Information Systems in a Future of Decreased and Redistributed Global Growth

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ABSTRACT

Information systems cycles of innovation rely on global economic growth. However, a 2015 study in *Nature* predicted that climate change will dramatically slow and redistribute growth in the coming decades. This paper explores how decreased and redistributed growth may impact future information systems and digital innovation. While a long-term global slowdown is not certain, different countries will likely experience significant changes in their growth trajectories, and resulting civilizational transformations. We seek to establish quantitative and theoretical foundations for how a future characterized by climate change would impact information systems around the globe.

CCS CONCEPTS

• **Social and professional topics → Professional topics →** Computing industry • **Social and professional topics → Professional topics →** Computing industry → Sustainability

KEYWORDS

Sustainability, Climate change, Innovation, Degrowth, Diffusion of innovations, Resilience, Adaptation, Implications for design, Economic growth

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1 INTRODUCTION

Economic growth and technological innovation have been hallmarks of industrial civilization for many decades [[49]]. The spread of computer-based information systems over the past half-century has both contributed to and relied on global economic growth [[9], [14], [28], [32], [55], [65]]. But if global growth slows or even reverses, what are the implications for the future of information systems? A 2015 analysis in *Nature* by Burke et al. [[11]] has projected that climate change is likely to dramatically slow the global economic growth rate in coming decades, and change the distribution of growth among countries. Growth over the past 50 years has fostered the information systems that run industrialized civilizations: everything from computationally-managed global supply chains to the World Wide Web. How will the economic effects of climate change impact the future of information systems and digital innovation more broadly?

In this paper, we engage in quantitative analyses to project the effects of climate-change-adjusted economic futures on information systems across different countries. We examine the potential implications of long-term reduced or negative growth for information systems design. We also discuss the theory of frugal innovation as it relates to these implications, and offer a theory of the *retreat of innovations* to accompany the findings from our quantitative analyses.

While the global economic downturn predicted by Burke et al. [[11]] is not a certainty, the possibility that many decades of relatively continuous growth may now be beginning to wane merits further attention. Predicting the exact nature of the information systems in use decades in the future is well beyond the scope of this work; however, predicting the processes that will affect the global distribution of information systems is potentially attainable.

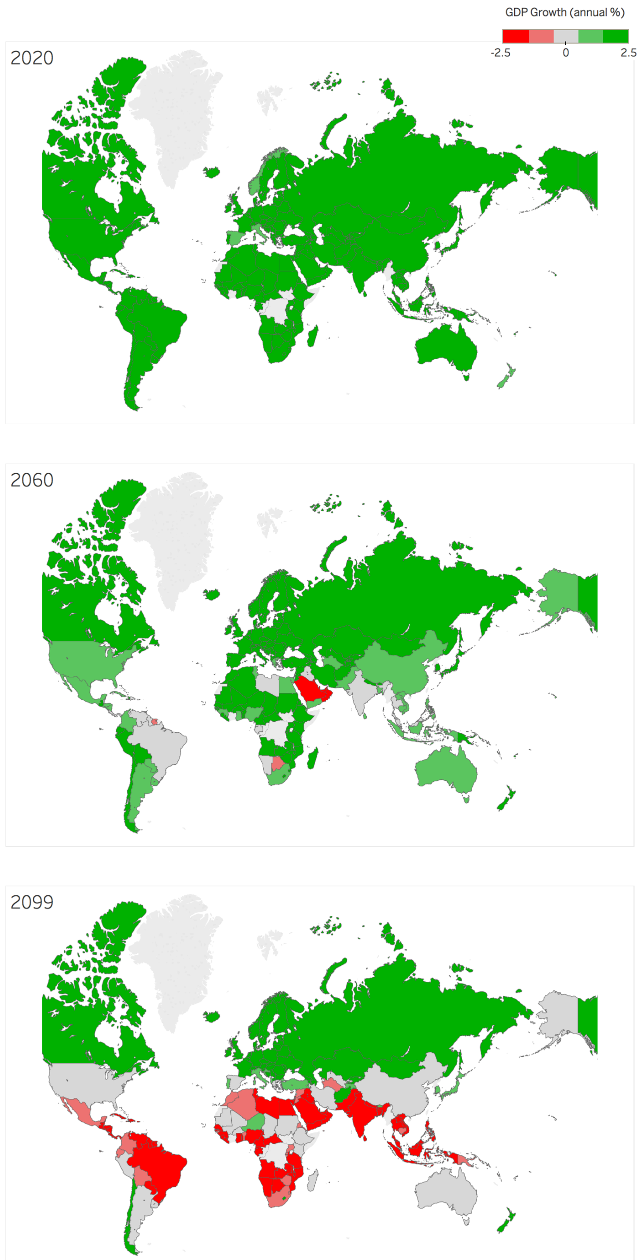

Figure 1: World maps in the years 2020, 2060, and 2099, with countries colored by economic growth rate. Many countries near the equator will be experiencing substantial negative growth by 2099. Adapted from data in Burke et al. [11]. The original figures included a chart of "Country-level income projections with and without temperature effects of climate change" and a map of "Change in GDP per capita (RCP8.5, SSP5) relative to projection using constant 1980–2010 average temperatures" Burke et al. [[11]]. The maps above merge these two phenomena, so that the effects on particular countries and regions over time are visible, and also show projected absolute growth rates in a world with climate change, rather than growth rates relative to a world without climate change.

2 PREDICTED FUTURE OF GLOBAL GROWTH

In their 2015 Nature paper [[11]], Burke et al. analyze the relationship between temperature and economic activity. Their analysis suggests that an average annual temperature of 13°C leads to peak productivity, with productivity falling off slowly below that temperature and strongly above it. Based on their analysis, if adaptation efforts in the future are similar to adaptation efforts to date, average global incomes in 2100 will be 23% lower than they would have been without climate change. By the end of the century, 77% of countries will have their per capita income reduced compared to levels in a future without climate change.

Working from their data, we performed several additional analyses. We found that 104 of the 165 countries in their replication dataset are projected to be experience negative annual growth by 2099. Just 19 countries are projected to be growing faster in 2099 than they are in 2017. Figure 1 presents world maps colored by GDP growth rate in 2020, 2060, and 2099. By 2099, 113 countries are projected be below +0.5% annual growth (gray, pink, and red), and 65 will be contracting at a rate of 1.5%/year or greater (red).

Burke et al. discuss "widening global inequality" in the futures they project. Their data show many countries near the equator, which already tend to be poorer than countries farther from the equator, become poorer still in futures characterized by climate change. While some countries and regions in colder areas (Canada, Northern Europe, Russia) are projected to thrive throughout this time, many countries in Africa, South and Southeast Asia, and Central and South America are projected to fare poorly in the remainder of the 21st century.

The redistribution of growth across nations represented in these data would lead to substantial civilization-scale transformations. Disconcertingly, Burke et al. also note that "substantial observed warming over the period [from 1960 to 2010] apparently did not induce notable adaptation." Essentially, despite human civilizations having had half a century to address climate change, we haven't made much progress on that front.

3 IMPACT ON INFORMATION SYSTEMS

In this section we seek to understand some of the potential impacts that reduced and redistributed global growth could have on the flows of ICT goods and services among countries. Economic growth has been coupled to the rapid spread of computer-based information systems around the globe, with growth funding broad-scale information systems research and adoption [[32]], and information systems supporting growth across many sectors and countries [[9], [14], [28], [55], [65]]. If this growth is transformed, how will it impact the production and consumption of information systems?

3.1 Present and future global ICT goods exporting

We first set out to establish which countries currently dominate ICT goods exports, to serve as a baseline for a comparison to the potential future projected by Burke et al. [[11]]. We focused on the exporting of ICT goods as an important factor in how climate change effects in one country could affect ICT activity around the world. For example, if a key provider of ICT goods on the international market were to falter, countries that rely on that provider could suffer significant effects as well. Examining the exporting of ICT goods enables us to explore global factors more effectively than ICT sales or use.

Based on World Bank data [[69], [70]], the top five countries exporting ICT goods include: China ($580B in ICT exports1), the US ($150B), the Republic of Korea (South Korea) ($120B), Germany ($67B), and Mexico ($63B).

We then sought to examine which countries would dominate ICT exporting by the end of this century, if the climate changes discussed by Burke et al. come to pass. Since the nature of ICT goods exporting is complex, involving numerous geopolitical, economic, environmental, and cultural factors, projecting the future of this sector is complex as well. To provide an initial approximation in this arena, we integrated the World Bank statistics used above [[69], [70]] with GDP projections from Burke et al. [[11]] to examine which countries would be in the top five in 2099. In these calculations, we held constant all of the following: a) the percentage of ICT exports, b) the ratio between GDP and total exports, and c) population. Based on these calculations, the top five countries for ICT goods exports in 2099 would be China ($4.4T), South Korea ($730B), Germany ($500B), the Netherlands ($350B), and the US ($340B). Mexico is projected to fall to 8th ($190B).

We recognize that the factors that we held constant will not, in fact, remain constant; future work will involve engaging with each of these domains to improve the accuracy of the projections. In addition, significant geopolitical events such as wars or other transformations (e.g., Brexit) will be impossible to predict, and therefore any projections are at best approximate. For example, it is unclear what role China is likely to be able to play in ICT exporting, since it is both projected to show large gains relative to the rest of the world in terms of absolute GDP over the period from 2015 to 2099, but also projected to have fallen into negative growth after 2096.

Another factor that is difficult to anticipate but could accelerate the decline in ICT production is the ability of firms located in negatively impacted countries to sustain their research and development expenditures associated with the ICT sector. Research has shown that R&D expenditures were procyclical [[21], [51]]. Firms have reduced cash flow during recessions and it limits their ability to invest in R&D [[21]]. If the large ICT producers in the countries negatively impacted lower their investments in innovation, it will have an impact on global ICT production. Specific effects will in part depend on the level of diversification of firms, and on their interconnectedness with their innovation ecosystems [[19], [41]].

USA and China, currently the most dominant economies in the world [[46], [55]], are expected to be among the ones negatively affected in the long term by the effects of global warming. They are also the two largest exporters of ICT goods. This could have ripple effects on other economies. If the intensity of innovation in these two countries decreased, impact could be significant.

3.2 Present and future global ICT service exporting

We also calculated the current total amount of ICT service exported by each country. Based on World Bank data [[72], [73]], the top five countries exporting ICT service in 2014 include: the US ($160B), the UK ($130B), Germany ($110B), France ($110B), and India ($100B).

Conducting a similar calculation as with ICT goods above, integrating the World Bank data with Burke et al.'s projections, the top five countries for ICT service exports in 2099 would be the Russian Federation ($900B), the UK ($890B), Germany ($860B), China ($670B), and France ($590B). The US is projected to have fallen to 9th ($380B), and India to 14th ($260B).

We recognize that numerous factors not considered here will influence the realities that will unfold over the coming decades. For example, the Netherlands, projected to be the fourth greatest exporter of ICT goods by 2099, is also quite vulnerable to sea level rise [[31]]; for many low-lying countries, the effects of sea level rise could dwarf those of temperature changes, on which Burke et al. [[11]] based their analyses. Nevertheless, the analyses described above point to non-trivial shifts in the countries that may provide ICT goods and service at a global scale across the remainder of the 21st century.

3.3 Impact on countries reliant on ICT goods exporting

We also sought to examine which countries are most heavily invested in ICT goods exporting, and what effects the redistribution of global growth would have on those nations. To do so, we integrated data from Burke et al. [[11]] with data from the World Bank on ICT goods imports [[71]] and exports [[70]]2. We examined the 108 countries that were present in all three datasets for the year 2014.

[1] All values in current US$. Hong Kong ($240B) and Singapore ($130B) would be in this list as well, but since they are not included in Burke et al.'s analysis through 2099, they are omitted here.

[2] We focused here just on imports and exports, rather than ICT innovation, actual usage levels or other aspects of the ICT lifecycle. As will the analysis in Section 3.1, the goal was to understand the global trade in ICT goods, for which importing and exporting are key. In future work, we will seek to address additional aspects of ICT research, development, distribution, and use.

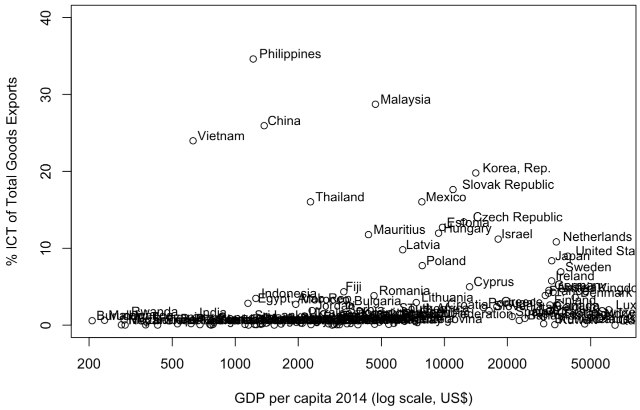

Figure 2: The percentage of total goods exports that is ICT exports vs. GDP per capita. While there are several low-GDP countries that are heavily invested in ICT exporting (e.g., Vietnam, Philippines, China), most low-GDP countries export very little ICT. Higher GDP countries are much more likely to export ICT goods.

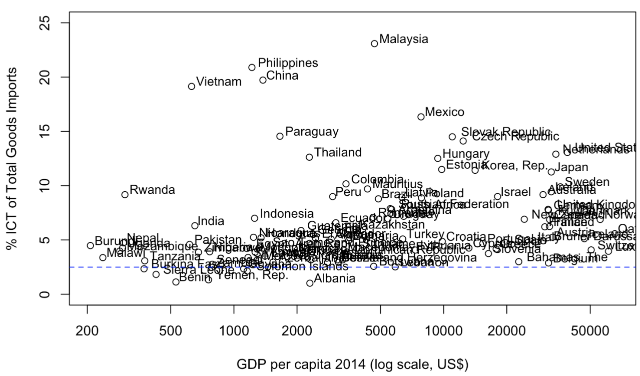

Figure 3: The percentage of total goods imports that is ICT imports vs. GDP per capita. All of the top 60% of countries have at least 2.5% ICT among their goods imports (blue dotted line).

Figure 2, which plots ICT goods exports vs. GDP per capita, shows that there is a wider spread among poorer nations for ICT exporting, with several countries in the lower range of GDP having ICT make up more than 25% of their total goods exports, while many poor countries export nearly no ICT goods. A larger number of rich countries, however, export 5-20% of their total goods exports in ICT goods. The bottom 15 countries are all well below 2% ICT goods export. Only 4/57 countries in the bottom half of GDP per capita export more than 5% ICT goods vs. 14/57 in the top half. The average export rate of the bottom half is 2.3%, whereas the average export rate of the top half is 4.7%. (Note: these figures are all straight averages across countries, rather than weighted by population. In terms of population, China, with 18% of the world's population, is in the bottom half of GDP per capita and exports 25.9% ICT goods, which represents a very large amount of global ICT exports.)

Looking across the economic futures projected by Burke et al., some interesting themes emerge. Four countries[3] exported more than 20% ICT goods in 2014—Vietnam, China, Malaysia, and the Philippines. In 2014, Vietnam was 132nd in GDP per capita out of 165 countries; China was 103rd; Malaysia was 58th; and the Philippines was 112th. By 2099, Vietnam is projected to fall 30 spots to 162nd; China will gain 13 spots to 90th; Malaysia will fall 61 spots to 119th; the Philippines will fall 14 spots to 126th. All four of these countries are projected to be experiencing negative growth (that is, falling GDP per capita) by 2099. Vietnam's growth rate peaks at 6.3% in 2015, and turns negative in 2067. Malaysia peaks at 3.6% in 2025 and turns negative in 2059. The Philippines peaks at 5.0% in 2030, and turns negative in 2075. China's growth rate is 8.4% in 2011 (the first year of their study), and decreases every year thereafter, finally turning negative in 2096.

These data point to the likelihood that ICT goods will play a reduced role in Southeast Asian economies by the end of this century. Vietnam, in particular, will be the country with the fourth lowest GDP per capita among the countries studied, and may no longer be able to support a high level of international trade.

So what countries or regions, if any, will see their role in ICT exporting increase? To explore this question, we looked for countries that have an established ICT exporting capability in the present, as well as strong economic prospects in the future.

The following countries exported at least 5% ICT goods in 2015 [[70]] (and thus have a clear engagement with this sector at present), and are projected to be in the top 25 countries by GDP growth rate in 2099 [[11]]: Slovakia (14.5% ICT goods exports in 2015, 3.0% GDP growth in 2099), Estonia (12.7% ICT goods exports in 2015, 4.4% GDP growth in 2099); Latvia (9.8% ICT goods exports in 2015, 3.8% GDP growth in 2099); Czech Republic (13.4% ICT goods exports in 2015, 3.1% GDP growth in 2099); Poland (7.7% ICT goods exports in 2015, 2.9% GDP growth in 2099); Ireland (5.7% ICT goods exports in 2015, 2.6% GDP growth in 2099); Sweden, (6.9% ICT goods exports in 2015, 4.0% GDP growth in 2099).

To summarize: Northern and Eastern Europe are well positioned to grow in future ICT goods exporting, as South and Southeast Asian economies see their role reduced substantially from changing climates.

It is worth noting again that these analyses are based only on the temperature effects of climate change. Other aspects of climate change, such as sea level rise, will also be key in transforming the ICT landscape. We have already seen the significant effects that flooding can have on the exportation of ICT goods in the 2011 hard drive crisis caused by flooding in Thailand [[18]]. Additionally, many raw materials on which ICT production often depends come from regions slated to suffer the worst effects of climate change (e.g., coltan from the Congo

[3] Andorra, Hong Kong, and Singapore all exported more than 20% as well according to the World Bank data, but since they are not included in the Burke et al. data, they are omitted from this analysis.

[[16]]). These additional effects of climate change are also likely to contribute to substantial shifts in the global ICT industry.

There are numerous reasons why the projections above may be invalidated in the coming decades. The entire premise of ICT goods may have changed so dramatically (e.g., via 3D printing [[39]]) as to render imports and exports of "ICT goods" (rather than, for example, raw materials) irrelevant. The fall-off of Moore's Law (supported by Gordon Moore's 2015 assertion that "I guess I see Moore's Law dying … in the next decade or so." [[56]]) could restructure the economic landscape of ICT. Similarly, there may be complex issues relating to the growth in data traffic [[22]] that impact demand for both ICT goods and services. Alternately, the indirect global effects of climate change could be so dramatic (e.g., wars, famines) that significant reductions in sociotechnical complexity [[59]] may have led to a great degree of deglobalization. Even if the concept of ICT goods is still relevant, and global trade still occurs, many regions of the world may be transformed by accompanying environmental issues (sea level rise, etc.) to such an extent that the effects discussed here may be dwarfed. Nevertheless, seeking to understand the effects of climate change is an important step in allow us to begin to grapple with those effects more effectively.

IMPLICATIONS FOR DESIGN

The overall reduction in global growth is likely to have overarching effects on ICT, and to have implications for the design of those systems. This section builds on previous work in design fiction and related topics [[45], [47], [66]], and on the role of limits explicitly in this domain [[4], [26], [53], [58]].

The question of what regions will lead future development and production of ICT goods may have far-reaching implications for the design of information systems that rely on those goods. The cultures that produce technology have significant impacts on the nature of that technology. While cultures are able to shift dramatically over a period of decades, cultures also have characteristics that persist across decades as well. Therefore, attributes of particular cultures in the present may offer some insight into those cultures in the future.

The prospect of profoundly reduced economic growth carries with it reduced innovation, so the rate of change in ICT systems, which has been a key element of this industry for the past two decades, may begin to slow, perhaps even reaching "peak ICT" [[63]]. Innovation (including ICT innovation) relies on energy surpluses [[59], [62]]. In the absence of economic growth and energy surpluses, innovation quickly dries up.

Reduced research and development funding and a slower production cycle than the rapid innovation and obsolescence of current ICT systems could create a context in which a focus on system longevity would be beneficial. This projection would be in line with Blevis's premise of "heirloom status" for technology [[7]].

Designs that are viable on a broader range of hardware and software4 configurations could also be favored. The design of software systems for recycled and repurposed hardware platforms could be of growing significance, as countries that previously had high levels of ICT penetration fall into negative growth. Without the economic capacity to fund internal research and development, or to purchase ICT from other countries, societies could benefit from systems design that embraced legacy components and platforms. Such an approach could actually lead to an increase in software innovation to compensate for a more stable hardware infrastructure.

The refactoring of society [[52]] and the "implication not to design" [[5]] are also deeply relevant to futures that may be characterized by a lack of reliable ICT presence. Rather than seeking to apply ICT in an ever-widening array of contexts, the possibility exists that "undesign" [[48]] and/or self-obviating systems [[61]] could be preferable to the forms of ICT innovation (with rapid cycles of innovation and obsolescence) that prevail in 2017.

THE FUTURE OF INNOVATIONS

Beyond its implications for the ICT industry, the dramatic decrease in GDP growth predicted by Burke et al. [[11]] in the remainder of the 21st century could also have significant implications for innovation more broadly.

Existing work has studied why certain aspects of information systems rely on positive growth (e.g. research funding [[32]]) and why others cause positive growth (e.g., ICT investment [[14], [28], [55], [65]]). However, aside from a number of analyses of the global financial crisis [[1], [33], [44]] and other short-term recessions and "shocks" [[19], [25], [35], [37]], little work has focused on the role of long-term decreasing and negative growth on innovation and information systems.

This suggests that it may be time to take a different perspective when studying innovation. Challenging two traditional underlying assumptions of innovation research opens new research streams. First, most research on innovation has been conducted in a resource-rich environment [[50]]. If this environment shifts and becomes resource-constrained, innovation will need to become more frugal. Second, a commonly discussed theory of how innovations spread through networks of users, firms, and other institutions is the theory of the diffusion of innovations [[17], [51], [67]]. This theory explains how new ideas are communicated among different stakeholders. In a situation of decline, the idea that innovation follows a strictly positive adoption progression must be revisited. Actors will likely shed innovations when resources become more limited. We propose that there is a need for new streams of research, and a departure from traditional theory. These two streams are discussed in sub-sections 5.1 and 5.2 respectively.

[4] The question of whether "hardware" and "software" will be a meaningful distinction in the next 80 years does arise.

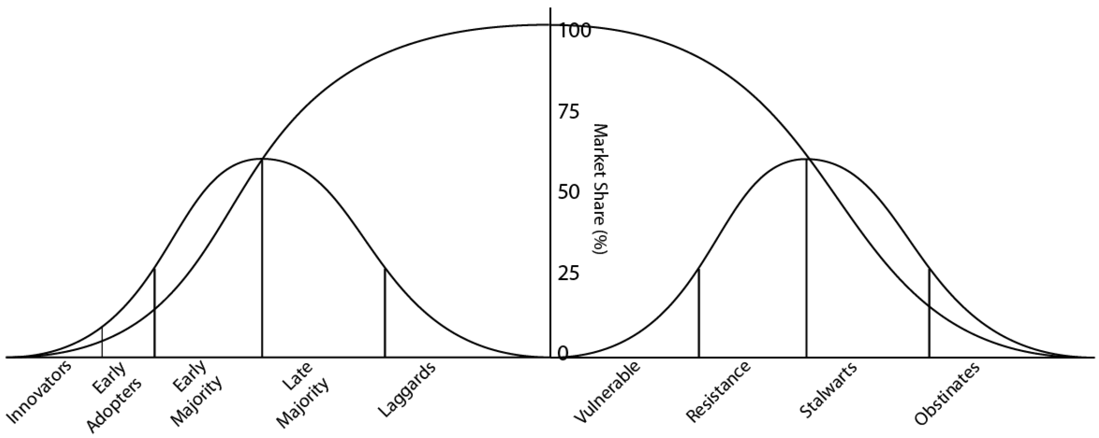

Figure 1: An extension of Rogers' diffusion of innovation (modeled after [[27], [54]]), adding the retreat of innovation. The right half of the chart shows the relationship between types of abandoners and their location on the anti-adoption curve.

5.1 Frugal innovation

First, in a world where growth may slow down and innovations may not be introduced at the same pace as before, it is important to better understand the last phase of diffusion innovation. Frugal innovation offers a response to resource constrained situations and describes low-cost innovation, which are usually seen as the tail-end of the diffusion of innovation cycle [[2]].

Negative growth may be a trigger for a major shift toward frugal innovation in the ICT sector. Frugal innovation is seen as a response to the sustainability challenge [[3]]. It consists in a form of improvisation, using the limited resources available at hand to provide low-cost and basic solutions [[75]]. It often relies on low cost solutions made available after the mass diffusion of an innovation, reusing existing tools to address needs that were not served before [[2]]. It is much closer to reorganization than pure invention.

A rise in frugal innovation is not independent from the geographical dispersion of innovation. Frugal innovation is associated with a decentralization of the innovation process. It is usually done through homegrown solutions for local problems [[75]]. If frugal innovation becomes more prevalent in the ICT sector, it could lead to a decentralization of the ICT industry. Frugal approaches rely on smaller bricolage centers, not on central well-funded research hubs [[23]].

5.2 The retreat of innovation

We also explore a theory that is complementary to Rogers' diffusion of innovations [[54]], but that explains how ideas fall out of usage. This theory explains the retreat of innovations5. Cameron Leckie has previously discussed the abandonment of technology [[34]], dividing the abandonment process into four stages: early abandonment, economic abandonment, systemic abandonment, and die hard abandonment. The parallel to Rogers' work was noted by a commenter on Leckie's original post. Here, we examine the relationship between the diffusion and retreat processes.

The key elements in the diffusion of innovations are the innovation itself, one or more communication channels, a social system across which the innovation may diffuse, and the passage of time. The key elements in the retreat of innovations are the innovation in use, the forces working toward abandonment (e.g., expense, failure to keep a critical mass of users), the social system across within which the innovation gradually retreats, and the passage of time.

The diffusion of innovations theory breaks stakeholders into "innovators", "early adopters", "early majority", "late majority", and "laggards"; we propose that the retreat of innovations would extend this structure (see Figure 4). Stakeholders that most quickly abandon an innovation are the "vulnerable", those without the resources or motivation to continue with a particular innovation. This group is followed by the "resistance" who are better positioned to continue to engage with the innovation, despite shrinking budgets or shifting priorities. The next group could be called the "stalwarts", who persist in using even as shrinking market share for a particular innovation renders it less useful (for example, due to decreased network effects, fewer potential employees with relevant skills, etc.). Finally, the "obstinates" continue using the innovation well past the point where most others have abandoned it, either out of an abundance of resources, force of habit, or some other suboptimal behavioral pattern.

While the diffusion of innovations accelerates when an innovation achieves "critical mass", in the retreat of innovations, the converse effect—in which the rate of abandonment of an innovation accelerates once a certain number of stakeholders have abandoned it— would be expected to be less pronounced. While adoption of an innovation carries with it previously-unknown benefits, the abandonment of an innovation is accompanied by known costs. Therefore, the process of abandonment is made under a condition of more consistent

[5] This theory complements the "diffusion of unsuccessful innovation" discussed in another paper in this workshop [[40]].

information than in the process of adoption, when the stakeholder first discovers the innovation.

Innovations with network effects [[30]], however, would be expected to be more symmetrical, with accelerating positive effects as the number of users increased, and accelerating falloff of those effects as the number of users decreased.

FUTURE WORK

In our future work, we will engage in further quantitative analyses to examine the effects of climate change on information systems used at the firm level [[13]] across different countries. Specifically, the dependent variable for the study will be the expected level of digitization (that is, investment in information technology) within firms. We will integrate data from Burke et al. [[11]] with current data on IT investment, e.g., [[10], [15], [41], [43], [70], [71], [72], [74]], to generate a set of potential trajectories for firm-level IT investment across different countries between 2017 and 2099. We will also examine the difference between flows of ICT goods and ICT services in these contexts. Each type of flow (goods or services) follows a different logic [[35], [36]] and will be modelled separately to understand the global effect. Throughout these analyses, we will engage with questions of changes in the percentage of ICT exports, the ratio between GDP and total exports, and the populations of various countries.

We will also expand our examination of the potential implications of long-term reduced or negative growth for information systems design. We will examine current uses of information systems in low income countries [[8], [64], [68]], short-term impacts of the 2007-08 global financial crisis on information systems in high income countries [[44]], as well as broader sustainability [[6], [59]] and de-growth [[21], [29], [38]] literatures to seek to extrapolate potential design implications of long-term reduced growth.

CONCLUSION

Climate change is profoundly consequential for the future of human civilizations. From sea level rise to shifting growing seasons to the numerous other human effects of increase temperature [[12]], a changing climate will transform the world around us. This paper has sought to explore one particular aspect of this transformation—the indirect effects of climate change on the future of information systems. Information systems coordinate and control a very large amount of human activity in the industrialized world; transformations in this industry will have far-reaching consequences. While this paper has just begun to touch on what these consequences may be, we hope that it will provide a starting point for broader discussions of how planetary limits will impact the information systems industry.

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