Lechman, Ewa

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FACULTY OF MANAGEMENT AND ECONOMICS

THE 'TECHNOLOGICAL TAKE-OFF' AND THE 'CRITICAL MASS'. A TRIAL CONCEPTUALIZATION.

Ewa Lechman*

GUT Faculty of Management and Economics

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* Gdansk University of Technology, Faculty of Management and Economics,
eda@zie.pg.gda.pl (corresponding author)

THE 'TECHNOLOGICAL TAKE-OFF' AND THE 'CRITICAL MASS'.

A TRIAL CONCEPTUALIZATION.

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Ewa Lechman, Ph.D.

Gdansk University of Technology

Faculty of Management and Economics

eda@zie.pg.gda.pl

Abstract

Similar to economic growth, the process of technology diffusion may well be approximated by easily distinguishable phases (stages). During the initial phase, the process of diffusion slows, whereas subsequently, under favourable circumstances, it accelerates and proceeds at an exponential growth rate, ultimately approaching relative stabilisation (maturity) when the growth rates gradually diminish. Following the proposed by Rostow (1956) conceptualization of the 'take-off', this work is a trial conceptualization of the concepts related to the technology diffusion process, namely – 'technological take-off' and the 'critical mass'. It demonstrates the 'step-by-step' procedure of the identification of the 'critical mass', and the interval when the 'technological take-off' emerges. We propose the term ***'technological take-off'*** and define it the time interval when the nature of the diffusion process is radically transformed due to shifting the rate of diffusion and forcing the transition from condition of stagnation into dynamic and self-sustaining growth (diffusion) of new technology; while the *'critical penetration rate'* we define as the *threshold* that, once passed, provokes the diffusion to become self-perpetuating.

Key words: technology, technology diffusion, critical mass, take-off

JEL classification: O3

The *'critical mass'*, may be defined as the minimal necessary number of user of new technology, which ensure the emergence of the *'take-off'* period along the diffusion trajectory, at which the further process of diffusion becomes self-perpetuating. The term 'take-off' itself, however has been originally introduced to the economic literature by Walt Rostow, who, in his founding paper *'The take-off into self-sustaining growth'* (1956), claimed that the process of economic growth is characterised by discontinuity *'centering on a relatively brief time interval of two or three decades when the economy and the society of which it is a part transforms themselves in such ways that economic growth is, subsequently, more or less automatic'* (Rostow 1956, p.1). He labelled this transformation the *'take-off'*. Rostow (1956, 1963,1990) also wrote that identifying the *'take-off'* entails seeking to isolate the specific period (interval) in which *'the scale of productive activity reaches a critical level, (…) which leads to a massive and progressive structural transformation in economic, better viewed as change in kind than a merely in degree'* (Rostow 1956, p. 16). The concept of the *'take-off'* was then developed and implemented in the works of, e.g., Hozelitz (1957), Ranis and Fei (1961), Bertram (1963), Olson (1963), Azariadis and Drazen (1990), Becker et al. (1994), Evans (1995), Baldwin et al. (2001), and Easterly (2006). In most of the cited works, the notion of the 'take-off' was, however, combined with Rosenstein-Rodan`s (1943) 'Big Push' doctrine, which was predominantly applied to describing and explaining the stages, patterns and determinants of economic development and growth.

Similar to economic growth, the process of technology diffusion may well be approximated by easily distinguishable phases (stages). During the initial phase, the process of diffusion slows, whereas subsequently, under favourable circumstances, it accelerates and proceeds at an exponential growth rate, ultimately approaching relative stabilisation (maturity) when the growth rates gradually diminish.

We adjust the conceptual background provided by Rostow (1956, 1990) and develop the term ***'technological take-off'*** and define it the time interval when the nature of the diffusion process is radically transformed due to shifting the rate of diffusion and forcing the transition from condition of stagnation into dynamic and self-sustaining growth (diffusion) of new technology. In this sense, the emergence of the *'technological take-off'* is essential for ensuring the sustainability of technology diffusion and enabling the widespread adoption of new technology throughout society. Generally, before the *'technological take-off'*, diffusion proceeds slowly, but once the *'technological take-off'* is achieved, diffusion proceeds more rapidly and the number of new technology adopters begins to expand rapidly, typically at an exponential rate. Finally, in the maturity phase, the number of new technology users reaches system carrying capacity (saturation) and stabilises. To remain in line with the previous, the long-term process of technology diffusion may be arbitrarily divided into four separate phases (stages). Firstly, the initial (early) phase is when the technology diffusion is initiated, but the annual growth and penetration rates are typically negligible. In the early stage of diffusion, the

preconditions for the *'technological take-off'* are also established. The second phase constitutes the *'technological take-off'* itself; then, in the third phase—'*post* technological take-off'—the increase in users of the new technology is self-perpetuating and becomes a normal condition in a given economy. Finally, the fourth phase occurs when diffusion significantly slows down, approaching saturation (maturity).

However, the emergence of the *'technological take-off'* is intimately related to and preconditioned by achieving the *'critical mass'*, which has yet to be defined. With this aim, we develop the following terms: the technology replication coefficient ($\Phi_{i,y}$) (hereafter, the replication coefficient), marginal growth in technology adoption ($\Omega_{i,y}$) (hereafter, marginal growth), critical year ($Y_{crit,i,y}$), and critical penetration rate ($critICT_{i,y}$), where i denotes country and y year.

Assume that for a given country (i) and a given technology (ICT), the term $N_{i,y}$ stands for the level of technology (ICT) adoption in y year. By definition, $N_{i,y} > 0$, because negative adoption is not possible, and if $N_y = 0$, the diffusion process is not reported. Along this line, the technology replication coefficient ($\Phi_{i,y}$) follows:

$$\Phi_{i,y} = \frac{N_{i,y}}{N_{(i,y-1)}} , \tag{1}$$

then:

$$N_{i,y} = \Phi_{i,y} [N_{(i,y-1)}] , \tag{2}$$

if $N_{i,y} > 0$ and $N_{(i,y-1)} > 0$, and $\Phi_{i,y} \in (0; \infty)$. The replication coefficient for respective technology (ICT) explains the multiplication of technology users that occurs because of the emerging *'word of mouth'* effect (Geroski 2000, Lee *et al.* 2010). Suppose that for y year, the $\Phi_{i,y}$=3. This shows that in $(y-1)$ year, each user of the given technology has 'generated' two **additional** new users of the new technology. In this sense, the replication is the cornerstone of the diffusion process itself. Fig.1 illustrates how respective values of $\Phi_{i,y}$ determine $N_{i,y}$ over time.

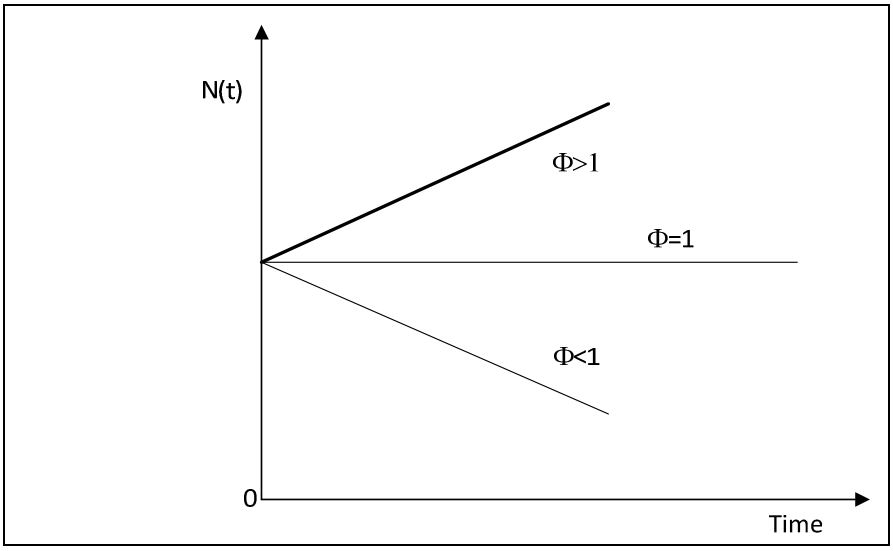

Fig. 1. Replication coefficient. Source: Author`s elaboration.

If $\Phi_{i,y} > 1$, it implies that in each consecutive year, the number of users of new technology increases, so that $N_{i,y} > N_{i,y-1}$. This indicates that the values of $\Phi_{i,y}$ must be higher than 1 to ensure diffusion. If $\Phi_{i,y} = 1$, the number of new technology users is constant over time, and thus $N_t = N_{(t+1)} = \cdots = N_{(t+n)}$ and no diffusion is reported. Finally, $\Phi_{i,y} < 1$ would imply that the number of users of new technology is decreasing over time, so that $N_{i,y-1} > N_{i,y}$. It may be argued that the replication coefficient ($\Phi_{i,y}$) exhibits the dynamics of the diffusion process and—to some degree—demonstrates the strength of the network effects that enhance the spread of new technology over society.

As was already claimed, if $\Phi_{i,y} > 1$, the number of new technology users is constantly increasing, so that $N_{i,y} > N_{i,y-1}$. Based on the latter, we propose the term 'marginal' growth in technology adoption ($\Omega_{i,y}$), which formally may be expressed as:

$$\Omega_{i,y} = N_{i,y} - N_{i,y-1}, \quad (3),$$

under the conditions that $N_{i,y} > 0$ and $N_{i,y-1} > 0$. The value of $\Omega_{i,y}$ expresses the change in the total number of users* of new technology over two consecutive years.

* In our case, expressed as number of users per 100 inhabitants.

It is easily observed that these two coefficients – $\Phi_{i,y}$ and $\Omega_{i,y}$, are closely interrelated. Assuming that $\Phi_y > 1$, the level of marginal growth in i country and in y year is:

$$\Omega_{i,y} = N_{(i,y-1)}[\Phi_{i,y} - 1] \ , \tag{4}$$

or:

$$\Omega_{i,y} = -N_{(i,y-1)}[1 - \Phi_{i,y}]. \tag{5}$$

Simply transforming Eq.4 yields:

$$\frac{\Omega_{i,y}}{N_{i,y-1}} = [\Phi_{i,y} - 1]. \tag{6}$$

Generally, the $\Omega_{i,y}$ depends directly on the strength of the replication process that is expressed through the $\Phi_{i,y}$.

Examining the $\Phi_{i,y}$ and $\Omega_{i,y}$ simultaneously, it is easy to conclude that:

1. If ($\Phi_{i,y} > 1$ then $\Omega_{i,y} > 0$), the replication process is sufficiently strong and the diffusion proceeds, which is demonstrated in the increasing number of new technology users $(N_{i,y} < N_{(i,y+1)})$;
2. If ($\Phi_{i,y} = 1$ then $\Omega_{i,y} = 0$), no replication is reported and the diffusion does not proceed, which results in a constant number of users of new technology $(N_{i,y} = N_{(i,y+1)} = \cdots = N_{(i,y+n)})$;
3. If $\Phi_{i,y} < 1$ then $\Omega_{i,y} < 0$, the replication process is so weak that the diffusion is limited, and there will be a decreasing number of users of new technology $(N_{i,y} > N_{(i,y+1)})$.

If the replication coefficient is constant over time $(\Phi_{i,y} = \Phi_{i,y+1} \ldots . = \Phi_{i,y+n})$, then in each consecutive period, the marginal growths in technology adoption are equal $(\Omega_{i,y} = \Omega_{i,y+1} \ldots = \Omega_{i,y+n})$; and the diffusion proceeds linearly. However, the technology diffusion process is far from linear but rather follows an S-shaped trajectory instead.

In this vein, we intend to examine the behaviour of respective coefficients—$\Phi_{i,y}$ and $\Omega_{i,y}$—along the sigmoid technology diffusion pattern (for visualisation, see Fig. 3.8), which allows for determining the critical year ($Y_{crit,i,y}$) and critical penetration rate ($critICT_{i,y}$), and finally for identifying the *'technological take-off'* interval.

In the early (initial) diffusion phase, the replication coefficient tends to be higher than marginal growth $(\Phi_{i,y} > \Omega_{i,y})$, and thus, a gap emerges between $\Phi_{i,y}$ and $\Omega_{i,y}$. However, as the diffusion proceeds and the replication process is gains strength (so that $\Phi_{i,y} > 1$ and $\Omega_{i,y} > 0$), the $\Omega_{i,y}$ ultimately increases gradually while the $\Phi_{i,y}$ decreases in consecutive years, which will inevitably lead to closing the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ (the paths that show the changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ are converging; see Fig.2). If the latter is satisfied, the paths that show changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ finally intersect (the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ is closed), so that in the next years, the replication coefficients are *lower* than marginal growth $(\Phi_{i,y} < \Omega_{i,y})$, and the paths that show changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ diverge. The specific time when the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ is closed (theoretically, $\Phi_{i,y} = \Omega_{i,y}$) we label the critical year ($Y_{crit,i,y}$); meanwhile, the penetration rate of new technology in $Y_{crit,i,y}$ we name the critical penetration rate ($critICT_{i,y}$). Technically, the critical year denotes the specific time period when the dynamic of the diffusion process is transformed, as the early diffusion phase is left behind and the new technology begins to diffuse exponentially; the *'critical penetration rate'* we define as the *threshold* that, once passed, provokes the diffusion to become self-perpetuating, which implies overcoming the *'resistance to steady growth'* (Rostow 1990). The *'critical penetration rate'* traces the number of individuals—'innovators'—who demonstrate little risk aversion and high propensity to acquire novelties and who thus are the first new technology adopters and the ones who propagate its further diffusion throughout society. Finally, we argue that the *'critical penetration rate'* approximates the *'critical mass'* of new technology adopters, which preconditions the further spread of technology and forces the emergence of the *'technological take-off'*.

It is important to note that following this procedure would yield rigid identification of the exact date when $\Phi_{i,y} = \Omega_{i,y}$. However, to satisfy the latter, daily data on new technology penetration rates would be required, which for obvious reasons is scarcely possible. To challenge this obstacle, we choose to treat as the critical year $(Y_{crit,i,y})$ the first year when $\Phi_{i,y} < \Omega_{i,y}$, **if** in the previous year, the $\Phi_{i,y-1} > \Omega_{i,y-1}$ was reported (see Fig.2). As was already mentioned, once it passes the $Y_{crit,i,y}$, the new technology begins to diffuse at an exponential rate, which is exhibited in the increasing values of $\Omega_{i,y}$. Finally, the process of diffusion slows and inevitably approaches the maturity phase when the desired saturation $(N_{y,i})$ is achieved. The slow-down and maturity phase $\Phi_y \to 1$ and $\Omega_y \to 0$ determines the termination of the diffusion process.

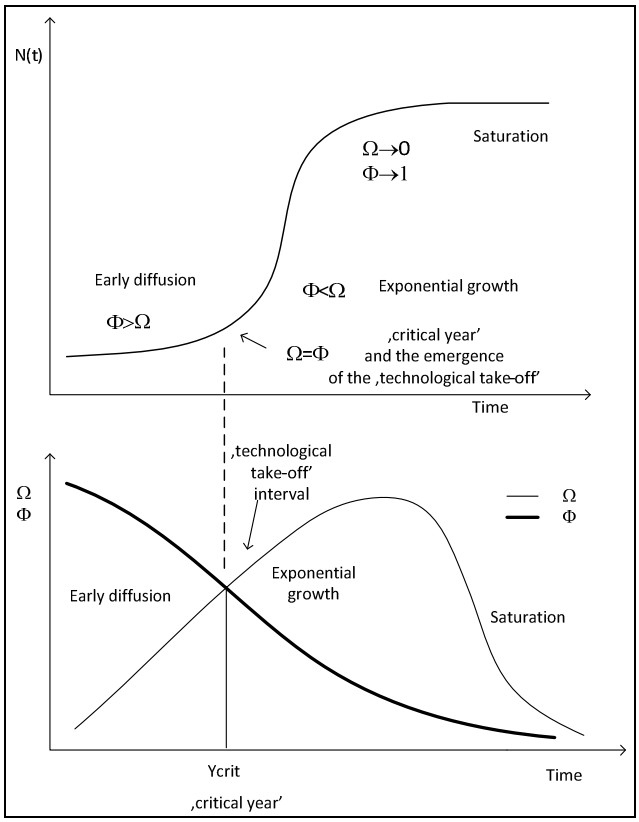

Fig.2. Relationships between technology replication coefficient ($\Phi_{i,y}$), marginal growth in technology adoption ($\Omega_{i,y}$), critical year ($Y_{crit,i,y}$) along the S-shaped technology diffusion trajectory.

Finally, we propose labelling the 2-year interval right after the $Y_{crit,i,y}$ as the *'technological take-off'*, which, as was previously defined, denotes the time period when the nature of the diffusion process is transformed because the diffusion rate shifts and forces the transition from stagnation to the dynamic and self-sustaining growth (diffusion) of the new technology.

Presuming that y stands for $Y_{crit,i,y}$ and to address the assumption that the *'technological take-off'* is the period during which the rate of diffusion is radically shifted, we suggest the following formalization of the conditions under which the *'technological take-off'* emerges:

$$\begin{cases} \Omega_{i,(y+1)} > 0 \\ \Omega_{i,(y+2)} > 0 \\ \Omega_{i,(y+1)} > \Omega_{i,(y)} \\ \Omega_{i,(y+2)} > \Omega_{i,(y)} \end{cases} . \tag{7}$$

Following Eq. (3.39) we argue that if y stands for $Y_{crit,i,y}$, the *'technological take-off'* interval occurs during the period $< y+1; y+2 >$.

If the critical year ($Y_{crit,i,y}$) is not identified, the conditions specified in Eq.(7) are also not satisfied, and this implies that the emergence of the *'technological take-off'* has been restricted. Technically, this indicates that during the initial diffusion phase, the replication lacked the strength to ensure gradual increases in $\Omega_{i,y}$, which would allow for closing the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ (see Fig.3). As result, the paths that show the changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ diverge rather than converge, and the critical year does not emerge. If $\Phi_{i,y} = 1$ or $\Phi_{i,y} < 1$, the situation is similar, and the technology diffusion is impeded. The countries where the $Y_{Crit,i,y}$ has not been identified are those where the process of entering exponential growth has been restrained and they remained virtually locked in the 'low-level-technology' trap, becoming latecomers in this respect.

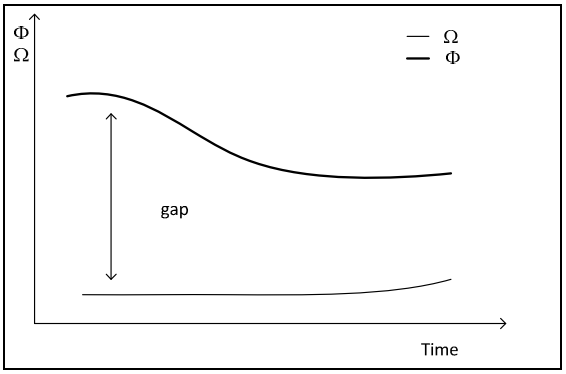

Fig.3. The 'low-level-technology' trap. Source: Author`s elaboration.

Finally, we strongly argue that the *'critical year'*, the *'critical penetration rate'* and the *'technological take-off'* do not emerge unconditionally or in isolation but are heavily predetermined by multiple social, economic and instructional prerequisites. The *'technological take-off'* is preconditioned and induced by strong stimuli that are typically well-established in the early diffusion phase. In this vein, we claim that the analysis of the '*critical mass*' should be considered in a broad context that allows for capturing a broad array of factors that could potentially foster or impede the *'technological take-off'*. We suggest that identifying both the critical penetration rate and the *'technological take-off'* interval should be complemented by broad analysis of the socio-economic and institutional conditions under which the *'technological take-off'* emerged. This approach places the purely numerical analysis in the broad macroeconomic perspective and is essential for capturing those factors that potentially foster or hinder the emergence of the *'technological take-off'*. This proposed broadening of the *'critical mass'* analysis sheds light on countries' socio-economic and institutional characteristics and situates the analysis in a broad macroeconomic perspective. These preconditions generally combine institutional change, economic performance, political regimes, social norms and attitudes, and the state of development of any backbone infrastructure. In a broad sense, the *'technological take-off'* requires that a society and an economy be prepared to actively respond to newly emerging possibilities (Rostow

1956). If these requirements are not sufficiently fulfilled, the *'technological take-off'* will not occur. Our concept of *'critical mass'* is, to a point, related to what was stressed in the works of Baumol (1986), Perez and Soete (1988), and Verspagen (1991), that a country`s ability to adopt new technologies is preconditioned by a wide array of factors. Societies assess and assimilate technological novelties by relying upon 'intellectual` capital (Soete and Verspagen, 1993) and institutional, governmental and cultural conditions. Some empirical evidence shows that the most prominent factors in a country`s ability to adopt and effectively use new technologies are education and the skills of the labour force (Baumol, 1989). Countries that experience significant lacks in these factors will likely never be able to ensure the widespread use of new technologies and use the full potential of technological change. As a result, they will never catch up with richer countries and will continue to lag behind as technologically disadvantaged regions.

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