3: Trust in the Internet vs. Trust in the e-Declaration	237.05	***	Support
H4: Internet Experience vs. Trust in the e-Declaration	39.926	***	Support
H5: Trust in e-Declaration vs. Future Intention to Use the e-Declaration	207.73	***	Support

Note: The adopted level of the statistical significance was 0.05
Source: elaborated by the author.

trate on building trust in the Internet and trust in the development of technology and science in general. Trust in the Internet is considered a critical factor in the success of e-government development [*Belanger, Carter,* 2008; *Lee et al.,* 2011]. One of the tools for building trust in the Internet is SLA (Service Level Agreement) agreements defining the level of services. In Poland, for example, for the ePUAP (Electronic Platform for Public Administration Services) offering e-Government services, the SLA availability rate in 2015 was 96.38%.

Conclusions

This article covers issues that are particularly important in the context of explaining the reasons for the relatively low level of digital interaction between Poles and public institutions. The share of Polish citizens engaged in digital interactions with public institutions is only 30%, while in Scandinavian countries, it amounts to 88.0% in Denmark, 85.0% in Norway, and 82.0% in Finland.[2] According to available Eurostat data, in 2013, only 12.0% of Polish citizens submitted electronic tax returns, while in other countries, this indicator was as follows: Denmark — 63.0%, Iceland — 61.0%, Norway — 50.0%, and Sweden — 46.0%.[3] The delay in this development of Polish society in relation to other Western European countries is often the cause of inappropriate comparative analyses on an international scale.

Research conducted by Alzahrani et al. confirmed that in many countries, citizens still did not trust the services provided by the government, which has a significant negative impact upon the process of its further adaptation and dissemination [*Alzahrani et al.,* 2017]. The study aimed to show the relationship between the determinants of trust in the studied e-Government technology and the impact of this trust upon future intentions to use e-Government technology. The author's object of interest was the technology enabling taxpayers to fill and send tax returns via the Internet (e-Declaration).

Table 4. **Results of Multiple Regression Analysis**

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig. p-value
	B	Standard Error	Beta		
Constant	2.359	0.263		8.976	0.000
Internet Experience	0.069	0.041	0.051	1.704	0.089
Trust in the Internet	0.250	0.025	0.314	9.897	0.000
General Trust	0.029	0.021	0.040	1.355	0.176
General Trust in Science and Technology	0.233	0.035	0.212	6.641	0.000

Model Summary:

R	Adjusted R^2	Standard Error	df1	df2	Mean Square	F	Sig.
0.480	0.227	1.165	4	1041	106.306	78.373	0.000

Dependent variable: Trust in e-Declaration. Predictors: Internet Experience, Trust in the Internet, General Trust, and General Trust in Science and Technology

Source: elaborated by the author.

[2] Digital Economy and Society Index, 2017. Available at: http://ec.europa. eu/eurostat/web/digital-economy-and-society/data/database, accessed 07.08.2019.
[3] Digital Economy and Society Database, 2017. Available at: https://ec.europa.eu/digital-single-market/en/scoreboard/poland, accessed 19.03.2019.

The conducted research confirmed that the future scope of the use of e-Government solutions will be determined by the trust of the users of the proposed solutions. Ensuring a high level of security in using the Internet is a key factor shaping trust in technological solutions offered by the government.

In the context of the obtained results, future research efforts should focus on clarifying the tools of building trust in the Internet and general trust in science and technology. An important tool for building social trust in the Internet is an awareness of threats, risks, and measures to mitigate those perceived risks. User experience with the use of e-Declaration technology with a lack of undesirable or accidental events (loss of data) will gradually build trust in such technological solutions. Also, the popularity of using other ICT solutions in other areas of life will force users to use e-Declaration solutions. Unfortunately, the processes of building both interpersonal trust and trust in technology are time-consuming processes and it is often necessary to wait a few years for the expected results in behavior changes of the users.

It also indicates the direction in which technological innovation in the area of e-government should develop so that it is aligned with the Responsible Research and Innovation paradigm [*Nazarko,* 2016].

Research on the dynamics of changes in the level of trust in science and technology of Polish society may prove to be an interesting research topic. Currently, the relatively high level of trust of Polish society in technology and science is inversely proportional to the low level of interpersonal trust.

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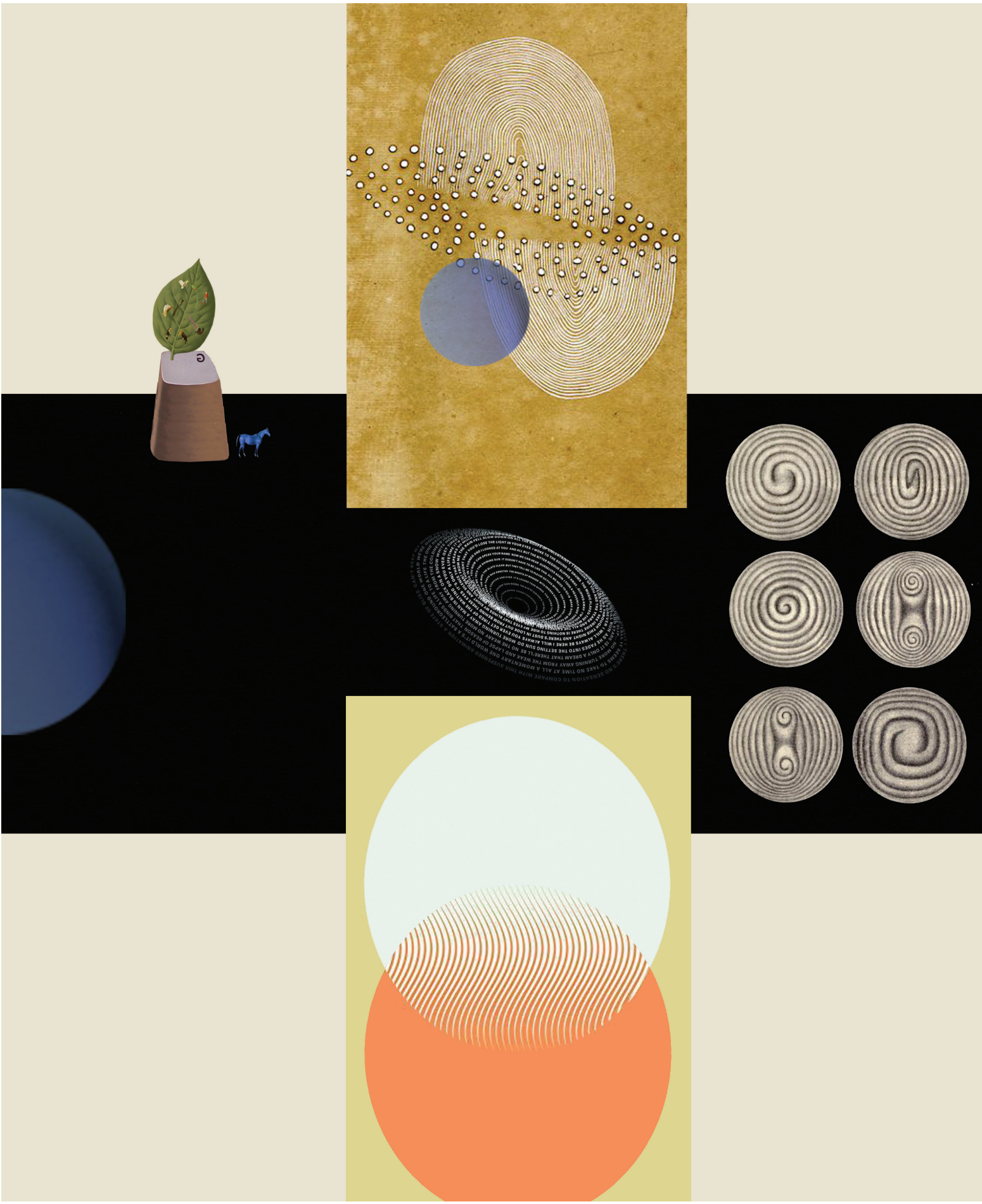

Impact of Self-driving Cars for Urban Development

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Abstract

The advent of self-driving vehicles is no longer just science fiction conjecture but the reality of the coming decade. Various countries have already made real progress in self-driving technologies moving beyond slogans and to meaningful action – multi-country amendments to the law, for one thing. Due to the rethinking of the transport planning process and new ways to organize passengers, the urban transport system is considered a single unit, not a set of separated transport subsystems (metro, land transport, etc.). Thus far, however, there has been no extensive study of the potential urban impact of self-driving technologies upon a city and its residents.

This paper presents a methodology for the urban impact assessment of self-driving transportation, which was developed based on an appropriate analysis for the city of Moscow. To that end, the urban environment as a research subject is described as a set of environmental, transport, technological, economic, social, and regulatory blocks of indicators. We propose to evaluate these indicators: roads congestion, need for parking spaces, changes in the employment structure, new users of automobile transport, and others. To estimate the effects on the city, we describe four scenarios for the introduction of self-driving cars, differentiated by the speed of technological introduction and the development of co-using economics. To achieve the maximum effect of self-driving technology, one needs to adopt a proactive transport policy, including a set of measures defined by a current survey.

The survey is indispensable for future research into the impact of self-driving technology upon a city. Also, the survey has practical uses for administrations responsible for urban transport policy.

Keywords: self-driving car; self-driving technology; urban environment; transportation policy; scenario forecasting; transportation and mobility management; Moscow

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The mass proliferation of self-driving vehicles in cities is predicted in the next decade. The technological and economic aspects of self-driving transport are being studied the world over [*Hörl et al.*, 2018], while certain countries (the US, Germany, France, and the UK in particular) are taking practical steps to adapt legislation and traffic rules accordingly [*Hoyle,* 2016; Tomtom, 2017]. In the EU, self-driving vehicles and electric buses are being tested not only on specifically allocated roads but within entire metropolitan areas [Morgan Stanley, 2013]. At the same time, self-driving vehicle technology obviously belongs in the disruptive innovations category [*Christensen*, 1997], that is, it is *irreversibly* changing the value of using a car as such. Self-driving vehicles will be available to those who cannot drive a car for health reasons or are unwilling to waste time in traffic jams [*Collie et al.*, 2017]. The very principle of owning a car will greatly change, for example, families may stop owning several cars. Multi-agent transport modeling shows that adopting self-driving vehicles can reduce the size of the daily operated fleet by ten-fold [*Fagnant, Kockelman*, 2014]. Paradoxically, an increased number of car trips will be accompanied by the decreased private ownership of cars and their reduced total number.

Researchers point out the many advantages of self-driving technology, from improving vehicle efficiency and reducing accident rate to expanding the range of users and improving the environmental situation. According to Morgan Stanley, the combined effect of resource saving and increased productivity in the US economy due to the adoption of self-driving vehicles will amount to 8% of GDP [Morgan Stanley, 2013], due to fuel economy, reduced mortality, and reduced transportation costs for goods and passengers alike. The downsides include job cuts, the parking problem, excess mileage, and a limited scope for the private use of self-driving vehicles.

Over the last three years the number of academic papers and consulting reports on self-driving vehicles and their shared use has markedly grown. [*Van den Berg, Verhoef*, 2016] present a dynamic model of increasing street and road network (SRN) capacity and changing costs of self-driving vehicle users' time. The model allowed for calculating the recommended self-driving vehicle subsidy rates using US and Netherlands data. [*Llorca et al.*, 2017] demonstrated how the load on the SRN in the Munich metropolitan area will be changing using a MATSim simulation: the average travel distance and travel time increase under any scenario.

A number of studies are devoted to specific aspects of self-driving technology unrelated to their impact upon the urban environment [*Martin, Shaheen*, 2016; *Skinner, Bidwell*, 2016]. A report by the Organisation for Economic Co-operation and Development (OECD) [OECD, 2015] demonstrated the effectiveness of car sharing services: if for a personal car the average time of use is about one hour, with the load factor of 1.2 persons per car, shared cars on average are used for 13 hours, with the load factor of 2.3 persons per car. According to a Boston Consulting Group (BCG) report [*Collie et al.*, 2017], the total time of use for a shared car is estimated at 15 hours per day. Numerous studies estimated the changes in throughput and transport capacity using micro- and macro-modeling. For example, with the mass adoption of self-driving shared vehicles, the total useful mileage will increase by 8% [*Moreno et al.*, 2018]. The report [WEF, BCG, 2015] examined the social aspect of self-driving vehicles' dissemination: it turned out that on average only a third of the respondents believed they would use an self-driving vehicle, with Asian countries being the most optimistic in this regard. Zakharenko [*Zakharenko*, 2016] presents a theoretical model for assessing self-driving vehicles' impact upon the structure of land use. This study predicts further urbanization, increased land costs in inner cities, and the need to set up special parking lots for self-driving vehicles.

In the future, urban residents' mobility is forecast to increase due to the adoption of the "mobility as a service" (MaaS) digital concept and the emergence of new transport services such as, for example, taxi-buses: ridesharing on small buses along user-defined routes [*Smith*, 2016]. Technology is expected to change the vehicle fleet as such, leading to an increased share of two-seater cars and minibuses. Gruel and Stanford [*Gruel, Stanford*, 2016] present three scenarios for the adoption of self-driving vehicles: from *adaptation* through *changing transport behavior* to *transforming the car ownership model*. The authors insist on the need to carefully monitor the number of cars and the extent of their usage to avoid the uncontrolled proliferation of vehicles and negative consequences such as environmental degradation, increased number of accidents, expansion of cities, and so on.

Recently researchers have shown growing interest in the prospects of self-driving vehicle sharing or shared autonomous vehicles (SAV). This format is expected to make transport services more accessible, reduce vehicle fleet size and parking lots' acreage, and users' time and financial costs. Electric cars are believed to be the most suitable for these purposes, due to their environmental characteristics. The use of electric motors in shared autonomous electric vehicles (SAEVs) will increase SAVs' efficiency in terms of user costs and the throughput of urban SRNs [*Loeb et al.*, 2018].

A BCG report [*Collie et al.*, 2017] addresses the last mile problem with SAEVs. The need to walk to the nearest available vehicle (which can be located at a considerable distance from the potential passenger) reduces the appeal of car sharing services and hinders their growth. If cars were able to cover even short distances on their own, it could significantly increase demand for them. Self-driving transport is being researched quite actively [*Milakis et al.*, 2017], but a number of promising topics still remain outside researchers' attention [*Kockelman, Fagnant*, 2015].

Transportation policy significantly affects the size of the self-driving vehicle fleet and the rate of such vehicles' use, depending on the sharing format: ride sharing (50%) and car sharing (100%), as shown, in particular, Lisbon's experience [*Martinez, Crist*, 2015]. Specifically, in all scenarios the load on SRN grows, while the duration of peak periods increases from three to four hours. Using the example of Sweden, Meyer et al. [*Meyer et al.*, 2017] describe how, with minimal investments in transport infrastructure, accessibility zones for residents can be dramatically expanded. The human factor should be taken into account too, not just technological aspects of adopting self-driving technologies, including the proper interaction with pedestrians who together with self-driving vehicles make a common ecosystem, which does not exclusively follow formal rules [*Straub, Schaefer*, 2018].

Along with providing a conventional description, this paper for the first time presents a comprehensive assessment of the urban environment indicators which will change with the adoption of self-driving vehicle technology. For this purpose, a model comprising transport, technological, economic, environmental, social, political, and regulatory indicator groups was used as a basis. The last of the above groups of indicators was left outside the scope of this study due to the ambiguity and low predictability of its long-term impact upon the urban environment. We mean indicators such as safety regulations and traffic rules, liability for traffic accidents, insurance, data collection and storage, compatibility with the overall transport policy, and so on. Issues related to responsibility, data collection and storage, and traffic rules and norms deserve a separate in-depth study involving relevant experts. We also do not consider purely technical indicators measuring the development of self-driving technologies and road transport in general. Since this is a "definite uncertain future", i.e. the future that will definitely come but with non-obvious consequences, the scenario method was used [HBR, 1999]. Using the city of Moscow as an example, we consider below the impact of self-driving technology depending on the car usage model and transport policy. A number of management recommendations are suggested for various self-driving vehicle adoption scenarios.

Methodology

Analysis of Urban Factors

Self-driving vehicles' impact upon the future development of cities can be assessed using a number of indicators, which we have arranged into the aforementioned groups on the basis of the disciplinary principle (Table 1). They describe the urban and political environment, residents, governance, and technology. Such an approach to studying the impact of transport of the future on the urban environment was applied in, for example, [*Parfionov*, 2017].

Transport and technological indicators. The number of cars on the streets per unit of time, which equally depends on vehicle fleet and SRN size was applied as the main assessment parameter in this indicator group, calculated in absolute and relative (compared with 2017) terms. This indicator's growth given latent demand and lack of constraining factors will be proportional to the growth of SRN. If the active vehicle fleet decreases, the number of cars on the streets per unit of time decreases only slightly: according to the Lewis-Mogridge postulate, residents tend to use their personal cars more often, the freer the roads are [*Mogridge*, 1990]. To assess the traffic situation and the time needed to get through traffic jams, the load on SRN and traffic flow density parameters were applied. To assess the need for parking spaces, only qualitative changes in their structure, number, and location were considered.

Economic indicators. The costs of and damage from road accidents were assessed on the basis of car and driver liability insurance data, with the assumption that the ratio of accidents with varying degrees of damage and fatalities remains unchanged with a decrease in their total number. Trip costs were calculated on the basis of both constant (car value taking into account depreciation, insurance, parking) and variable (petrol and maintenance) costs.

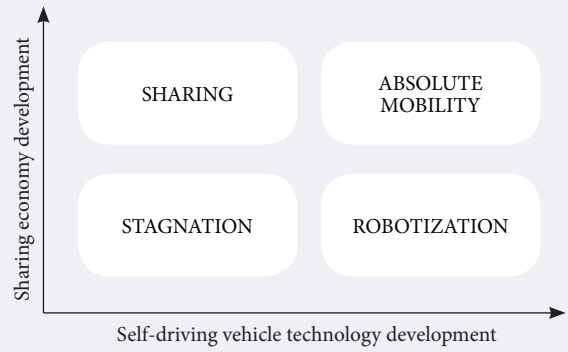
Environmental indicators. Areas freed due to the reduced number of single-level parking lots were expected to be used exclusively for planting greenery to improve the environmental situation. The environmentally friendly urban travel parameter is associated with reduced emissions of harmful substances into the atmosphere per one person's ride and is measured depending on the ride type and peak load on SRN.

Social indicators. Sharply reduced demand for couriers and taxi drivers leads to equally reduced employment in all scenarios. The reduced accident rate

was estimated only depending on the level of those adopting self-driving technology.[1] Parameters such as *social risks* (number of deaths in road accidents per 100,000 people) and *transport risks* (number of deaths in traffic accidents per 10,000 cars) were taken into account. The *involvement of new users* indicator was estimated both quantitatively (ratio of the number of new users to the total number of rides) and qualitatively (service availability for low-mobility and low-income population groups, on a five-point scale).

Political indicators. General recommendations on political and fiscal measures to regulate the number of cars and their usage were prepared on the basis of the developed matrices. This aspect plays a key role in the adoption of self-driving technology [*Milakis et al.*, 2015].

Figure 1. **Scenarios for the Adoption of Self-driving Vehicle Technology**



Source: composed by the authors.

Scenario-Based Forecasting

Each indicator group was assessed within the scope of self-driving technology adoption scenarios [*Litman*, 2016; *Ticoli*, 2015] for two aspects: "penetration rate of self-driving technology" and "shared economy development". The following four scenarios were used (Figure 1):

- *Stagnation*: Characterized by a low penetration rate of self-driving technology and the poor development of the shared economy. This scenario implies that the transport services market lags behind the best practices of self-driving vehicles' application.
- *Sharing*: Characterized by a low penetration rate of self-driving technology and the robust development of the shared economy. This scenario provides for the further development of classic car sharing services such as ride sharing (shared car rides along a common route), etc.
- *Robotization*: Characterized by the rapid penetration of self-driving technology and the weak development of the shared economy. This scenario implies the gradual replacement of personal vehicles with self-driving ones, with car sharing accounting only for a small percentage of daily rides.
- *Absolute Mobility*: Characterized by a high penetration rate of self-driving technology combined with the robust development of the

Table 1. **Parameters of Self-driving Vehicles' Impact upon the Future Development of Cities**

Indicator Groups	Studied Aspects	Parameters
Transport and technological indicators	Impact on the traffic situation and need for space, depending on the supply/demand balance for road transport services	• Traffic situation • Reduced time in traffic jams • Need for parking spaces
Economic indicators	Indirect impact of self-driving technology on city budget and consumers' financial resources, depending on the supply/demand balance for road transport services	• Development of related infrastructure • Reduced costs of, and damage from traffic accidents • Changes in property values • Transport efficiency
Environmental indicators	Environmental impact	• Conversion of no longer needed parking lots into green areas • More environmentally friendly urban transport
Social indicators	Self-driving technologies' impact on living conditions in the city and the accessibility of these technologies	• Changes in employment structure • Street and road safety • Involvement of new users
Political (regulatory) indicators	Transport policy and regulations	• Management of self-driving transport services

Source: composed by the authors.

[1] To clarify: in the process of adopting this technology a temporary surge in the number of accidents due to the coexistence of vehicles driven by artificial intelligence and people is very likely to be observed, due to the differences in the decision-making mechanisms. However, to study this technology's impact on the environment as a whole, this assumption seems to be valid enough.

Table 2. **Basic Conditions for Self-Driving Vehicles' Adoption in Moscow**

Scenario	Stagnation		Sharing		Robotization		Absolute Mobility	
	2030	2035	2030	2035	2030	2035	2030	2035
Vehicle fleet size (thousand)	5313	5676	2685	1925	5685	6073	2391	1670
Motorization rate (vehicles per 1,000 people)	407	434	206	145	435	464	183	126
Self-driving vehicles' share (%)	10	39	9	34	18	61	16	52

Source: composed by the authors.

shared economy. Under this scenario, self-driving technology is beginning to be applied to provide car sharing services, while daily transportation by such vehicles accounts for the lion's share of total rides. In other words, transportation is carried out mainly by SAVs.

Building these scenarios, we relied both upon the published official forecasts and our own estimates [Distanz, 2017]. Forecasting comprises extrapolation (analysis of time series, trend – nonlinear) and an alternative approach where scenario building is determined by technological, economic, and demographic factors which affect the final scenario to varying degrees. In this paper, scenario modeling methods were applied (based on the forecast vehicle fleet and SRN size within the "old" Moscow city limits and the share of self-driving vehicles), comparative analysis, expert estimates, and analogies.

The basic prerequisites for self-driving vehicle adoption scenarios include the following parameters:

- vehicle fleet size;
- share of self-driving vehicles in total fleet;
- percentage of shared vehicles in total fleet;
- motorization level.

The technological impact was estimated for the long term until 2030 and 2035, that is, the probable implementation period of the forecasts used as the basis for scenario modeling. 2030 is important as the starting point for self-driving vehicle sales and their saturating the vehicle fleet over a short five- to seven-year period. 2035 remains the most chronologically distant point in the existing official forecasts: longer prospects are difficult to consider due to the poor source data quality. Still, 2035 is sufficient to assess the consequences of self-driving vehicles' arrival for the development of the city, while comparing the scenarios' basic assumptions for the above dates allows one to estimate the dynamics of changes over a five-year period for each of them.

2022 was chosen as the start of self-driving vehicle sales in the report [Morgan Stanley, 2013], but their share during the first two years remains insignificant in all scenarios since the first models on the market will most likely be purchased by car sharing companies and taxi services. During the transition period, operators will be testing self-driving vehicles' interaction with the urban infrastructure. Upon its completion, vehicle sales to individuals will begin to grow.

Data on the average load on a personal car in Moscow (1.2 passengers with an average of 2.9 rides a day, based on an online survey) was used as the starting points for scenario forecasting. New car sales growth is predicted on the basis of the expected economic growth in the Russian Federation, at 2-4% a year. With minor adjustments, it correlates with AUTOSTAT and PwC data [PwC, 2017]. The predicted increase in SRN throughput is based on the current trends and allows for a 20% increase by 2035 within the "old" Moscow city limits.[2] The growth of the city's population is assumed to match the figure published in the Moscow Development Strategy until 2035 (13.3 million by 2035).

The "Stagnation" scenario assumes the current trends on the automotive market will continue, including the weak development of shared services (car and ride sharing), and a low share of self-driving vehicles in the total passenger vehicle fleet. The sales forecast is based on PwC's estimates for 2015 and 2016 which provide for annual medium-term new car sales growth of 7-13% and their decline in Moscow from 112% to 103% in 2022 [PWC, 2017].

According to our estimates, the share of self-driving vehicle sales on the new vehicles market will grow from 36% in 2030 to 85% in 2035 and subsequently will continue to asymptotically approach full coverage.

Taking into account the projected population growth, the motorization rate may increase to 435 vehicles per 1,000 people, with the total fleet size reaching 5,770,000 vehicles by 2035.

[2] For more details see: https://stroi.mos.ru/road; last accessed on 20.02.2019.

According to the forecasted growth of sales and the share of new self-driving vehicles, under the "Stagnation" scenario, the share of self-driving vehicles in the total fleet will increase from 9% in 2030 to 34% in 2035.

In general, the full benefits of self-driving technologies will not be obtained under this scenario even by 2035. The share of conventional cars in the total fleet will remain at 65%, while the latter is expected to grow by 35% and 47% in 2030 and 2035, respectively, exceeding the increase in SRN. The low level of self-driving technology development in this scenario will not allow for significantly reducing the accident rate, since the probability of having an accident in a conventional car is much higher. Lagging behind in the development of vehicle sharing services will hinder the efficient use of the vehicle fleet, leading to a deteriorating road situation.

The "Absolute Mobility" scenario prioritizes the simultaneous development of self-driving vehicles and the sharing economy (car and ride sharing), with the following indicator dynamics:

- Average shared vehicle load will increase from the current 1.7 passengers per car (for taxis) [Moscow Government, 2017a] to 2.3 passengers per car, matching the best car sharing practices (e.g., in Toronto) [WEF, BCG, 2015];
- Average ride duration including waiting time for delivery of a shared car will reach 55 minutes by 2035, which according to HSE estimates matches the average duration of a private car ride in Moscow in 2016;
- The usage rate of shared cars will increase from the current 6.6 rides a day (car sharing) [Moscow Government, 2016] to 13.9 by 2035: with 13-hour-long daily operation, the average load of 2.3 passengers, the proper level of service (for example, in Toronto), and the 55-minute average ride duration (as in Moscow), up to 32 people will be able to use one car during the day, making up to 13.9 shared rides.

Increased supply and the growing popularity of car sharing services will lead to an outflow of passengers from the classic public transport segment and the closure of less popular routes. The redistribution will amount to 5.6 million rides per day [Moscow Government, 2017b].

This scenario describes a gradual merger of taxis and shared cars into a single (aggregate) service: the provision of self-driving public vehicles (SAVs). Such vehicles may be integrated into the "mobility-as-a-service" format which allows for setting the optimal route and choosing the best fare by identifying the passenger's current location, choosing the destination and ride type – private (one person in the vehicle) or shared with other passengers (ride sharing). Self-driving vehicles greatly increase the efficiency of programmed ride sharing, when the algorithm calculates possible routes and automatically stops the car when another request for a similar route is received. This approach to organizing self-driving transportation allows operators reduce costs and passengers to save on travel expenses. Ultimately, the popularity of this service will grow and the need for personal vehicles will decrease. Various elements of the service are being tested by various car sharing companies around the world taking into account, among other things, the prospects for applying artificial intelligence.

According to the most optimistic forecasts, if the sales start in 2022, equipping all car-sharing vehicles and taxis with self-driving technology may take 10-12 years, that is, with appropriate financial and legal support urban transport will become 100% "self-driving" only by 2034. Under the most favorable scenario, the number of daily rides in shared cars will reach 58% of the total by 2030 and 77% by 2035. These figures are completely consistent with the results of BCG research [*Mosquet et al.*, 2018] according to which car- and ride-sharing in major cities will amount to 40%-80% of the total number of rides by 2030

The "Sharing" and "Robotization" scenarios are based on combining the basic forecast parameters of the first two scenarios depending on the importance and penetration rate of self-driving technologies, or the development of the shared economy. All scenarios are built taking into account the current trends in vehicle fleet development in Moscow.

The calculated data presented in Table 2 indicates that the same number of rides can be made with a different urban transport structure. A natural limitation for the implementation of any road transport development scenario is the SRN: fleet growth is inversely proportional to the efficiency of its use. Ensuring vehicles' availability for passengers in the "Absolute Mobility" and "Sharing" scenarios requires fewer vehicles, that is, resources are spent as efficiently as possible. In other scenarios, while the right to own a car remains in place, the motorization rate grows without a significant increase in costs. Under the "Robotization" scenario, the fleet reaches its maximum size: self-driving technologies make vehicles available to resident groups who did not have access to them previously.

Comparing the scenarios shows the futility of an uncontrolled expansion of vehicle fleet. Even given the declared increase in Moscow's SRN, it is impossible to fully meet the demand for travel by personal cars, due to the natural limitations of the city's road infrastructure. Further growth of the vehicle fleet will only aggravate the road situation, creating additional parking problems in residential areas.

Figure 2. **Regulating the Vehicle Fleet Size and Vehicle Use in the City**

	Regulatory Measures	*Fiscal Measures*
Regulating vehicle fleet	1. Banning use of vehicles older than certain age 2. Limiting motor vehicles' access to certain areas 3. Limiting use of motor vehicles on certain dates 4. Limiting use of motor vehicles during certain hours	1. Paid parking 2. Paid vehicle entrance into certain areas 3. Road pricing 4. Increased fuel excise duties
Regulating use of vehicles	1. Banning empty mileage (over 1 km) 2. Banning sale of conventional cars 3. Allowing one to register cars only to people who own a parking space near their home 4. Auctioning car purchasing rights	1. Incentives to use shared cars 2. Increased car registration fees 3. Increased vehicle tax rates

Source: composed by the authors.

The dynamics of the basic scenarios under consideration depends on which measures will be implemented in the framework of the city's transport policy. Some approaches to regulating the number of cars and their usage in Moscow are shown in Figure 2.

Achieving each scenario's target parameters requires specific urban transport policies varying in terms of the toughness of the measures applied and priorities for self-driving transport development [*Li et al.*, 2018].

Unit ride costs in each scenario were estimated based on car prices, operating costs, and usage rate [PWC, 2016]. Vehicle maintenance costs (their estimated growth is 25% and 50% in the "Robotization" and "Stagnation" scenarios, respectively) is a kind of ownership tax on personal self-driving and conventional vehicles. Under current legislation, such an increase in maintenance costs is equivalent to increasing the vehicle tax rate by 15 and 30 times, respectively, compared with the 2017 level. Introducing a differentiated toll system (road pricing) by the calculation period of 2030–2035 along with the adjustment coefficients for the standard per kilometer rates will increase vehicle maintenance cost by the same 25% and 50% under the above scenarios. For shared vehicles, accelerated depreciation over a two year period, free parking spaces, and fixed vehicle tax rates compared with the 2017 level (or a lowering adjustment coefficient for road use tariffs) will be implemented if a road pricing system is introduced by 2030–2035, plus additional VAT for transport service operators.

Replacing conventional cars with self-driving ones leads to a gradual decrease in road accidents. When this replacement is complete, the number of accidents will be reduced by 94%. We leave outside the scope of this study the question of the transport system's state while vehicles driven by artificial intelligence (which calculates how the traffic situation may develop) and ordinary cars with human drivers (who often make rash and suboptimal decisions) will be present on the roads simultaneously.

As an option to convert some of the SRN areas for non-transportation use, planting greenery (parks, gardens, etc.) is seen as the most neutral way to change urban lands' functionality, though other solutions are possible. Such areas may be used for retail, housing construction, building infrastructure, and so on. This study does not consider the environmental aspects of changing the structure of vehicles' fuel balance. Obviously the currently popular SAEV concept will develop in different countries at different rates, depending on the local technology level, availability of certain fuel types, severity of environmental problems, and the climate. Inexpensive and environmentally friendly gas motor fuel, the proliferation of hybrid engines, and climatic conditions (long periods of low temperatures) limit electric vehicles' appeal. This segment's development and further dynamics of the fuel balance structure require a separate study. To minimize uncertainty regarding the choice of the dominant fuel type for future car generations, the ride resource intensity parameter was included in the environmental section of the forecast (it is directly proportional to the way in which vehicles are used and the format of their ownership, the load on SRN, and increased environmental friendliness of vehicles' engines).

Results of the Study

The combined effect of the basic parameters of the four self-driving vehicle technology adoption scenarios in Moscow on specific characteristics of the city's environment is presented in Table. 3.

Table 3. **Summary Indicators of Self-driving Vehicles' Impact upon Urban Environment Parameters (the example of Moscow)**

Scenario	Stagnation		Sharing		Robotization		Absolute Mobility	
Year	2030	2035	2030	2035	2030	2035	2030	2035
	Transportation and technological indicators							
Street vehicle fleet size (*thousand*)	873	928	899	840	917	944	899	840
Change in load on city's SRN (%)	+11	+13	+16	+6	+11	+13	+14	+3
Change in amount of time wasted in traffic jams (%)	+5..10	+5..10	..0	0..5	5..10	5..10	0..5	5..10
	Economic indicators							
Reduced costs of traffic accidents (*million rubles*)	5 571	10 028	5 571	10 028	8 728	10 771	12 256	15 042
Change in property values	Property values increase in areas with limited transport access		Homes' and commercial property values grow everywhere		Property values increase in areas with limited transport access		Homes' and commercial property values grow everywhere	
Ratio of unit shared/private ride costs	0.38		0.31		0.38		0.26	
	Environmental indicators							
Using former SRN areas to plant greenery	–		+1 m² of green areas per resident		–		+1 m² of green areas per resident	
Change in unit ride costs (%)	-8	-10	-32	-47	-11	-21	-23	-52
	Social indicators							
Reduced employment (*number of jobs*)	-200,000		-200,000		-200,000		-200,000	
Reduced accident rate (%)	-32	-58	-47	-58	-66	-88	-66	-81
Transport-related risks (*number of deaths per 10,000 vehicles*)	0.53	0.30	0.82	0.90	0.25	0.08	0.60	0.48
Social risks (*number of deaths per 10,000 people*)	2.17	1.31	1.70	1.34	1.09	0.38	1.10	0.60
New users (*million*)	1.03	1.36	2.23	2.51	2.23	2.51	2.70	2.82
Access for population groups with limited mobility	3*	3*	3*	4*	3*	4*	5*	5*
Access for low-income population groups	1*	2*	4*	5*	1*	2*	5*	5*

* on a 5-point scale where 1 is the lowest access level and 5 is the highest.

Source: composed by the authors.

The analysis showed that the "Stagnation" and "Robotization" scenarios lead to aggravated transport problems in the city, an increased number of cars on the roads as self-driving vehicles become more available, and a deteriorating environmental situation (depending on the type of engines used). Transport-related risk measured as the number of deaths in traffic accidents per 10,000 *vehicles* a year will sharply decrease, from 1.5 to 0.30 and to 0.08. The reduction in social risk (measured as the number of deaths in traffic accidents per 100,000 *residents*) will be equally significant, from 8.1 to 1.31 and to 0.38 for the two above scenarios, respectively. With a similar motorization level, the difference is due to the fact that the human factor remains the key cause of road accidents. According to various estimates, it accounts for up to 94% of all accidents [*Skinner, Bidwell*, 2016]. Self-driving vehicles will minimize the role of the human factor, with a downward effect on the overall accident rate. Under the "Robotization" scenario, which implies the highest proportion of self-driving vehicles due to their availability for a wide range of new consumers, these risks become much lower. At the same time, the load on the SRN and the amount of time spent in traffic jams will equally increase in both scenarios despite the larger total number of vehicles on the roads under the "Robotization" scenario. Programming self-driving vehicles' routes, minimizing the number of driving errors, and up-

dating traffic information in real time will reduce the accident rate, homogenize the traffic flow, and make it more predictable. Equal unit ride costs in both these scenarios are due to the fact that the higher initial expenditures (to purchase a self-driving car) do not allow for reducing this indicator value in "Robotization".

In both the "Stagnation" and "Robotization" scenarios, low-mobility and low-income population groups' access to transport services remains limited. For the former, the very emergence of self-driving vehicles potentially capable of arriving to pick up a passenger on their own is more important. For the latter, the proliferation of car sharing services which offer much cheaper rides than personal vehicles eliminates the need to save and take out a loan to buy a car. Since having access to a car makes it possible to travel to jobs offering more attractive working conditions, the development of car sharing infrastructure will contribute to higher economic efficiency and better living standards, becoming a relatively inexpensive alternative to conventional public transport. However, because present-day car-sharing services are not available to users without a drivers' license, they will only be able to use the ride sharing format. Despite the high share of self-driving vehicles in the "Robotization" scenario, their convenience and maximum mobility, people with physical or financial problems will have to purchase a personal self-driving vehicle due to the insufficient development of car sharing services under this scenario. Obviously, the high costs will limit the overall access of these groups to transport services.

The "Absolute Mobility" and "Sharing" scenarios have much in common. Both imply a slightly easier traffic situation and completely solve the parking and vehicle utilization problems. Under the first scenario, transportation services for low-mobility and low-income population groups are more developed. The accident rate, waste of time, and ride costs are minimized, while the efficiency and the environmental situation are improved regardless of the engine type. Under the second scenario, the availability of transport services for vulnerable population groups is not as good. In the context of the insufficient application of self-driving technologies in carsharing, low-income individuals still need to have a drivers' license. People with limited mobility will only be able to use cars when accompanied by other people, which does, however, allow them to get by without owning a car.

The "Sharing" scenario implies a lower accident rate and a greater increase in the SRN load, since the low dissemination of self-driving vehicles does not allow for taking advantage of programmed routes. Transport risks are reduced from 1.5 to 0.48 and 0.90, social risks from 8.1 to 0.60 and 1.34 for the "Absolute Mobility" and "Sharing" scenarios, respectively. These results are consistent with the estimates of accident rate reduction following the extensive use of car sharing (by 60% by 2030) [*Collie et al.*, 2017]. The difference between indicator values under these scenarios is due to the low adoption of self-driving vehicles in the "Sharing" scenario, which reduces the human factor's impact upon the accident rate. For the same reason, unit ride costs somewhat increase, given the low adoption of self-driving technology in the scenarios. The lack of programmable routes and not taking into account the traffic situation lead to increased mileage and drivers' choosing suboptimal routes, especially in ride sharing. The latter format allows one to share travel costs and save end-users' expenses, but it is more difficult to maintain without programmable self-driving vehicles. This explains why the vehicle operation scheme in the "Sharing" scenario is less efficient than the "Absolute Mobility" scenario, where the wide application of self-driving services allows users to save travel time and not worry about finding a parking space.

Scenarios that imply the active use of shared vehicles allow one to meet higher demand for transportation with a smaller fleet. Ride sharing allows several passengers use the same vehicle at the same time. These scenarios lead to an improved (or, at least, non-deteriorating) traffic situation compared to 2017, with the increased use of vehicles.

Scenarios providing for a significant share of public cars confirm that the more popular the sharing formats are, the more environmentally neutral each ride becomes, since total per-ride energy consumption is reduced. Thus, according to the analyzed trends, per-ride resource intensity in the "Absolute Mobility" and "Sharing" scenarios is reduced by half compared with the 2017 level, due to the more efficient exploitation of vehicles, ride sharing, and more environmentally friendly engines.

Only the "Sharing" and "Absolute Mobility" scenarios imply dismantling some of the single-level parking lots. With the reduced overall vehicle fleet, the number of cars on the city streets during peak hours remains comparable in both scenarios. Therefore, the need declines not for SRN, but for parking spaces in residential areas. Converting parking spaces into green areas in Moscow will lead to an increase in green areas' acreage by one square meter per person, or by 1,600 ha in total. With the total green areas' acreage within "old Moscow" city limits of 36,100 ha in 2014, the increase will amount to about 4.5%. Moreover, new green areas can be created just where people live, which will positively impact property values.

Regardless of the self-driving technology adoption scenario, the labor market will experience significant changes, mainly due to the reduced demand

for taxi drivers and couriers, traffic police, and traffic inspectors. Up to 200,000 jobs may be eliminated, or 2%-3% of their total number [Business Planner, 2016].

The analysis of self-driving transport and sharing technology development based on comparing the data presented in Table 3 shows that sharing technology turns out to be the most important for the city and its residents: it allows one to deal with transport problems, ease the traffic situation, reduce resource consumption and car ride costs, and increase the number of users of this type of transport. Meanwhile the effect of self-driving vehicle technology mainly amounts to a reduced accident rate and more environmentally friendly travel (reduced resource consumption per ride).

Mechanisms for providing transport services are assessed using the management (political) indicators of self-driving vehicles' impact. The analysis is based on the experience of Asian and European cities.

Regardless of the share of self-driving vehicles, all scenarios imply the development of appropriate infrastructure at the expense of the municipal authorities or funded by a municipal-private partnership, including:

- broadband 5G and Wi-Fi networks with base stations at intersections;
- precision maps to support self-driving transport;
- services for marking and finding the nearest parking space;
- a network of parking hubs, to minimize mileage and the need to bring private self-driving vehicles home.

To promote the transition to self-driving transport, municipalities can introduce co-funding mechanisms (in the framework of public-private partnerships), or fully fund budget projects out of the city budget such as data processing centers (DPC) and data protection facilities (at DPCs, police departments, or independent ones) to support the uninterrupted operation of the transport system and prevent illegal interference [*Maurer et al*., 2015].

The "Sharing" and "Absolute Mobility" scenarios (a large proportion of shared cars) require additional services involving private companies. We mean creating a network of "mobility-as-a-service" stations required to map routes and request cars as well as specialized services (such as repair and dispatch) for public transport.

One of self-driving vehicles' advantages is the lack of a need to find a parking space. At first glance, this seems to be critically important in a city center with its high economic activity. The self-driving vehicle that delivered the passenger can move on without parking or look for a parking space on its own without human input. However, in the reality of Moscow, this would hardly be possible, especially during rush hour when dense traffic flows clog the city center, taking unpredictable routes which further complicate the situation at intersections. A logical solution seems to be introducing a ban on empty mileage above a certain limit and the active construction of automated multi-level parking lots along the perimeter of the central part of the city, to end the route of any vehicle heading to the city center without a guaranteed parking space. An alternative to the empty mileage ban can be a pay-as-you-go tax differentiated depending on the zone and time of day.

The scenarios with less-developed car sharing services ("Stagnation" and "Robotization") do not provide for significant changes in transport policy. These scenarios' negative effects require an adequate reaction from the city authorities, among other things to regulate the transport services market. In particular, the aforementioned multi-level automated parking lots around the perimeter of the central part of the city and in residential areas can be a solution to the parking problem and shared cars' empty mileage. In residential areas, the cost of renting a parking space near residential buildings should match or even exceed the price of parking in such parking lots to reduce the use of areas adjacent to apartment buildings for these purposes. In the absence of direct incentives for buying self-driving vehicles, introducing an age limit for conventional cars could prompt people to change them more often. For example, cars could be automatically deregistered after 10 years in operation (the period applied in our calculations). This would lead to an increased share of self-driving vehicles and help achieve the highest potential effect of applying self-driving vehicle technology under this scenario. In the "Robotization" scenario, additional fiscal restrictions on owning a conventional car (> SAE level 4) will be applied. With underdeveloped sharing services, no benefits for SAVs are provided here either. Generally, transport policies underlying both these scenarios do not seem to be perfect for the future development of the city, for the use of space, and the efficient provision of transport services.

Scenarios that imply a significant proportion of shared cars ("Sharing" and "Absolute Mobility" scenarios) propose curbing the demand for personal cars using fiscal and regulatory methods. The first include various ways to increase the cost of owning a car. If transport legislation remains unchanged, the most effective way is to increase the vehicle tax rate. The advantages of this measure are that it allows potential buyers to estimate the additional car maintenance costs in advance. When shared

cars are used, the tax is shared by a wider circle of users, which reduces total ride costs for each of them and encourages them to abandon personal cars. The disadvantages of the tax-based incentive include the lack of direct correlation between the vehicle's mileage and the use of SRN on the one hand and the amount due on the other. Replacing the conventional vehicle tax with a fee for the actual use of the SRN (pay-as-you-go tax) is being actively discussed now. Such a road pricing system would make it possible to differentiate the costs of using specific SRN segments depending on their condition, direction of travel, time of day, and the importance (rank) of the transport arteries. Being fairer in terms of the specific rate of SRN use, such a system would promote a more economic mode of road use and make it possible to compensate for reduced fuel tax revenues due to the increased share of electric and hybrid vehicles. However, introducing such an advanced payment system requires changing the legislation and putting in place an automated digital system to monitor the load on the SRN, predict demand, and pay the tolls, which would be burdensome both financially and technologically.

We did not try to assess the feasibility of such changes but switching to a road pricing system increases the likelihood of introducing such a system by 2030-2035. Under the "Sharing" and "Absolute Mobility" scenarios, not so much the payment procedure would matter for end users as the difference in ride costs between personal and shared cars. Thus, the currently applied vehicle tax and road pricing system will allow one to achieve comparable parameter values under both scenarios.

If in the framework of the "Sharing" scenario just the increased costs of owning a personal car turn out to be sufficient, in the "Absolute Mobility" scenario a differentiated approach could be applied, which implies the minimal costs of owning an SAV (and, with due justification of the advantages of electric models, an SAEV), and maximum ones for owning conventional cars (with the SAE autonomy level below 4).

Possible restrictive measures to curb demand for personal transportation include a legal ban on empty mileage (e.g. more than 2 km, or 30 minutes), and allocating dedicated parking spaces for shared cars. The scenarios under consideration also require introducing a legal requirement according to which only people who own (or have a long-term lease of) a parking space within walking distance from their home would have the right to buy and own a private car, and regulating high capacity public transport fares to maintain its competitiveness (Table 4).

With the seemingly obvious advantages of the "Sharing" and "Absolute Mobility" scenarios, their implementation requires significant restrictions on the use of personal vehicles. Such initiatives are fraught with social costs, as they involve a forced change in the transport behavior model or significantly higher travel expenditures combined with the need to adapt to new technologies. It will not be possible to achieve these scenarios' target indicator values without the city authorities' actively working with the public to minimize the negative consequences of the decisions made and ensure that residents clearly see the future advantages. To study the latter on theoretical and practical levels, municipalities can independently fund self-driving vehicle research and use the results to justify the inevitable unpopular decisions under the "Robotization" or "Absolute Mobility" scenarios.

The potential effects of implementation the aforementioned self-driving vehicle adoption scenarios for the city as a whole and its residents in particular are presented in Table. 5.

Conclusion

Today we can confidently say that self-driving vehicles technology will be adopted in one form or another in the foreseeable future and will significantly change the very approach to transporting people and owning a car. Self-driving vehicles will lose their purely personal status in favor of the sharing model. Further, self-driving technology can positively affect the urban environment and transportation only if sharing services are adequately developed at the same time. In the next decade, car sharing and ride sharing services are expected to grow the world over and self-driving vehicles will make them especially attractive.

In the scope of our study, the role of the transportation policy in promoting the adoption of self-driving vehicles was illustrated using the city of Moscow as an example. In the absence of restraining fiscal or regulatory mechanisms, the number of cars in personal ownership will steadily grow as the barriers limiting access to them diminish, leading to a catastrophic overload on the city's SRN. In practice, this would mean hours wasted in traffic jams, which will not allow one to fully implement self-driving vehicles' advantages. A set of measures to reduce traffic, regulate the use of urban transport, and encourage car sharing companies to purchase self-driving vehicles in bulk and change their service delivery model would help achieve a radical improvement in the traffic situation, including certain urban environment factors as well. However, the costs of this kind of improvement may turn out

Table 4. **Steps to be Taken to Accomplish the Target Parameters of the Scenarios under Consideration (the example of Moscow)**

Scenario	Steps to be Taken
Stagnation	• Prohibiting the use of cars over 10 years old • Building multi-level parking lots in residential areas and along the Third Transport Ring • Uniform parking rates for single- and multi-level parking in residential areas for local residents • Continued support for car sharing providers • Promoting the development of conventional public transport services
Sharing	• Registering personal cars only to people who own a parking space near their home • Paid parking for private cars throughout the city • Increased vehicle tax on private cars (x15 relative to 2017 rates) or introducing road pricing tool with a similar increase in ownership costs • Segregating parking lots in residential areas by ownership type; making parking spaces along the streets available to shared cars only • Increasing car sharing costs to make sure conventional public transport remains attractive • + "STAGNATION" SCENARIO STEPS
Robotization	• Increased vehicle tax on private cars (x15 relative to 2017 rates), or introducing a road pricing tool with a similar increase in ownership costs • Prohibiting empty mileage (more than 2 km or 30 minutes) • Promoting automated multi-level parking services in residential areas and along the Third Transport Ring and petrol station services • Municipalities co-fund the construction of infrastructure for self-driving vehicles (5G networks, data processing centers, data protection centers, and dedicated parking lots) • + "STAGNATION" SCENARIO STEPS
Absolute Mobility	• Increased vehicle tax on private cars (x15..x30 relative to 2017 rates) depending on SAE autonomy level (the higher the level, the lower the rate) or introducing a road pricing tool with adjustment coefficients for a base rate depending on the car autonomy level • Making car sharing services fully available throughout the Moscow metropolitan area • Municipal funding for SAV/SAEV research • + "SHARING" and "ROBOTIZATION" SCENARIO STEPS

Source: composed by the authors.

to be prohibitive for the public. For example, with the strongest incentives to use shared cars in place, the maintenance costs of a personal vehicle for its whole life cycle (including depreciation) would increase 50% compared with the current rates and prices, while parking would become paid across the city all the way to the Moscow Ring Road, including territories adjacent to residential buildings.

An alternative to the traditional vehicle tax collection scheme is a more advanced road pricing system, with the rates differentiated by time and zone. Its adoption could lead to revolutionary changes, even if they are extended over a long period. We are talking about dramatic changes in the accustomed way of life occurring in a relatively short period of time, which, being extremely sensitive for the residents (users), will inevitably cause discontent and opposition.

The stronger the fiscal restrictions for owning private vehicles are, the more attractive public transport becomes, and the higher the specific efficiency of the entire fleet. Car sharing will have the highest positive effect when these services become available outside Moscow, in the near Moscow Region (Moscow metropolitan area), which will require car sharing operators to increase their capacities and cooperate with the Moscow Region services.

Our results show that the future transport policy should include both shared economy elements and incentives to adopt self-driving vehicle technology. The transport policy should be proactive, anticipating the negative consequences of the implementation of a particular scenario and keeping residents as well-informed as possible. Fiscal and regulatory measures would allow one to accomplish these objectives, the specific set of which (recommended in

Table 5. **Self-driving Vehicles' Impact upon the City and its Residents**

Scenario	Impact upon Residents	Impact upon the Urban Environment
Stagnation	• Affordability of personal cars • Problems with keeping a car in residential areas • Waste of time in traffic jams • High unit ride costs • Low access to road transport services for low-mobility and low-income groups • Loss of transportation-related jobs	• Permanent traffic jams • Acute shortage of car storage places (+1.7 million cars compared with 2016) • Need to build multi-level parking lots • Reduced accident rate (-58%) • Deteriorating environmental situation
Sharing	• Wide access to motor transport services regardless of wealth and health • Low- and middle-income groups abandon personal cars in favor of car sharing • Low travel costs, but higher than conventional public transport • Sharply increased costs of owning a personal car • Increased mobility • Loss of transportation-related jobs	• Local traffic jams: current load on SRN remains unchanged • Reduced accident rate (-58%) • Improved environmental situation • Increased property values in areas with limited transport accessibility • Slightly improved environmental situation
Robotization	• High appeal of owning an self-driving vehicle • Low affordability of personal cars • Sharply increased costs of owning a conventional personal car • Increased availability of motor transport services for people with limited mobility • Loss of transportation-related jobs • Fewer problems with parking and storing vehicles	• Permanent traffic jams with no traffic accidents • Need to build automatic parking lots along the Third Ring Road and in residential areas • Among the highest reduction in accident rate (-88%) • Increased property values in areas with limited transport accessibility • Slightly improved environmental situation
Absolute Mobility	• Low affordability of personal cars • Only high-income population groups can afford a personal car • Wide access to car sharing services regardless of wealth and health • Low travel costs, but higher than conventional public transport • Loss of transportation-related jobs • Increased social tension, dissatisfaction with the transport policy • Increased mobility	• Reduced road congestion, highly predictable travel • Among the highest reduction in accident rate (-81%) • Highest improvement in environmental situation • Increased commercial and home property values across the city • Opportunity to convert unused SRN areas

Source: composed by the authors.

the study for inclusion in such a proactive policy) will lead to the increased total costs of owning a car and create administrative barriers to purchasing personal vehicles. These measures should be introduced gradually and be announced in advance, several years before the relevant decisions enter into force.

It was demonstrated that the current policy remains ineffective, as it causes the uncontrolled growth of the personal vehicle fleet in the city and requires an adequate expansion of the SRN at the cost of other public expenditures. The uncontrolled expansion of the self-driving personal vehicle fleet would be equally undesirable, since it would only increase the load on the city's transport system and the overall losses of all traffic participants. This development would lead to a further degradation of the urban environment, which could be prevented by implementing the proposed transport policy measures.

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Technology Selection Using the TOPSIS Method

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Abstract

Innovative technologies are increasingly determining the competitive advantage of enterprises. They also form the basis for modern manufacturing processes, enabling them to meet the needs of society. Awareness of the need for technological development has become widespread, which has been confirmed by international and national programs, scientific and research activities, as well as emerging institutions. Considering the increasing demand for innovative technologies and a developed market, it appears important to use specific methods and tools for the effective analysis and selection of technologies. This paper presents a proposal to use multi-attribute decision-making methods during technology assessment and selection. The proposed concept combines an S-life-cycle analysis (S-LCA), which determines the performance of a technology, the method of Technology Readiness Levels (TRL), which examines the technological maturity, and the TOPSIS method, which allows for developing a technology ranking. To verify this approach, the example of a ranking and selection of the best road technology in Poland is presented, considering the proposed set of criteria and sub-criteria. In the assessment, the criteria for innovation, competitiveness, and usefulness of this technology were used in addition to S-LSA and TRL methods.

Keywords: technology; innovation; technology selection; technology assessment; technology readiness levels; TOPSIS; Multi-Attribute Decision-Making methods

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The selection of technologies is based on a set of pre-defined criteria, the aggregation of which allows one to create a ranking. The task of the ranking is to collect information on alternative technologies from different sources and to assess these alternatives based on a set of criteria, considering the priorities of the organization that carries out or commissions the assessment. The selection of appropriate technologies allows for the empirical evaluation of current technology parameters and its development potential. It is used for the assessment of a set of existing technical solutions, a portfolio of technologies, products, or patented inventions owned by an organization. Selection and ranking require either the measurement of relevant parameters of the technology, an organization and its market environment, or the use of expert evaluations to determine the values of some of these parameters. Technology Assessment (TA) is an integral part of the ranking.

The concept of technology assessment was first introduced in the mid-1960s to determine the consequences arising from the development of new technologies [*van den Ende et al.*, 1998; *Carlsen et al.,* 2010]. Over time, the concept of technology assessment was created to evaluate the effects of the introduction or development of new technologies, especially focusing on the negative impacts. This concept responded to technologies emerging in the second half of the 20th century that were widely recognized as risky or dangerous, such as biotechnologies, nanotechnologies, and nuclear technologies [*Goulet,* 1994; *Coates*, 1998; *Tran, Daim*, 2008]. Technology assessment is intended to provide an early warning system and identify opportunities and risks for the use of a technology so that the legitimacy of its implementation and development can be verified. For many years, specialists have been tasked with making the public aware of the potential that new technologies have in order to convince people to implement the innovations [*Halicka*, 2017; *Halicka*, 2018].

From the literature review, it can be seen that initially the concept of Technology Assessment was used for political decision making. It was mainly used for strategic economic assessments of complex technologies, such as conventional and nuclear energy technologies and aeronautical technologies. Most of these technologies have been developed and implemented by government institutions. Over time, TA has been used for business decision making and the evaluation and selection of implemented technologies. A literature review shows that there are several varieties of TA (Table 1) [*Carlsen et al.*, 2010; *Tran, Daim*, 2008; *van den Ende et al.*, 1998].

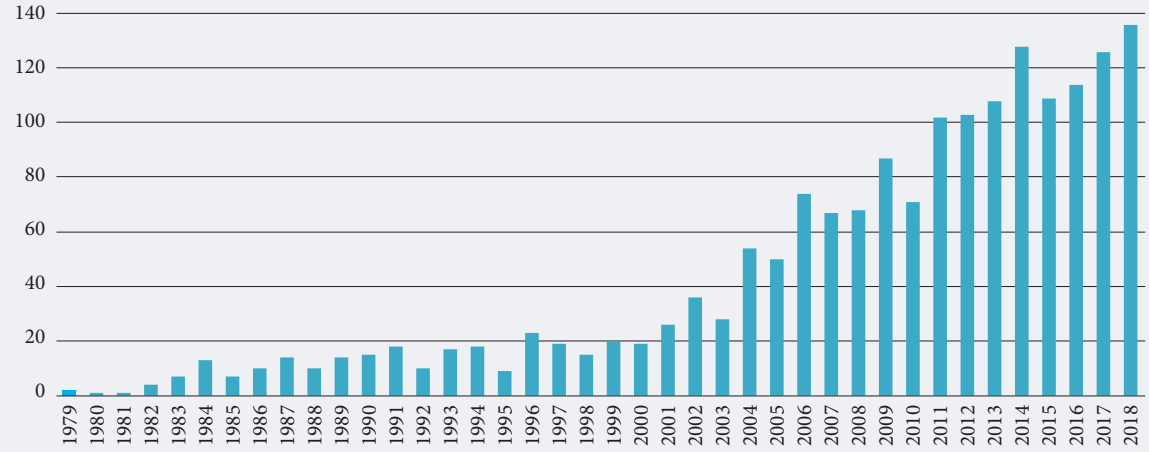
Participatory Technology Assessment (PTA) is about increasing the participation and influence of the public in the decision-making process based on what is already known about a technology, rather than anticipating the unexpected effects of future technologies [*Goulet*, 1994; *Tavella*, 2016]. Awareness TA (ATA), on the other hand, focuses on anticipating a technological change and its impact, with a particular focus on unplanned and unexpected consequences [*Coates*,1998; *Arora et al.*, 2014]. Constructive TA (CTA) makes it possible to shape the course of a technological development in socially desirable directions [*van den Ende et al.*, 1998; *Schot, Rip,* 1997; *Versteeg el al.*, 2017]. Backcasting is about developing scenarios for the desired future and launching innovative processes based on these scenarios [*Zimmermann et al.*, 2012]. Strategic TA (STA) supports specific entities or groups of entities in formulating their policies and strategies for specific technological developments [*Daim et al.,* 2018; *Grimaldi et al.,* 2015]. The first four types of TA are currently used for political decision making. The last type of technology assessment (STA) points to the emergence of a further stream of TA research in the business, industry, and non-governmental environments.

The strategic technology assessment was first carried out in the 1980s, but a more detailed version followed after the 1990s. This approach can be used for the economic assessment of alternative technologies, for the selection and purchase of strategic technologies, or strategic planning. It considers technological readiness, commercial potential, or innovative technology. In this case, the dominant role is played by a potential or current supplier or user interested in the commercialization or implementation of the most appropriate technologies. Therefore, the technology assessment can be made by organizations developing technologies (e.g. research institutes) or enterprises that want to select and implement the most appropriate technologies for their needs. In this trend of technology assessment, the importance of technology is examined from the point of view of the recipient, current and expected plans for its implementation, and the application by the recipient and other entities. This trend in technology assessment is an unsavory element of technology selection.

Literature Review

Technology selection is a dynamically developing area, which is reflected in a growing number of publications. Over the last 40 years, 1,753 publications have been indexed in the Scopus database with the keyword "technology selection". The number of publications between 1979 and 2018 is shown in Figure 1. According to the figure, initially — during the first twenty-five years — there was no significant interest in this issue. Until 2003, no more than 40 articles in this field were published annually. Only since 2004, has interest in the selection of technologies started to significantly increase, which is reflected in the number of publications in the Scopus database.

Figure 1. **Number of Publications in the Scopus Database in 1979–2018**



Source: own calculations based on the search results in the Scopus database for the term "technology selection" in the title, abstract, or the keywords of an article.

The largest number of publications on technology selection was announced in journals such as SAE Technical Papers (31 articles), A Journal Of Cleaner Production (31 articles), International Journal of Production Research (18 articles) and the International Journal of Advanced Manufacturing Technology (16 articles).

For the selection of technologies, both qualitative and quantitative methods can be used. The first group is aimed at identifying features that may potentially impact the effect of implementation and commercialization. The second group of methods should be used to identify the relevant characteristics that explain the reasons for the differences between technologies. Practical methods are usually a combination of qualitative and quantitative approaches. Research conducted around the world suggests that it is impossible to choose one method, which is best suited for technology analysis. Consequently, there is a noticeable trend in the use of several methods in each procedure.

The process of evaluating and selecting technologies is difficult. The reasons for this arise from the uncertainty surrounding the production of technology, including the ambiguity of the assessments (judgements) of the experts involved in the ranking research, the interdependencies between technologies, and the multidimensional nature of technologies. Considering the specific features listed above, multi-attribute decision-making methods are used to solve the problem of the selection and ranking of technolo-

Table 1. **Types of TA**

Types of TA Publications	Application	Recipient's Profile	Selected Criteria for Technology Assessment
Participatory Technology Assessment (PTA) [*Goulet*, 1994; *Tavella*, 2016]	to make political decisions	policymakers	• the economic value of a technology • opportunities to obtain advantages based on differentiation • opportunities to influence technological progress through government intervention • appropriateness of government intervention • low potential for misappropriation • significant social benefits
Sustainability Assessment of Technologies (SAT) [*Ren et al.*, 2017]			
Awareness Assessment of Technologies (ATA) [*Coates*,1998; *Arora et al.*, 2014]			
Constructive Assessment of Technologies (CTA) [*van den Ende et al.*, 1998; *Schot, Rip,* 1997; *Versteeg el al.*, 2017]			
Backcasting [*Zimmermann et al.*, 2012]			
Strategic Assessment of Technologies (STA) [*Daim et al.,* 2018; *Grimaldi et al.,* 2015]	to make business decisions	decision-makers	• validity from the point of view of the recipient • current implementation/application plans • expected implementation/application plans • time of market introduction • number of suppliers/points of sale

Source: author's study based on [*Goulet*, 1994; *Tavella* 2016; *Ren et al.*, 2017; *Coates*,1998; *Arora et al.*, 2014; *van den Ende et al.*, 1998; *Schot, Rip*, 1997; *Versteeg el al.*, 2017; *Zimmermann et al.*, 2012; *Daim et al.*, 2018; *Grimaldi et al.,* 2015].

Table 2. **Number of Publications in the Scopus Database between 1999–2019**

Year	Number of publications
1999	1
2009	1
2011	1
2012	4
2013	3
2014	1
2015	2
2016	5
2017	5
2018	6
2019	4

Source: own calculations based on the search results in the Scopus database for keywords "technology selection" and "TOPSIS", or "technology assessment" AND "TOPSIS" in the title, abstract, or keywords of an article.

gies [*Winebrake, Creswick*, 2003]. MADM methods define procedures for processing the information on the value (assessment) of options against criteria to prioritize solutions and select the best one. Using the approach described above, a wide range of methods was distinguished, including [*Zavadskas et al.*, 2016; *Mardania et al.*, 2018; *Vavrek, Adamisin, Kotulic*, 2017; *Tamošiūnas*, 2018; *Roszkowska, Kacprzak*, 2016; *Chodakowska, Nazarko*, 2017]: the SAW (Simple Additive Weighting) method, ELECTRE (Elimination and Choice Expressing the Reality) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) ranking methods, as well as methods based on the degree of distance from the ideal/anti-ideal VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje — Multicriteria Optimization and Compromise Solution). The most important of these are Multicriteria Optimisation and Compromise Solution, Technique for Order Preference by Similarity to Ideal Solution, Analytic Hierarchy Process, ANP (Analytic Network Process), and MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). The literature review shows that the AHP and TOPSIS methods are most frequently used to select technologies. A characteristic feature of the AHP method is that it compares the adopted criteria with each other, which results in a comparison matrix. The next step in the AHP method is to determine global and local preferences based on a comparison matrix and to calculate the compliance factor. The final step is to create a final ranking of the accepted alternatives. This is possible by calculating the usefulness function of the variants. The TOPSIS method, on the other hand, is a method of similarity to an ideal solution, which is classified as a distance method. The variants are evaluated by determining their distance from the ideal and anti-master. The determination of the preferential sequence requires the consideration of the weights of the criteria and the standardization of the assessment of the alternatives in the light of the criteria. The best solution is the one closest and the one furthest from the ideal. This allows for determining the value of a synthetic meter, which indicates the position of particular variants in the ranking. AHP methods are not usually used in situations with a large number of criteria. For example, for 24 criteria, the matrix has 24 columns and 24 rows. It is usually used when there are less than 10 criteria. Moreover, in the AHP method, weights for particular criteria are often determined subjectively, based on expert opinions. Moreover, problems frequently result from interdependencies between alternatives and criteria. This may lead to inconsistencies between the decision and ranking criteria and the reversal of the ranking [*Nermed,* 2015; *Velasquez, Hester,* 2013; *Anand, Vinodh*, 2018; *Mobinizadeh et al.*, 2016; *Oztaysi,* 2014]. Therefore, this study uses the TOPSIS method to select road technologies.

Table 3. **Breakdown of Publications by Subject Matter of the Identified Articles**

Subject Area	Number of Publications
Engineering	19
Computer Science	8
Environmental Science	7
Business	5
Energy	3
Medicine	4
Social Sciences	2
Decision Sciences	2
Materials Science	2
Agricultural and Biological Sciences	1
Biochemistry	1
Chemistry	1
Mathematics	1
Physics and Astronomy	1

Source: own study based on records from the Scopus database.

Initially, a detailed literature review was carried out and a bibliographic analysis of publications on technology selection using the TOPSIS method was performed. In the Scopus database for the period 1999–2019, 33 records are indexed with the keywords "technology selection" and "TOPSIS" or "technology assessment" AND "TOPSIS". The number of publications is presented in Table 2. The first articles in this field were published in 1999.

The identified publications were analyzed in terms of subject areas (Table 3). Each article could be assigned to several areas. More than half of the identified publications concerned engineering issues. Issues attributed to the area of Computer Science were addressed

Table 4. **TOPSIS Method in Technology Selection**

Authors (year)	Type of Technology
[*Habbal et al.,* 2019]	radio access technologies
[*Gladysz et al.,* 2017; *Wan et al.,* 2016]	radio frequency identification (RFID)
[*Zhang et al.,* 2019]	energy storage technology
[*Restrepo-Garcés et al.,* 2017; *Hirushie et al.,* 2017]	renewable energy sources
[*Karatas et al.,* 2018]	energy technology
[*Streimikiene,* 2013a,b; *Streimikiene et al.,* 2013; *Streimikiene, Balezentiene,* 2012]	electric vehicles
[*Zheng et al.,* 2012]	green buildings
[*Peng et al.,* 2019]	restoration technology in engine remanufacturing practice
[*Aloini et al.,* 2018]	advanced underwater system
[*Büyüközkan, Güler,* 2017]	smart glass (SG)
[*Ansari et al.,* 2016; *Puthanpura et al.,* 2015]	automotive technology
[*Elahi et al.,* 2011]	ABS sensor technology
[*Govind et al.,* 2018]	treatment and disposal technology
[*Ren,* 2018]	ballast water treatment
[*Vivekh et al.,* 2017]	desalination technology
[*Kalbar et al.,* 2012; *Fu et al.,* 2012]	wastewater treatment technology
[*Jiří,* 2018; *Mobinizadeh et al.,* 2016; *Gajdoš et al.,* 2015; *Lu et al.,* 2016]	health technology
[*Lee, James Chou,* 2016]	emerging three-dimensional integrated circuit (3DIC)
[*Tavana et al.,* 2013]	advanced-technology projects at NASA
[*Oztaysi,* 2014]	information technology
[*Towhidi et al.,* 2009]	iron-making technology
[*Parkan, Wu,* 1999]	robots to perform repetitious, difficult, and hazardous tasks with precision

Source: own study.

in eight articles, and seven articles were dedicated to the area of Environmental Science. Other articles dealt with Business, Energy, Material Sciences, and Social Sciences.

The review of the publications shows that the TOPSIS method was used most frequently to select energy technologies, such as energy storage or renewable sources as well as health technology (Table 4). This method was also used to rank environmental technologies (i.e., treatment and disposal, ballast water treatment, desalination, wastewater treatment, healthcare waste treatment technologies) and automotive industry technologies (i.e., the restoration in engine remanufacturing practice, ABS sensors). It was also used for such technologies as smart glass (SG), emerging three-dimensional integrated circuit (3DIC), or iron making as well as advanced underwater systems.

This article looks into the use of the TOPSIS method to rank the following five road-pavement technologies [*Nazarko et al*., 2015; *Nazarko*, 2017; *Kikolski, Chien-Ho Ko*, 2018]: road pavement with rubber-asphalt binder (T1), pavement with porous asphalt mixture (T2), Perpetual Pavement (T3), the traditional cement concrete (T4), and pavement with elastomeric binders (T5). Literature studies and exploratory research conducted gave rise to the following research questions: (1) How does one apply the TOPSIS method to the assessment of road pavement technology? (2) What are the criteria for assessing road pavement technology? (3) How has technology been assessed against various criteria?

Table 5. **Scheme for the Operationalization of the Assessment and Selection of Road Pavement Technologies**

Research Task	Contractor	Method	Result
1. Assessment of Technology Maturity and Performance	The author, experts	Literature review, Technology Readiness Levels, life cycle analysis	Life cycle phases of technologies, levels of technological maturity
2. Identification of Technology Assessment Criteria	The author	Literature review	The criteria catalog
3. Technology Assessment	Experts	Surveys	Completed technology assessment questionnaires
4. Technology Selection	The author	TOPSIS	Ranking

Source: compiled by the author.

Research Methods

The process of road pavement technology selection was carried out in four successive stages. The operational diagram of road pavement technology selection is presented in Table 5.

Completing the first research task, the author and key field experts assessed the level of technological maturity of the prioritized road surface technologies in Poland. The model of Technology Readiness Levels (TRL) was applied for this purpose. According to the literature, this technology has a low level of technological readiness. In the case of the three levels of technological readiness, the basic principles of the analyzed technology were observed and described, the concept of the technology and/or its application was defined, and the key functions and/or the concept of the technology were confirmed analytically and experimentally. Technologies with a medium level of technological preparedness have TRL 4, 5, and 6. Technologies with a medium level of preparedness have already been tested in a near-real environment. Technologies with a high level of technological readiness have TRL 7, 8, and 9. Technologies with a low to medium level of technological readiness include fundamental research consisting of the acquisition of new knowledge of the underlying principles and observable facts, without a direct practical or industrial application focus. This is aimed at acquiring new knowledge and skills to develop new products, processes, and services or to bring a significant improvement to existing products, processes, and services. The phases of the life cycle of individual technologies are then determined. The following life phases of a technology are listed in the literature: the birth phase, which is characterized by high uncertainty, research intensity, and the reduction of investment; the development phase, which is characterized by average uncertainty, an emphasis upon applications, and high investment; the maturity phase, which is characterized by low uncertainty, cost reduction, and the reduction of investment as well as a decline in technology assessment where the technology is outdated and replaced by a new technology with a higher competitive value.

During the second task, three groups of technology assessment criteria were selected on the basis of a literature review [*Ejdys et al*, 2016, *Ejdys*, 2015]: (1) innovation, (2) competitiveness, and (3) usability. The criteria were developed in the form of questions. The author's catalogue of criteria consisted of

Table 6. **Catalogue of Technology Assessment Criteria**

Acronym	Name of the Criterion
TRL	Technology Readiness Levels
S	S-life-cycle analysis
	Innovation
I1	What is the level of technological innovation?
I2	Is the technology original according to the current state of knowledge?
I3	Is there an improvement in the technology compared to existing alternatives?
	Competitiveness
C1	Is the market position of the technology threatened by existing solutions?
C2	How will the dissemination of the technology affect the existing alternative solutions?
C3	Are the new opportunities offered by the technology compared to the alternatives relevant for road users?
C4	Is the improvement in the comfort of use compared to the alternatives to the technology relevant for road users?
C5	How many similar alternatives to technologies are available on the Polish market?
C6	What is the popularity of the alternatives to the technology?
C7	Are there entry barriers for potential competitors?
	Usability
U1	Does the technology have measurable value for users?
U2	Will potential users gain additional benefits from the use of the technology that are not available when alternatives are used?
U3	Does the technology or the product based on it offer higher user-friendliness and ease of use than the available alternatives?
U4	Is the technology or product based on it compliant with the formal requirements applicable in Poland and the European Union?
U5	Can the demand for a technology or a product based on it be related to transitional fashion?
U6	Do recent changes in the environment make the technology or a product based on it more attractive to users (for example, due to new legislation, consumer trends, or technological standards)?
U7	At what point in time may the technology or product based on it become obsolete?
U8	Will the technology solve technical problems that are perceived as important by potential customers?
U9	Are the technical benefits offered by the technology important to potential customers?
U10	Are potential customers sensitive to the possible technical problems related to the use of the technology?

Source: own study.

Table 7. **Decision Matrix**

	TRL	S	I1	I2	I3	K1	K2	K3	K4	K5	K6
T1	8	2	4	4	4	1	3	4	4	2	1
T2	8	2	4	1	4	3	3	4	4	3	1
T3	7	1	5	3	4	5	4	5	5	5	5
T4	9	3	1	1	1	1	3	3	1	2	1
T5	9	2	4	3	3	3	2	4	3	3	4
	K7	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
T1	3	5	5	3	4	4	4	5	4	4	3
T2	4	3	3	4	4	4	4	5	4	4	1
T3	3	5	5	4	5	4	4	5	5	5	4
T4	4	3	2	1	5	2	3	5	3	3	2
T5	5	4	1	1	5	5	1	5	4	4	4

Source: compiled by the author.

22 questions. Three questions concerned innovation (I1 — I3), seven questions concerned technological competitiveness (C1 — C7), and ten questions concerned technological usability (U1 — U10). The list of criteria used for the assessment of road pavement technologies is given in Table 6. The selection of road pavement technologies has not been carried out so far. This is the first (pilot) study of this type in Poland. One important goal of the study is to develop an objective ranking of road pavement technologies. It was imperative that the position of a given technology in the ranking should be determined only by the properties of a given technology in the context of a given criterion. Therefore, decision-makers were not consulted regarding the importance of the assessment criteria for these technologies. Also, a conscious decision was made not to assign weights to the criteria based on the opinion of the experts or decision-makers. Rather, the weights of the criteria were developed using the entropy method. The entropy method makes it possible to estimate the importance of analyzed criteria describing the considered solution options based on each of their value discrepancies [*Lotfi, Fallahnejad*, 2010; *Kacprzak,* 2017].

Next, experts evaluated the assessment of the analyzed technology using the 5-point Likert scale, where 1 was the lowest score and 5 was the highest score. Each expert assessed one technology. The experts were selected purposively, considering their knowledge and experience in the field of road surface technology in Poland. Employees of the Warsaw University of Technology participating in the Team of Materials and Road Surfaces Technology were invited to be the experts. Then, during the fourth task, using the TOPSIS method, a ranking of road pavement technologies was developed.

Research Results

The TOPSIS technology ranking [*Hwang, Yoon,* 1981] was achieved in seven consecutive steps, as shown below.

Step 1. Initially, there was a set of criteria consisting of 24 elements:

$$\{C_j, j = 1, \ldots n\} \quad (1)$$

The first criterion was the TRL, followed by life-cycle phases of technologies, three further criteria for technology innovation, seven more for competitiveness, and ten more for usability. The TRL could range from 1 to 9, life-cycle phases of technologies — from 1 to 4, and the remaining criteria — from 1 to 5.

Step 2. Then, based on the assessment of technology by experts in terms of the subsequent criteria, a decision matrix was developed (Table 7):

$$X = (x_{ij}), \quad (2)$$

where $x_{ij} \in R$

$$X = \begin{bmatrix} x_{11} & \ldots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \ldots & x_{mn} \end{bmatrix}, i = 1, \ldots m; j = 1, \ldots n \quad (3)$$

The analysis of Table 7 shows that T1 technology had a TRL of 8 and the second life-cycle phases of the technology. The T1 technology was assessed by an expert as regards the criterion I1 at the level 4, as well as the criterion K1 – 1 and the criterion U1 – 5 (on a scale from 1 to 5). The T4 technology, on the other hand, was assessed in terms of criteria I1 and K1 at level 1, while also evaluated in terms of the criterion U1 at level 3.

Step 3. A normalized (vector-based) decision matrix (Table 8) was then developed:

$$R = (r_{ij}), \quad (4)$$

$$R = \begin{bmatrix} r_{11} & \ldots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \ldots & r_{mn} \end{bmatrix}, \quad (5)$$

where

$$r = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (6)$$

Step 4. The next step was to determine the criterion weight vector (Table 9). For this purpose, the entropy method was used [*Kacprzak*, 2017; *Rudnik, Kacprzak,* 2017]:

$$E = (e_1, e_2, \ldots e_n), \quad (7)$$

where E — an entropy vector,

and

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} z_{ij} \ln z_{ij}, \quad (8)$$

and

$$z_{ij} \ln z_{ij} = 0, \text{ where } z_{ij} = 0, \quad 9)$$

with a vector of criteria weights:

$$w = (w_1, w_2, \ldots, w_n), \quad (10)$$

Table 8. **Normalized Decision Matrix**

	TRL	S	I1	I2	I3	K1	K2	K3	K4	K5	K6
T1	0.435	0.426	0.465	0.667	0.525	0.149	0.438	0.442	0.489	0.280	0.151
T2	0.435	0.426	0.465	0.167	0.525	0.447	0.438	0.442	0.489	0.420	0.151
T3	0.380	0.213	0.581	0.500	0.525	0.745	0.583	0.552	0.611	0.700	0.754
T4	0.489	0.640	0.116	0.167	0.131	0.149	0.438	0.331	0.122	0.280	0.151
T5	0.489	0.426	0.465	0.500	0.394	0.447	0.292	0.442	0.367	0.420	0.603
	K7	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
T1	0.346	0.546	0.625	0.457	0.387	0.456	0.525	0.447	0.442	0.442	0.442
T2	0.462	0.327	0.375	0.610	0.387	0.456	0.525	0.447	0.442	0.442	0.147
T3	0.346	0.546	0.625	0.610	0.483	0.456	0.525	0.447	0.552	0.552	0.590
T4	0.462	0.327	0.250	0.152	0.483	0.228	0.394	0.447	0.331	0.331	0.295
T5	0.577	0.436	0.125	0.152	0.483	0.570	0.131	0.447	0.442	0.442	0.590

Source: compiled by the author.

$$w_j \in [0, 1], \sum_{j=1}^{n} w_j = 1, \quad (11)$$

where w_j — the criterion weight. If all the criteria were equally valid, the weights were calculated according to the formula:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (12)$$

$$d_j = 1 - e_j \quad (13)$$

Aiming to determine entropy, the decision matrix should be normalized:

$$Z = (z_{ij}), \quad (14)$$

$$Z = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix}, \quad (15)$$

where

$$z = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (16)$$

All the weight factors are presented in Table 9.

Table 9 shows the most important criteria: K6 (w=0.164), K1 (w=0.109), and U3 (w=0.097). The least important criteria were U7 (w=0.000), TRL (w=0.003), and U4 (w=0.004).

Weight factors were determined and the weighted normalized decision matrix (Table 10) was developed:

$$V = (v_{ij}), \quad (17)$$

where

$$v_{ij} = r_{ij} w_j \quad (18)$$

Step 5. The next step involved the recognition of the positive-ideal solution A^+ and the negative-ideal solution A^- [*Kacprzak,* 2019].

$$A^+ = [v_1^+, v_2^+, ..., v_n]^+ = [\max v_{i1} \max v_{i2} ... \max v_{i3}] \quad (19)$$

$$A^- = [v_1^-, v_2^-, ..., v_n]^- = [\min_i v_{i1} \min_i v_{i2} ... \min_i v_{i3}] \quad (20)$$

After selecting the distance measure, the separation measures s_j^+ and s_j^- of each alternative were calculated from the intuitionistic fuzzy positive-ideal and the negative-ideal solutions. This paper used the normalized Euclidean distance:

$$s_j^+ = \sqrt{\sum_{j=1}^{n} (v_i^+ - v_{ij})^2}, \quad (21)$$

$$s_j^- = \sqrt{\sum_{j=1}^{n} (v_i^- - v_{ij})^2}, \quad (22)$$

Step 6. Then, the relative closeness coefficient is calculated. The relative closeness coefficient of an alternative A_i with respect to the positive-ideal solution A^+ is defined as follows:

$$C_i = \frac{s_j^-}{s_j^+ + s_j^-}, \quad (23)$$

where $0 \le C_i \le 1$.

Table 9. **Weights of the Evaluation Criteria**

	TRL	S	I1	I2	I3	K1	K2	K3	K4	K5	K6
e	0.997	0.967	0.944	0.916	0.949	0.894	0.986	0.992	0.940	0.961	0.840
d	0.003	0.033	0.056	0.084	0.051	0.106	0.014	0.008	0.060	0.039	0.160
w	0.003	0.033	0.058	0.087	0.053	0.109	0.014	0.008	0.061	0.040	0.164
	K7	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
e	0.988	0.984	0.916	0.906	0.996	0.977	0.949	1.000	0.992	0.992	0.940
d	0.012	0.016	0.084	0.094	0.004	0.023	0.051	0.000	0.008	0.008	0.060
w	0.012	0.016	0.087	0.097	0.004	0.024	0.053	0.000	0.008	0.008	0.062

Source: compiled by the author.

Table 10. **Weighted Normalized Decision Matrix**

	TRL	S	I1	I2	I3	K1	K2	K3	K4	K5	K6
T1	0.001	0.014	0.027	0.058	0.028	0.016	0.006	0.004	0.030	0.011	0.001
T2	0.001	0.014	0.027	0.014	0.028	0.049	0.006	0.004	0.030	0.017	0.001
T3	0.001	0.007	0.034	0.043	0.028	0.081	0.008	0.004	0.037	0.028	0.001
T4	0.001	0.021	0.007	0.014	0.007	0.016	0.006	0.003	0.007	0.011	0.001
T5	0.001	0.014	0.027	0.043	0.021	0.049	0.004	0.004	0.022	0.017	0.001
	K7	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
T1	0.025	0.004	0.009	0.054	0.044	0.001	0.011	0.028	0.000	0.004	0.004
T2	0.025	0.006	0.005	0.032	0.059	0.001	0.011	0.028	0.000	0.004	0.004
T3	0.124	0.004	0.009	0.054	0.059	0.002	0.011	0.028	0.000	0.004	0.004
T4	0.025	0.006	0.005	0.022	0.015	0.002	0.005	0.021	0.000	0.003	0.003
T5	0.099	0.007	0.007	0.011	0.015	0.002	0.013	0.007	0.000	0.004	0.004

Source: compiled by the author.

C_i measures the effectiveness of each alternative. The best alternative and the order of the alternatives are obtained according to this measure.

Step 7. Once the relative closeness coefficient of each alternative is determined, alternatives are ranked in the descending order of C_i [*BoranGenç et al.*, 2009; *Yue*, 2014].

As a result (Table 11), the Perpetual Pavement (T3) was found to be the most desirable product among these alternatives, overtaking its nearest competitor, pavement with elastomeric binders (T5). Rubber-asphalt binder (T1) ranked third, followed by the pavement with porous asphalt mixture (T2), leaving the traditional cement concrete (T4) last.

Conclusion

The paper presents a proposal to apply the TOPSIS method to the assessment and selection of road pavement technologies, such as road pavement with rubber-asphalt binder (T1), pavement with a porous asphalt mixture (T2), the Perpetual Pavement (T3), the traditional cement concrete (T4), and pavement with elastomeric binders (T5). Initially, based on the literature, the maturity and efficiency of the five road technologies were evaluated. Then, technology selection criteria were identified for the assessment of innovation, competitiveness, and usefulness. Experts evaluated the technology considering the level of maturity and efficiency of the technology and the 22 criteria identified on the basis of the literature. The TOPSIS method was followed by a ranking of the best road pavement technologies. T3 — the Perpetual Pavement was the best of the assessed technologies. T4 — the traditional cement concrete technology was ranked last.

Table 11. **Relative Closeness and the Preferential Ranking of Alternative Options**

Road Pavement Technology	s_j^+	s_j^-	C_i	Rank
T1	0.121653105	0.082644528	**0.40453**	**3**
T2	0.119536825	0.073261956	**0.37999**	**4**
T3	0.020692762	0.149284031	**0.87826**	**1**
T4	0.147440469	0.024541157	**0.14270**	**5**
T5	0.081536767	0.095672852	**0.53989**	**2**

Source: compiled by the author.

The conducted research found answers to the following research questions: (1) How does one apply the TOPSIS method to the assessment of road pavement technology? (2) What are the criteria for assessing road pavement technology? (3) How has the technology been assessed against various criteria?

It can also be argued that the present method of decision making can also be used effectively in a more complex analysis.

In future studies, when constructing the ranking, the opinions of decision-makers regarding the substance of the criteria will be considered. It is also planned to extend the study to other European countries and compare road pavement technology rankings in different countries. It is also planned to expand the catalogue of criteria and develop rankings using other methods.

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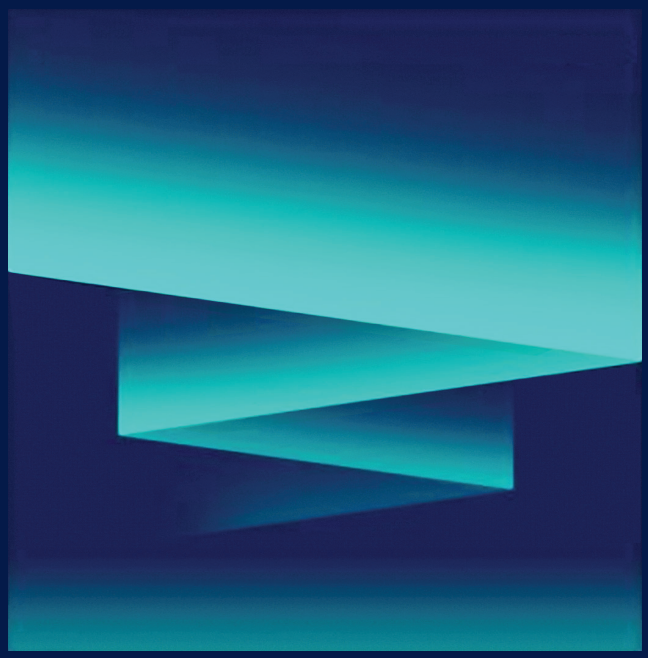

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