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The socio-economic change and technology diffusion and competition: Population dynamics of the voice communication technologies in the Czech and Slovak Republics in 1948-2009¹

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Abstract

The paper applies concepts of population dynamics to the evolution of communication technologies. The dynamics of voice communication technologies in the Czech and Slovak Republics in 1948-2009 are examined via the Lotka-Volterra equations. Fixed lines and mobile phones are considered predatory technologies hunting for their 'prey' – voice service subscribers. Each technology squeezes out carrying capacity from its competitor. Mobile phones, however, exert a far greater impact on numbers of fixed telephone lines than vice versa. The conclusions consider some limitations of population dynamics approaches in economic modelling and discuss the different growth strategies associated with particular types of technologies.

Keywords: Technology change; Population dynamics; Lotka-Volterra models; Communication technologies; Social and economic change

1. INTRODUCTION

Population dynamics observed in biological systems proved to be a fruitful inspiration for modelling processes of social, economic and technology change. Concepts of variety generation, selection, compartmentalisation, and preservation and reproduction within a specific market niche were adopted and exploited by several science fields, including organisational ecology [1]. There have been numerous studies of population dynamics in organisational ecology, which covered an impressive range of organisational types, e.g.

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breweries [2], car producers [3], [4], health care organisations [5], day care facilities [6], trade unions [7], newspapers [8], financial institutions [9]. Interest also was paid to processes and institutions with disperse character, e.g. technologies and/or some socio-economic concepts. Some recent examples include works by Andersen [10] on the development of European railways, Cappello and Faggian [11] on growth by Italian cities, Chen and Watanabe on the dynamics of Japanese ICT market [12], Modis on numbers of US Nobel Laureates [13], and Lee, Lee and Oh [14] on behaviour of the Korean stock markets.

The population dynamics of organisations, but also economic agents, institutions and technologies arise from the intervention of two major forces: (1) legitimation and (2) competition. Legitimation operates when an organisational form becomes institutionalized, socially taken-for-granted, e.g. if its products, services or technologies are demanded by market participants. Existing members of the niche population generate positive externalities for themselves and new entrants. Once sufficiently legitimated, the population expands rapidly in its niche as plentiful market resources attract entrants to exploit those opportunities. As the population density increases and approaches the niche's carrying capacity, increasing resource scarcity increases competition among niche participants. Competition is a motor of the selection process. If a population overshoots its niche's carrying capacity, the population density plunges, then recovers to stabilize at a density sustainable by the external environment. Legitimation force operates on a broader scale than competition. Competition is primarily about the struggle for local niche resources, while legitimation can spread easily across boundaries, transferred by cultural diffusion.

Population dynamics concepts have motivated studies of technology evolution and contributed to cross-fertilization between organizational ecology and industrial economics [15]. Technologies survive, thrive and perish in similar ways to species. Like the evolution of biological systems, technology change also is characterised by significant degrees of cumulativeness and path dependency. Systems with positive feedback can generate outcomes strongly affected by random events or noise even in the presence of strong systematic forces, such as market selection [16].

Alfred J. Lotka and Vito Volterra [17] developed a system of differential equations for analysing relations by competing species. Final numbers of competing populations in a current niche are given by rates of reproduction (r), incumbent counts of competing populations (N), carrying capacity of competing populations (K), population mortality rates (m) and degree of interdependence and strength of competition by particular population (α). The Lotka-Volterra models were later adopted by scholars in organisational ecology, technology studies, economics and sociology, and used for analysing of population dynamics in various socio-economic environments.

There are plenty of studies analysing impacts of technology on social and economic change. This paper turns attention to impact by the socio-economic change on the technology advance. It applies the population dynamics and organizational ecology concepts to analysis of industrial and economics change and examines the evolutionary dynamics of two voice communication technologies in the Czech and Slovak Republics in 1948-2009. The two countries have had very similar language, cultural and institutional settings². In 1948-1989 Czechs and Slovaks were forced to follow identical technology and economic policies. Two nations entered a period of central planning with similar institutional environments, but different levels of economic and technology development in 1948 (Slovakia was much poorer than the Czech Republic). Failure of experiment with central planning, re-introduction of

² Czechoslovakia was established in 1918 and developed a liberal market economy. The Communist Party took power in 1948 and applied strict central planning till 1989. In 1993 Czechs and Slovaks separated and established two independent states.

market economy and later development of two independent nations provide an interesting opportunity to examine technology diffusion in two comparable socio-economic populations under different institutional settings.

This paper assumes that parameter of reproduction rate ' r ' is not constant, but varies over time. Changes in numbers of population, per capita wealth, regulatory arrangements and/or shifts in population's technology skills happen alongside with technology advance. Reproduction rate reflects co-evolution of some intrinsic properties by a technology and changes in broader socio-economic, institutional and technological environments. Instead of estimating one universal value of reproduction rate parameter, values of the parameter ' r ' are imputed into model equations. When difference between actual and modelled counts of fixed line and mobile phone subscriptions is zero, values of the parameter ' r ' are assumed to reflect actual growth potential, with regard to market size and its institutional settings in current period.

The Lotka-Volterra model is based on longitudinal time series, which enable analysing development of fixed line and mobile phone technologies in the Czech and Slovak Republics in 1948-2009. The fixed and mobile phone technologies will be considered classes of living organisms – 'predators', which hunt for 'prey' – voice service subscribers. Data on fixed line technology were available for the period 1948-2009, for mobile phones for period 1994-2009 [18], [19], [20], [21]. Comparative international data were provided by the International Telecommunication Union [22].

2. MODEL PARAMETERS

The Lotka-Volterra equations come in several variants. The basic model takes shape of a logistic differential equation of density-dependent growth:

$$\frac{dN}{dt} = rN \left(1 - \frac{N}{K} \right) \quad (1)$$

The model implies that the growth in numbers of a certain population is given not only by current counts of population (N) and its reproduction rate r , but also by carrying capacity K of a niche, inhabited by this population. The niche of a particular population is a set of resources which can sustain that population. The more N approaches to K , the less resources are left in the niche and the lower the growth rate r is.

The density models describe the effects of competition among members of a single population. A community usually consists of multiple populations competing for scarce resources within the same niche. Models of competitive exclusion by different populations can be described by a system of differential equations. If two populations are considered, model (1) is transformed to model (2a) and (3a), which also covers the mutual interdependence of these populations:

$$\frac{dN_A}{dt} = r_A N_A \left[1 - \frac{(N_A + \alpha_{AB} N_B)}{K_A} \right] \quad (2a)$$

$$\frac{dN_A}{dt} = r_A N_A \left[1 - \frac{(N_A + \alpha_{AB} N_B)}{K_A} \right] - m_A N_A \quad (2b)$$

$$\frac{dN_B}{dt} = r_B N_B \left[1 - \frac{(N_B + \alpha_{BA} N_A)}{K_B} \right] \quad (3a)$$

$$\frac{dN_B}{dt} = r_B N_B \left[1 - \frac{(N_B + \alpha_{BA} N_A)}{K_B} \right] - m_B N_B \quad (3b)$$

where:

r_A ; r_B = reproduction rates of population A and B;

N_A ; N_B = counts of populations A and B;

K_A ; K_B = carrying capacity of populations A and B;

m_A ; m_B = mortality rates of populations A and B;

α_{AB} ; α_{BA} = coefficients of interdependence by populations A and B (competition coefficients).

Eq. (2a) and (3a) describe the dynamics of a community inhabited by two populations (A, B). The populations are interdependent. Each population affects the growth rates of its competitor via squeezing out its carrying capacity. The Eq. 1 characterises the dynamics of population A (dependent on growth in population B). The Eq. 2a, 2b, 3a, 3b mirror the first one and describe the dynamics of population B (dependent on growth in population A).

Parameter r denotes the growth rate of a population and can be compared with the reproduction rate of organisms. The value of r is highest, when an organisation or technology enters an empty niche, N_t is very small. As N approaches K , the value of r decreases, and with $N_t = K$, the value of r equals zero. Should $N_t > K$, the carrying capacity is surpassed, r becomes negative and N_t falls back to K . K is defined as the maximum sustainable amount of an economic activity or technology in a given environment. It depends on both the resources which a niche population needs and the efficiency with which they can be extracted from the environment. Socio-economic systems can be quite dynamic and the value of K tends to vary over time. As demonstrated later, shifting carrying capacity K may have essential consequences also for parameters r , and α_{AB} and α_{BA} .

Biological systems must consider both the reproduction rate r and mortality rate m . Encompassing mortality in technology modelling sometimes is problematic, as it may be difficult to find meaningful proxies for technology mortality. This model defines the market niche of each voice communication technology by numbers of subscribers. Individual (non-firm) subscribers, at least are human beings with limited lifespans³. Including mortality in the model is meaningful and equations (2a) and (3a) are replaced with equations (2b) and (3b). The adjusted model combines particular processes of population development (reproduction and mortality) in a single density-dependent growth model of population dynamics and competitive exclusion.

The direction and strength of the interdependence shaping the development of populations A and B are characterised by parameters α_{AB} and α_{BA} . The coefficients of these parameters express the effects which each member of one population exerts on the carrying capacity of the second population. The higher coefficient α_{AB} is compared to coefficient α_{BA} , the faster that population B squeezes population A out of the shared niche.

³ Data on sectoral structure of subscribers and business mortality rates were available only after 1995. Mortality rates of communication technology were approximated by human mortality rates.

The system of differential equations (2b) and (3b) is solved by the 2nd order Runge-Kutta method.

3. MODEL DYNAMICS

A model of population dynamics must find realistic coefficients for parameters r , m , K and α . The fixed lines and mobile phone technologies accounted for diverse growth patterns. Development of each technology must be modelled separately.

3.1. Fixed lines

Fig. 1 demonstrates annual increases in counts of phone subscribers in the Czech and Slovak Republics, 1948-2009. These increases varied significantly in the abovementioned period. It can be assumed that increases in fixed lines were generated by four major factors: (1) increases in human population; (2) increases in income (expressed in per capita GDP); (3) socio-economic changes, which either promoted or hampered technology diffusion; (4) technological innovations, which improved access to voice communication service by individuals, firms and organisations. All these factors exhibited their own dynamics and contributed to the total dynamics of fixed line technology.

The identification of the nature and volume of carrying capacity is a departure point for explanation of system dynamics. Both the fixed line and mobile phone technology satisfy customer demand on voice communication service. The higher the efficiency of the technology that satisfies this need the higher its chances to win in the competition with other technologies.

There is a number of potential ways for measuring the efficiency of competitive exclusion by voice communication technologies, e.g. numbers of service subscribers, numbers of calls per phone, total minutes called, and/or total industry sales. The latest approach based on sales probably is the best for measuring exploitation of a market niche. Numbers of subscribers, unfortunately, were the only data set available for the whole period under observation. The next step is the decision relating to level of carrying capacity. Should it be considered static or dynamic? In theory, each inhabitant or organisation may subscribe to indefinite numbers of main telephone lines. Many organisations in fact are multiple subscribers. In the real world, the numbers of fixed lines has been confined to a relatively stable interval in past decade. The density of main telephone lines per 100 inhabitants varied between 50 and 70 in the majority of advanced European countries (Germany, France, Switzerland, Denmark, Sweden, UK). Statistics by the International Telecommunication Union point to a strong correlation between per capita GDP and numbers of telephone lines. The correlation is best expressed by the logarithmic curve, which describes gradual saturation of the phone service market. In 2009, for example, the correlation coefficient was $R^2 = 0.69$ for main telephone lines and $R^2 = 0.60$ for mobile phones in sample of 191 ITU members (Fig. 2). The b_1 coefficient in regression equation is much lower for fixed lines (8.96) than those for mobile ones (22.60). This difference points to fact that fixed line networks are relatively more demanding on capital investment than cellular networks. When a country's wealth increases, numbers of fixed lines grows slower than numbers of mobile phones. A relatively low critical level of the per capita GDP is enough to start a rapid growth in mobile phone lines. Many countries with lower income levels actually have accounted for faster growth in mobile phone numbers than fixed ones.

The correlation between income levels and numbers of fixed line subscribers operates also for the Czech and Slovak Republics in the period 1948-2009 (Fig. 3).

Figures 1, 2 and 3 about here

Increases in phone numbers closely followed (with some notable exceptions) annual changes in per capita GDP. Correlation coefficient for per capita income and numbers of fixed line subscribers was $R^2 = 0.72$ in Slovakia and $R^2 = 0.59$ in the Czech Republic. Slovakia accounted for higher growth rates in phone numbers than the Czech Republic. Slovak per capita GDP and population numbers grew from lower levels, and faster, than the Czech ones. In the period 1948-2009 Slovak per capita income grew by 11.64 times and the Czech one 6.50 times (Slovak per capita GDP in purchasing power parity started from significantly lower levels and, notwithstanding higher growth rates, remained some 10 percent lower in 2009). The numbers of main telephone lines per 100 inhabitants rose from 0.75 to 18.48 in Slovakia and from 2.19 to 19.72 in the Czech Republic in 1948-2009 (respective densities of fixed lines actually peaked with 31.4 and 37.7 lines per 100 inhabitants in 2000 and decreased thereafter). Increases in population numbers also contributed to different growth rates in phone numbers in Slovakia and the Czech Republic. The higher the population numbers, the higher the absolute demand for voice communication services, even if the phone density remains unchanged. The Slovak population increased by 57.4 percent and the Czech one by 18.0 percent in the abovementioned period. Changes in income levels and population numbers proved highly significant for increases in fixed line numbers. The carrying capacity of this technology, thus, was dynamic rather than static and followed developments in income and population.

At one extreme the carrying capacity can be set at infinite, and at the other extreme set to or below actual counts of phone numbers. There rarely is a technology operating on 100 percent of its carrying capacity. The capacity seldom is identical to an equilibrium level or satisfied demand. Exactly how much spare capacity there is, however, may prove difficult to estimate, because of combined influence by many socio-economic and organisational settings.

Turning to the real world, the former Czechoslovakia was a centrally planned economy and accounted for chronic deficits in satisfying customer demands. Czech and Slovak statistics, for example, revealed that there were 10 percent more potential customers (asking for fixed lines) than actual counts of service subscribers in the 1980s. We can reasonably argue that large numbers of potential customers did not apply for the service, as they had considered the odds to be too low. The sectoral structure of the centrally planned economy, which overrepresented large enterprises, was another factor distorting the carrying capacity of the voice communication service. Small and medium size enterprises (SMEs) account for great deal of total enterprises in market economies and generate a substantial part of total demand on voice communication services. The centrally planned economies, however, are dominated with large enterprises and generate relatively lower demand on communication services. There is strong evidence in support of this hypothesis.

Fig. 3 demonstrates several positive and negative impacts by socio-economic change on technology growth in 1948-2009. In 1948 the market economy was replaced by the centrally planned one. All SMEs were nationalised and enterprises with similar productions merged to large sectoral monopolies. Socio-economic change and organisational transformation of national economy slowed down growth in GDP. This change was reflected in sharp decreases in fixed line numbers (Fig. 3) and lower values of the 'r' parameter in the period 1948-57 (Table 1, Fig. 5). Late 1950s and early 1960s witnessed partial thawing in Stalinist command economy, higher pace of industrialisation and higher demand on communication technologies.

It is impossible to decouple the impacts of socio-economic change and economic slowdown on fixed line diffusion in 1948-57. Decoupling is possible to detect for period 1990-93 and clearly visible (Fig. 3).

Economic transition generated hundreds of thousands of SMEs in the Czech and Slovak Republics in 1990s. Introduction of a market economy and organisational re-structuring (dissolution of industry monopolies and creation of high numbers of SMEs) were likely to generate great deal of increased demand for voice services after 1989. The available statistics, unfortunately, fail to provide data for the most exciting period 1990-1995, when the bulk of the increase in corporate main telephone lines happened. Data for period 1995-2000 indicate that counts of main telephone doubled in the business sector and increased by 50 percent in household sector in five years. The effect of socio-economic change on carrying capacity of the voice communication service was immense (Fig. 3). The numbers of main telephone lines accounted for rapid increases in 1990-93 despite the deep fall in GDP and late arrival of digital exchanges (after 1990). The new sectoral structures of the Czech and Slovak economies proved major legitimization force enhancing growth in demand for voice communication service. It is, therefore, reasonable to assume that the carrying capacity of this niche was considerably higher than actual counts of fixed line numbers before 1989. Unsatisfied demand by household and business sectors was combined and the coefficient of spare capacity was estimated to be 1.5. The level of carrying capacity should be computed as a product of the actual density of main telephone lines per 100 inhabitants (which already reflects changes in income levels) D_t in time t , population numbers P_t and coefficient of spare capacity 1.5: $K_A, K_B = D_t * P_t * 1,5$ (Table 1).

Later fall in numbers of fixed line subscribers was related to introduction of competing technology species – mobile phones in late mid 1990s. Mobile phone technology was introduced in 1994 in the Czech Republic and in 1995 in Slovakia. It soon started to affect the carrying capacity of fixed line technology. Despite high growth in GDP and rapid technology advance (introduction of digital exchanges), growth in numbers of main telephone line at first slowed down in late 1990s and turned negative after 2000 in both countries. The actual density of main telephone lines could no more be included in the computation of carrying capacity of this technology. Instead, development of carrying capacity has to be projected in absence of mobile phone technology (Fig. 4). Density of main telephone lines was supposed to increase by 8.45 percent per annum in the Czech Republic and 9.0 percent in period 2000-2009⁴. Had there been no mobile phones, the hypothetical density of fixed lines per 100 inhabitants would have reached 73.6 in Slovakia and 78.2 in the Czech Republic in 2009. The hypothesised densities of fixed lines would resemble to those in advanced EU members in early 2000s, before full onset of mobile phones.

Figure 4 about here

Increases in population numbers and income levels, and socio-economic change impact increases in fixed line numbers indirectly, via the rising carrying capacity of the niche. These factors, however, cannot explain all developments in technology diffusion. Numbers of fixed lines were growing also in periods when GDP was falling. Persistent positive growth rates in fixed line numbers are explained by technological innovations. Technological innovations impact on the diffusion of a technology directly, as they open new market niches or

⁴ The 8.45 and 9.0 percent growth rates refer to averages for period 1990-1999 and were used for forecasting hypothetical growth rates in 2000-2009. Forecasting for longer periods would have to rely on logistic growth model (Chen and Watanabe [12]). It, however, is difficult to know actual limits for density of fixed limits in absence of mobile phones.

considerably extend existing ones. Two major waves of technological innovations in fixed line technology were observed the period 1948-2009. The first one occurred in 1958-69, when manual exchanges were replaced for automatic (analogous) ones. The second one was related to substitution of analogous exchanges for digital ones in 1990-2000.

The Czech Republic had lower reproduction rate r of fixed lines than Slovakia in the period of central planning (1948-1989) (Table 1). This was a combined effect of slower growth rates in GDP and population numbers, and relatively lower benefits from technology diffusion. Slovakia started from very low levels, but experienced a boom in the numbers of fixed lines after 1948. Almost all new fixed lines were switched via automatic exchanges. The Czech Republic introduced automatic exchanges somewhat earlier and had lower relative increases in its main telephone lines than Slovakia. In other words, the voice communication service niche was emptier in Slovakia and this country benefited relatively more from introduction of new technologies than the Czech Republic in 1948-1989. Technological and income differences between both countries diminished over time and so did the differences in impacts of technology diffusion. The onset of digital exchanges, on the other hand, was faster and the reproduction rate r higher in the Czech Republic than in Slovakia after 1990.

3.2. Mobile phones

The reproduction rate r of mobile phone technology was remarkably high in most World countries. There is a significant correlation between income levels and phone density (Fig. 2), but the correlation is less clear for income growth and phone density. Neither GDP growth nor increase in population numbers can explain rapid expansion of mobile phone technology after 1994/5 in the Czech and Slovak Republics. The boom in mobile communication technology can be explained only by the existence of a large empty niche and strong legitimization force.

Organisational ecologists equal the legitimization process to legitimization of organisations. We can, however, argue that it is the products, services and technologies offered by organisations which matter for consumers. Legitimation forces initially tend to be low and so is the initial growth rate of a technology. Standard explanations of slow take-ups by technologies include: (1) slow information diffusion, (2) competition among technology producers in establishing dominant designs, and (3) the standardisation process. The first explanation refers to Rogers [23]. When the technology density is low, it is difficult to gain acceptance for it amongst market participants, because most potential customers have low awareness about the potential benefits from this technology. As most people are risk-averse, personal traits will play major roles in the decision to adopt the innovation. Rogers established the idea that adoption happens through a domino effect. The innovators and early adopters used to be popular and trusted opinion leaders, whom the broader public followed when making important decisions about adopting new ideas, innovations or technologies. With technology density growing, awareness of the technology increases exponentially, the legitimization force increases and technology spreads very rapidly ('epidemic model of diffusion'). The dominant design hypothesis suggests that there is a number of competing prototypes of young technology markets [24]. Consumers learn the potential benefits of each of these and start to prefer one technology. It later becomes a dominant design produced by the majority of producers. The standardisation hypothesis assumes that it takes some time for a technology to obtain a form widely accepted by and useful for all market participants [25]. Standardised technologies can enjoy benefits from economies of scale. The three explanations are not mutually exclusive when explaining the initial slow take-up and later epidemic diffusion of some technologies. The diffusion speed, however, may greatly differ across

countries, because of the different components of the legitimization force. Information deficits are likely to be most important in the countries of origin of the technology, where new products and services must generate awareness amongst the broader public. Once the awareness is established, legitimization can rely on a ‘cultural’ diffusion process that is less constrained by local boundaries. Some technologies, (e.g. internet or mobile phone communication) diffuse almost seamlessly across countries with very different political and/or socio-economic regimes. Late adopters of a technology can benefit from established dominant designs and a standardisation process which has already happened in other countries. Mobile phone technology developed over several decades in Germany and Sweden. In the Czech and Slovak Republics, in contrast, the technology catch up took some three years. The first mobile phones appeared in 1991. Regular networks of cellular phones have been operating since 1994 and 1995 respectively.

The ITU statistics report the highest densities of mobile phones per 100 inhabitants in Europe for Montenegro (207.3), Russia (163.6), Lithuania (150.9) and Portugal (148.8) and related to middle-high income countries with low densities of fixed lines in 2009. Advanced European economies, on the other hand, accounted for high densities of fixed lines and medium-high density of mobile phones (UK = 133.6; Germany = 127.8; Netherlands = 127.7; Denmark = 125.0). In terms per capita GDP the Czech and Slovak Republics were closer to Portugal than advanced economies. Their respective densities of mobile phones per 100 inhabitants were 137.6 and 101.7 mobile phone subscribers per 100 inhabitants in 2009. The curve gradients (Fig. 2) indicated that the density of mobile phones in the Czech and Slovak Republics were not far from current carrying capacity. The value of the capacity was set fixed and estimated for 200 mobile phone subscribers per 100 inhabitants in both countries. Carrying capacity set to this level produced an average reproduction rate $r = 0.6670$ in Slovakia in 1995-2009 and $r = 0.6134$ in the Czech Republic in 1994-2009. The higher Slovak average reproduction rate r is explained by the one-time high increase in subscriber numbers in 1996-1997 (from 28.7 to 200.0 thousands).

Technological advance came in uneven waves both for fixed lines and mobile phones. The reproduction rate r of mobile phones fluctuated in the period 1994-2006. The empty niche was saturated in a few years, but the reproduction rate was not decreasing evenly, but exhibited some notable increases in some years (Fig. 5). Periods of resurgent growth rates overlapped with waves of technological and organisational innovations. Major technological innovations included introduction of the NMT-450 MHz, GSM-900/1800 MHz and UMTS networks, and continuous innovations in mobile phone sets. Organisational innovations, e.g. introduction of call packages and discount call prices, were no less important for the diffusion of mobile phone technology.

3.3. Coefficients α_{AB} ; and α_{BA}

In socio-economic systems, there are limited options for setting coefficients of the α_{AB} ; α_{BA} parameters via direct observation and/or experiments. We have to rely on estimates. Growth in mobile phones numbers was very rapid. It follows that apart from a high legitimization force, competition by the fixed line technology was fairly weak and α_{BA} coefficients low. The maximal actual density of the main telephone lines per 100 inhabitants peaked with 36.34 in the Czech Republic and 28.55 in Slovakia in 2000. Maximal mobile phone subscription densities were 115 and 95 respectively in the same year. If no fixed line subscriber had bought a mobile phone, Czech and Slovak coefficients α_{BA} would have reached maximal values -0.32 and -0.30 respectively. Fixed lines would have squeezed out about one third of mobile phone niches in both countries. In fact, most fixed line subscribers *did* buy a

mobile phone. Moreover, many subscribers cancelled their fixed lines after purchase of a mobile phone and only a minority decided against buying mobile phone.

Numbers of ‘loyal’ and ‘disloyal’ fixed line subscribers can be estimated from shares of population not using mobile phones. Mobile phones are least purchased by the age groups 0-6 and 60+. These population groups probably have the lowest need for an instant, out-of-home voice communication service and also some difficulties in handling mobile phone technology. A survey by the Orange Foundation in Slovakia [26] found that some 95 percent children aged 6-15 years while 70 percent of people aged 60+ years used mobile phones in 2010. The mobile phone used some 63 percent of people aged 60+ years in the Czech Republic in 2009 [27]. The shares of adult population group not using mobile phones accounted for about 5% of total population in each country. Of course, there were many mobile phone users in the 60+ age group and there were fixed line-only subscribers in the rest of population. The shares of mobile phone-unfriendly customers, however, probably were the highest among the older population. It is assumed that shares of people declining use of mobile phones are similar among fixed line subscribers and non-subscribers. It is therefore assumed that fixed lines seized about 5% of the mobile phone market niche.

Value of the α_{AB} coefficient can be derived from numbers of fixed lines squeezed out by the introduction of mobile phones. Numbers of fixed lines grew by 9% per annum in Slovakia in 1991-1995 and by 8.4% in the Czech Republic in 1991-1994. By 2009 numbers of fixed lines would grow to 3.74 million in Slovakia and 7.35 million in the Czech Republic (Fig. 4). The actual numbers, however, were 1.01 million and 2.07 million in the respective countries. It follows that 5.50 million mobile phones squeezed out 2.72 million fixed lines in Slovakia 14.22 million mobile phones squeezed out 5.28 million fixed lines in the Czech Republic. The estimated coefficients α_{AB} took values of -0.50 in Slovakia and -0.37 in the Czech Republic.

The estimated parameters were applied to the Lotka-Volterra model and a close correspondence to the predicted values was found (Fig. 6). The model was significant at the 0.001 levels both in the Czech Republic and Slovakia.

In order to minimise potential errors arising from inaccurate estimates of the α_{BA} coefficients, the model was run with alternative coefficients values $\alpha_{BA} = -0.03$ and -0.1 respectively. The alternative model results differed little from those by original model. The model with coefficient $\alpha_{BA} = -0.05$ accounted for the best fit with actual data (Table 1). Low values of the α_{BA} coefficients and high values of the α_{AB} coefficients imply asymmetric overlaps by the fixed line and mobile phone niches. Both technologies provide the same voice services, but in different ways. Mobile phones offer this service at any time and any place, and their subscribers are ready to pay higher prices per minute of a call.

Coefficient α_{AB} was higher in Slovakia than in the Czech Republic. In general, calls by mobile phones are more expensive than those by fixed lines. A fixed line service, however, was only provided in call packages in Slovakia. Mobile phone services, on the other hand, were offered both via pre-paid cards and call packages. Some low-income groups had low numbers of outgoing calls and considered mobile phones to be a cheaper alternative to fixed lines (Slovak per capita GDP was 10 percent lower than the Czech one). In more affluent societies, fixed line and mobile phone voice services interfere less with each other and their market niches are more complementary. Fixed lines are used for longer, but relatively cheaper calls (e.g. international ones). Mobile phones, on the other hand, serve instant, if more expensive voice communication. Interestingly, fixed line density decreased only slightly in some European countries (Britain, Norway, Belgium) in the period 2000-2005. The arrival of mobile phone technology had a weaker effect on the displacement of fixed lines in these countries than in the Czech and Slovak Republic.

Table 1

Model parameters

	Czech Republic		Slovakia	
	fixed lines	mobile phones	fixed lines	mobile phones
r_A, r_B :				
1948-2009	0.2357	0.6670 ¹⁾	0.2196	0.6134 ²⁾
1948-1957	0.3287	x	0.1694	x
1958-1969	0.4479	x	0.2843	x
1970-1990	0.2005	x	0.1672	x
1991-2009	0.1009	x	0.2196	x
K_A, K_B : ³⁾				
1948-1994	$D_t * P_t * 1.5$	x	$D_t * P_t * 1.5$	x
1995-2009	$K_{t+1} = K_t * 1.05^{1)}$	200 per 100 pop.	$K_{t+1} = K_t * 1.05^{2)}$	200 per 100 pop.
M : ⁴⁾	0.957	0.957	1.137	1.137
$\alpha_{AB}; \alpha_{BA}$:	$\alpha_{AB} = -0.50$	$\alpha_{BA} = -0.05$	$\alpha_{AB} = -0.37$	$\alpha_{BA} = -0.05$
d	0.015	0.003	0.016	0.005

Notes: 1) Average for 1995-2009; 2) Average for 1994-2009; 3) carrying capacity is computed as product of phone density per 100 inhabitants in time t (D_t), population numbers (P_t) and spare capacity coefficient = 1,5; 4) Average of actual mortality rates, specific to each year of the 1948-2009 period;

Sum of weighted average absolute differences of modelled values (N'_t) from actual ones (N_t) was used to test model fit (Eq. 4). The d statistics values are stated in Table 1.

$$d = \sum \left(\frac{|N_t - N'_t|}{N_t} \right) \quad (4)$$

The curves of actual and modelled counts of fixed line and mobile phone subscribers were almost identical in both countries (Fig. 6).

Figures 5 and 6 about here

3.4. Equilibrium

There are four possible outcomes of the interspecific competition by two species in the Lotka-Volterra model, depending on carrying capacities (K_A ; K_B) and values of the α_{AB} ; and α_{BA} competition coefficients:

- if $K_A / \alpha_{AB} > K_B$ and $K_A > K_B / \alpha_{BA}$, species A wins and population size equals K_A ;
- if $K_B > K_A / \alpha_{AB}$ and $K_B / \alpha_{BA} > K_A$, species B wins and population size equals K_B ;

- if $K_B > K_A / \alpha_{AB}$ and $K_A > K_B / \alpha_{BA}$, there is an unstable equilibrium point, eventually species A or B wins and outcome depends on the initial abundances of the two species;
- if $K_A / \alpha_{AB} > K_B$ and $K_B / \alpha_{BA} > K_A$, species A and B coexists at stable equilibrium point, regardless of initial abundance.

The latest (2009) data were used for the equilibrium analysis. Setting Czech values of $K_A = 10.49$ million, $K_B = 20.98$ million, $\alpha_{AB} = -0.37$ and $\alpha_{BA} = -0.05$ results in stable equilibrium point $N_A = 1.75$ million fixed lines and $N_B = 23.62$ million mobile phones. Setting Slovak values of $K_A = 5.61$ million, $K_B = 10.85$ million, $\alpha_{AB} = -0.5$ and $\alpha_{BA} = -0.05$ results in stable equilibrium point $N_A = 0.19$ million fixed lines and $N_B = 10.84$ million mobile phones. Equilibrium numbers of fixed lines compare to mobile phones are lower in Slovakia than in the Czech Republic due to higher value of the competition coefficient α_{AB} (-0.5 versus -0.37).

4. CONCLUSIONS, DISCUSSION AND DIRECTIONS FOR FUTURE RESEARCH

The Lotka-Volterra models provide a promising framework for investigating the co-evolution of two or more technologies with a strong positive feedback. The model presented in this paper sought to learn interaction of two technologies, which partially shared the same market niche in the field of voice communication service. The fixed line and mobile phone technologies entered into full competition and the coefficients of model parameters α_{AB} , and α_{BA} were both negative. The two technologies, however, accounted for quite asymmetric modes of niche sharing. Mobile phone technology squeezed out the carrying capacity of the fixed line technology much more than vice versa. Coefficients of the α_{BA} parameters were close to zero and the community of the voice service technologies could also be considered on the verge of full and partial competition.

4.1 Limitations of the research

Applying Lotka-Volterra equations to modelling diffusion and interspecific competition of technologies is subject to some limitations. The usual reservations include assumptions on (a) constant carrying capacities (implying linear isoclines), (b) constant competition coefficients (nonlinear isoclines account for complex stability properties), (c) no spatial variation (geographical boundaries are supposed unchanging and no migration to new markets) and (d) homogeneity and no evolution of both predator and prey populations (basic characteristics of predator and prey are supposed to remain unchanged in observed period). These limitations indicate that population dynamics concepts cannot be not be transferred mechanically among different fields of study. The organising principles of socio-economic systems probably are more complex and diverse than those of living organisms. Particular market agents are not alike and may compete under diverse socio-economic, institutional and technological settings. The extent of the rewards and penalties, and the rates of introduction and diffusion of new techniques depend on a set of environmental and institutional considerations that sharply differ from sector to sector, country to country, and period to period.

The socio-economic systems account for very high levels of complexity. The r , m and K parameters, for example, tend to be rather more stable and/or vary in narrower intervals in biological systems than the same parameters in social systems. Moreover, interpretation problems may arise. It sometimes may be problematic to find interpretations for the r , m and K parameters in socio-economic systems. Methods and techniques relevant in biological

modelling, thus, may not necessarily be fully transferable to socio-economic analysis. Major reservations concern data generating and collecting. In biological systems, the r , m and K parameters are collected via direct observations and/or laboratory experiments. There usually is an option for repeated observation and/or experiment. This is out of the question in most socio-economic modelling, as we can't create two or more identical social populations and compare these. Each observation is unique and non-repeatable. The model parameters can only be analysed retrospectively, and parameter explanation is derived from analysis of logical links in the model itself. Comparison of modelled and actual populations suggests whether the model is realistic or not. Particular parameters in the Lotka-Volterra models are strongly entangled. Population dynamics involve strong feedback processes. Should the model be far from reality, it would be difficult to fine-tune all parameters and achieve a good fit between actual and modelled data.

Some of these limitations also impacted this study. Most reservations relate to establishing carrying capacity and α_{AB} and α_{BA} coefficients. Estimates of the α_{BA} and α_{AB} coefficients, for example, referred to the structure of subscriber populations and were derived from actual developments in period under consideration. These parameters may take different values with changing (i) demographical structure of subscriber population, (ii) technology skills and/or demand for particular services. Assumptions about the spare capacity of the fixed line technology were derived from the available data on excess demand and the sectoral structure of the Czech and Slovak economies in the 1980s. The spare capacity coefficient may have had different (and probably somewhat higher) levels in 1940s, 50s, 60s and 70s. There, unfortunately is no direct evidence on levels of spare capacity in the abovementioned periods. Similar potential pitfalls, however, are common for most longitudinal studies and any data in time series extending over six decades must be observed with caution.

4.2 Population dynamics of technologies

The model suggested several interesting conclusions about the reproduction rate (r) of voice communication technologies in different time periods. Neither fixed lines nor mobile phones appeared as single technologies with constant reproduction rates. Rather, they behaved as families of sub-technologies which were related in the same way that the Stephenson's Rocket locomotive is to the TGV train, and each of which had their own growth dynamics.

The evolution of biological species usually takes hundreds and thousands years (in macro-life at least. The average reproduction rate r of a (macro)organism, for example, is likely to remain more or less stable during several decades. Technologies may evolve much faster; evolution takes years and/or just months, as is the case of information and communication technologies. Modelling the co-evolution of two technologies, therefore, should take into account the potential evolutionary change of each technology, which results from innovations. Each wave has its own reproduction rate r . The diffusion of innovations is usually approximated by the S -shaped curve. Detailed observation of the S curve discovers smaller S s within the large one. These S s were related to time periods with different speeds of technology advance. Fixed line technology, for example, had above-average higher reproduction rates r in the periods 1958-69 and 1991-1996 in the Czech and Slovak Republics (Table 1, Fig. 5). These periods coincided with the introduction of major technological innovations (e.g. automatic analogous exchanges, digital exchanges). The periods 1948-57 and 1970-90, on the other hand, corresponded with lower rates of technology diffusion. An even more detailed observation would discern similar innovation waves within each sub-technology (e.g. advances in automatic analogous exchanges).

Coefficients α_{AB} and α_{BA} can account for diverse values, depending on the type of community and whether they refer to symbiotic or competitive modes of coexistence by the two populations. In symbiotic communities, particular populations inhabit different niches, but are complementary and profit from mutual coexistence [28]. The coexistence of hardware and software firms is a frequently stated example of a symbiotic community. In competitive communities, particular populations share the same niches and struggle for scarce resources. The degree of competition among populations is given by (a) extent, their niche overlaps and (b) survival efficiency. Aldrich [29] examined the basic scenarios of potential coexistence by populations:

- *Full competition* ($\alpha_{AB} < 0$; $\alpha_{BA} < 0$). Niches of both populations overlap. Growth in numbers of one population limits the carrying capacity of its competitor and causes decreases in numbers of second population.
- *Partial competition* ($\alpha_{AB} < 0$; $\alpha_{BA} = 0$). Populations account for asymmetric relations. One population negatively affects the other one, but not vice versa.
- *Predatory competition* ($\alpha_{AB} < 0$; $\alpha_{BA} > 0$). One population expands on expense of its competitor.
- *Full symbiosis* ($\alpha_{AB} > 0$; $\alpha_{BA} > 0$). Populations profit from coexistence in their community.
- *Neutrality* ($\alpha_{AB} = 0$; $\alpha_{BA} = 0$). Two populations are mutually indifferent, but may exert impacts on other populations in their community.

The model parameters for voice communication technologies in the Czech and Slovak Republic found that fixed lines and mobile phones entered into full competition in overlapping market niche for voice communication. The model implied an equilibrium and coexistence of both fixed and mobile phone subscriptions in 2009. The equilibrium is based on assumption that some part of population does not use the mobile phones (elderly people in particular). The equilibrium holds only under condition of constant preferences by customers and organizational arrangements by service providers. Actual developments in the ICT market may take different courses:

- Advance in phone construction and changes in pricing may make mobile phones friendlier for non-subscribers.
- The generation shift is likely to bring ‘new elderly’, who would account for higher skills in handling mobile phones.
- There also may be some minimal numbers of fixed lines which a phone company is ready to provide. When numbers of fixed line subscribers falls below certain threshold, the service may become unprofitable and cancelled.

As noted by Lomi et al [30] (p. 900) ‘(i) organizational environments are not constant throughout the history of the population, and (ii) dynamic feedback connections between environmental resources and organizational populations induce more general coevolutionary process, in which density plays only one part’. Technologies not only ‘hunt’ for prey (customers), but also change them. Increased technological skills generate demand on new products and services and open new market niches. Technologies both consume incumbent resources and produce new ones.

The success or failure of an organism and/or technology is given both by its ability to reproduce and adapt to the surrounding environment. It is possible to distinguish two contrasting diffusion strategies. One is pioneering and based on high growth rates and a strong legitimization force, while the other operates in crowded and routinised conditions. The

reproduction rate r is particularly high, when a technology enters an empty niche, typically with a high carrying capacity K (see introduction of digital exchanges and mobile phone communication in the model). Organisms and/or technologies with higher r rates are more successful in reproduction and squeeze out their potential competitors. In a business environment, these ' r -strategists' are associated with new technology-based firms. They prefer large-scale projects, with higher levels of potential profits, but also risks. If the niche population approaches its carrying capacity K , organisms and/or technologies with lower reproduction rates but finer tuning strategies, may take over the remainder of spare capacity K . The ' K -strategists' account for lower levels of innovativeness. Their projects promise lower profits, but also lesser risks, and are more likely to find a broad investor base. Turning to voice communication services, we can find some evidence for assumption that K -strategists (fixed lines) may successfully compete with the r -strategists (mobile phones). Fixed line numbers either for relatively low decreases in several European countries. These development patterns suggest that fixed lines may survive competition from mobile phones. Fixed line operators, for example, developed several organisational and economic innovations (discount calls, various packages combining call, cable-TV and internet services, price competition), which enabled utilisation of some spare capacity in voice communication service. Several technological innovations allowed for provision of services previously typical only of mobile phones (cordless phones, displays, text messaging services). It follows that the competition force need not necessarily result in extinction of a competitor with a low r rate. Technological innovations may lead to compartmentalisation, as they open new market niches for weaker competitors.

4.3 Directions for future research

Major limitations of this research relate to data constraints and assumptions on carrying capacity and competition coefficients in the Lotka-Volterra models for interspecific competition. Future research can further in several directions:

The market size is determined by many factors: population numbers and wealth, pricing methods, regulation arrangements, existence of monopolies and oligopolies, culture and spending habits of consumers, marketing and/or management practices by the technology operators. Creation of new products and services no less is important for increases in carrying capacity by particular technologies. Definition of carrying capacity should take into consideration as many contributing factors as possible. Researchers with more abundant data may examine importance of particular factors for market size by standard regression techniques.

There is an interesting question, as to whether the coefficients α_{BA} and α_{AB} change over time. They probably do, as waves of technological and organisational innovations alter competitive strengths of particular technologies. The more overlapping market niches are the stronger competition is. Development of new products and services may contribute to separation of market niches and decrease in competition. The community of the voice communication services seems to transit from full to partial competition and neutrality. If the market niches of the fixed line and mobile phones dissociate, both coefficients α_{BA} and α_{AB} decrease to zero. The fixed line technology may profit more from this resource partitioning, because it was affected by competition from mobile phone technology more than vice versa. Fixed line technology may exploit small specialised niches on the fringes of the central market in communication services, and investors in this industry may be more ready to invest in incremental innovations in fixed lines. These innovations, in turn, should support growth in the reproduction rate r of the same technology. There is an opportunity to follow

compartmentalisation processes and establish their dynamics. Linearity or non-linearity of the compartmentalisation (implying linear versus non-linear isoclines) in particular seems a promising field for studies in population dynamics of technologies.

Onset and diffusion of new technologies is related to force of legitimation. Each technology is brought on the market by organisations. Legitimation force therefore should not be considered separately from specific socio-economic conditions, including organisational arrangements. Character of a technology operator in terms of size, ownership type, specialisation and/or country of origin likely is impact on efficiency of technology diffusion. There are interesting opportunities for modelling markets with different types of ICT operators: (a) specialist versus generalists, (b) incumbent versus new entrants, (c) regional versus foreign/global operators.

Some fixed line and mobile phone operators are divisions of the same incumbent telecommunication companies, some are new entrants and/or independent entities. Extent of competition between the incumbent firms and new entrants is determined both by the market size and regulatory framework and may differ across countries. Regionally specialised firms may benefit from intimate (an in many cases tacit) knowledge of their markets and customers. This may translate to tailoring their services to customer needs and/or change in service portfolio. Global organisations, on the other hand, may benefit from more diverse knowledge and coming from other countries and industries. The former competition mode may be preferred by the ‘K-strategists’ and favour incremental innovations (text messages, discount international calls), the latter may better suit to ‘r-strategists’ and radical innovations (mobile phone communication). McKendrick and Wade [31] for example argue that there may be tradeoffs to high rates of incremental technological change related to organizational disruptions associated with frequent technological change and overestimating the advantages and receptiveness of the technological improvement. Large firms that frequently introduce incremental technological improvements cope better with organizational mortality and are more potent competitors. Smaller firms, on the other hand are more vulnerable to incremental, but frequent technical change.

Future research also may consider definition of carrying capacity out of geographical boundaries by particular countries. Many telecommunication companies operate on global level and combine markets in several countries. Sharing fixed costs of technology development and introduction among several national markets impinges on the magnitude of density-dependent competition and legitimation force.

Fig. 1. Annual change in counts of fixed line and mobile phone subscribers in the Czech and Slovak Republics. Sources: FSÚ [18], [19], ČSÚ [20] and ŠÚSR [21].

Fig. 2. Main telephone lines and mobile phone subscriptions per 100 inhabitants and GDP in 2009. Source: author's own computation based on original statistics by the ITU [22].

Fig. 3. Annual change in counts of fixed line subscribers and per capita GDP in the Czech and Slovak Republics. Sources: author's own computation based on original statistics by the FSÚ [18], [19], ČSÚ [20] and ŠÚSR [21].

Fig. 4. Actual and hypothetical fixed line subscribers in the Czech and Slovak Republics. Sources: author's own computation based on original statistics by the FSÚ [18], [19], ČSÚ [20] and ŠÚSR [21].

Fig. 5. Reproduction rate ' r ' for fixed and mobile phone subscribers in the Czech and Slovak republics. Sources: author's own computation based on original statistics by the FSÚ [18], [19], ČSÚ [20] and ŠÚSR [21].

Fig. 6. Actual and modelled counts of the fixed and mobile phone subscribers in the Czech and Slovak republics. Sources: author's own computation based on original statistics by the FSÚ [18], [19], ČSÚ [20] and ŠÚSR [21].

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