# The 'technological take-off' and the 'critical mass'. A trial conceptualization.

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# THE ‘TECHNOLOGICAL TAKE-OFF’ AND THE ‘CRITICAL MASS’.

## A TRIAL CONCEPTUALIZATION.

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**Abstract**
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.

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

In technology diffusion literature, there appear two interrelated terms: *critical mass'* and the *'take-off'*. While not much space is dedicated to the definition of the term *'take-off'*, which is usually simply recognized as the unique ‘stage’ along the technology diffusion trajectory, the concepts of the *'critical mass'* has attracted more attention. According to e.g. Marwell and Oliver (1993), Molina et al. (2003) or Puumalainen et al. (2011), in a very broad sense, the *'critical mass'* may be defined as necessary (critical, threshold) conditions for collective actions to emerge and become self-perpetuating; while Markus (1987) argues that seeking for the *'critical mass'* consist in identifying the threshold conditions under which the reciprocal behavior becomes self-sustaining. Although very inspiring, insofar both in theoretical and empirical literature on technology diffusion the concept of *'critical mass'* has been rarely undertaken. Some evidence may be traced in works of Cabral (1990, 2006), Economides and Himmelberg (1995a, 1995b), or Evans and Schmalensee (2010). The empirical evidence reported in works of Lim et al. (2003), Kim and Kim (2007), Grajek (2003, 2010), Grajek and Kretschmer (2011, 2012), Baraldi (2012), Arroyo-Barrigüete et al. (2010) or Villasis (2008), generally, concentrates on identification of the ***'critical mass',*** defined as the 'minimum' number of users of new technology, which assures the self-sustainability of the technology diffusion.

In this work we propose a trial conceptualization to the identification of the *'critical' mass'* and the *'take-off'* period. This approach is explained in the following paragraphs.

Walt Rostow, in his founding paper *'The take-off into self-sustaining growth'*, (1956), claimed that the process of economic growth is characterized 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 labeled this transformation as the *'take-off'*. Rostow (1956, 1963,1990) also wrote that identification of the *'take-off'*, yields seeking to isolate the specific period (interval) where *'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 hereafter developed and implemented in 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), Easterly (2006). In most of the cited works, the notion of the 'take-off' was however combined with the Rosenstein-Rodan`s (1943) 'Big Push' doctrine, predominantly applied for description and explanation of stages, patterns and determinants of economic development and growth.

We argue that the analogies between the long-term process economic growth and technology diffusion are extensive. Similarly to the economic growth, the process of technology diffusion may be well approximated by easily distinguishable phases (stages). During the initial phase the process of diffusion is slows, while afterwards, under favorable environment, it accelerates and the proceeds at exponential growth rate, finally heading toward relative stabilization (maturity) when the growth rates gradually diminish.

In this vein, to meet the objective is this work, we adjust the conceptual background provided by Rostow (1956, 1990) and develop the term ***'technological take-off'*** and define it as the time interval when the nature of the diffusion process is totally 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 such sense, the emergence of the *'technological take-off'* is essential for the technology diffusion process assuring its sustainability and enabling widespread adoption of new technology over society. Generally, before the *'technological take-off'* period emerges, the diffusion proceeds slowly, but once the *'technological take-off'* is achieved, the diffusion speeds up and the number of new technology adopters starts to expand rapidly usually at exponential rate. Finally, in the maturity phase, the number of users of new technology reaches the system carrying capacity (saturation) and stabilizes. To stay in line with the previous, the long-term process of technology diffusion may be arbitrary divided into four separate phases (stages). Firstly – the initial (early) phase when the technology diffusion is initiated, but the annual growth and penetration rates are usually 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; while in the third phase – '*post* technological take-off' – the growth of users of new technology is self-perpetuating and becomes a normal condition in a given economy. Finally, the fourth phase occurs when the diffusion significantly slows down heading toward the saturation (maturity).

However, the emergence of the *'technological take-off'* is intimately relater and preconditioned by achieving the *'critical mass'*, which yields to be defined. To this aim, we develop the following terms: technology replication coefficient ($\Phi_{i,y}$) (hereafter – 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 given technology (ICT), the term $N_{i,y}$ stands for the level of technology (ICT) adoption in $y$ – year. By definition the $N_{i,y} > 0$, as negative adoption is not possible, and if $N_y = 0$, the diffusion process is not reported. In this line, the technology replication coefficient ($\Phi_{i,y}$) follows:

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

then:

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

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 process of multiplication of technology users, which occurs due to emerging *'word of mouth'* effect (Geroski 2000, Lee *et al.* 2010). Suppose that for a $y$-year the $\Phi_{i,y}$=3. It shows that in $(y-1)$-year, each user of given technology has 'generated' **additional** two new users of new technology. In such sense the replication is the cornerstone of diffusion process itself.

Fig.1 illustrates how respective values of $\Phi_{i,y}$ determine the $N_{i,y}$ over time.

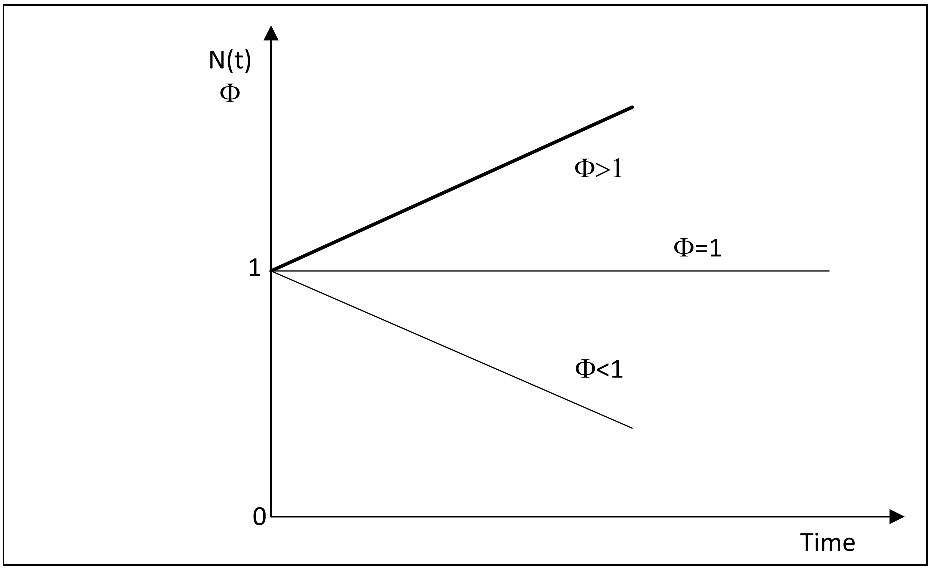


**Fig.1. Replication coefficient. Source: Author`s elaboration.**

If $\Phi_{i,y} > 1$ it implies that in each consecutive year, the number of users of new technology is growing, so that $N_{i,y-1} < N_{i,y}$. It shows that the values of $\Phi_{i,y}$ must be higher than 1, to assure the diffusion process. In case that $\Phi_{i,y} = 1$ , the number of new technology users is constant over time, thus $N_t = N_{(t+1)} = \cdots = N(t+n)$ and the diffusion is not reported. Finally if $\Phi i,y<1$ , 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 replication coefficient ($\Phi_{i,y}$) exhibits the dynamics of the diffusion process, and – to some point – demonstrates the strength of the network effects, which enhance the spread of new technology over society.

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

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

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

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

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

or:

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

Simple transforming the Eqs. 4 or 5, it yields:

$$\frac{\Omega_{i,y}}{\Omega_{i,y-1}} = [\Phi_{i,y} - 1] \quad (6).$$

Generally, the $\Omega_{i,y}$ depends directly on the strength of the replication process which 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 strong enough and the diffusion proceeds, which is demonstrated in the growing number of new technology users ($< N_{(i,y+1)}$);
2. If $\Phi_{i,y} = 1$ then $\Omega_{i,y} = 0$, no replication process is reported and the diffusion does not proceed, which results in the constant number of users of new technology ($= N_{(i,y+1)} = \cdots = N_{(i,y+n)}$);
3. If $\Phi_{i,y} < 1$ then $\Omega_{i,y} < 0$, the replication process is too weak so that the diffusion is held, which results in the decreasing number of users of new technology ($N_{i,y} > N_{(i,y+1)}$).

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

In this vein, we intend to examine the behavior of respective coefficients – $\Phi_{i,y}$ and $\Omega_{i,y}$ along the sigmoid technology diffusion pattern (for visualization see Fig. 2), which allows for determining the critical year ($Y_{crit,i,y}$), and critical penetration

[1] In our case, expressed as number of users per 100 inhabitants.

rate ($critICT_{i,y}$), and finally for identification of the *'technological take-off'* interval.

In the early (initial) diffusion phase the replication coefficient tends to be higher than marginal growth $(\Phi_{i,y} > \Omega_{i,y})$; hence the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ emerges. However as the diffusion proceeds and the replication process is strong enough (so that $\Phi_{i,y} > 1$ and $\Omega_{i,y} > 0$ ), finally the $\Omega_{i,y}$ are gradually increasing while the $\Phi_{i,y}$ are decreasing in consecutive years, which shall inevitably lead to closing the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ (the paths showing changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ are converging – see Fig.2). If the later is satisfied, the paths showing 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 paths showing 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 (hence theoretically $\Phi_{i,y} = \Omega_{i,y}$) we label as the critical year ($Y_{crit,i,y}$), while the penetration rate of new technology in $Y_{crit,i,y}$, we name as 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 and the new technology starts to diffuse at exponential rate; while the *'critical penetration rate'* we define as the *threshold*, which once passed provokes the diffusion process 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 henceforth are the first new technology adopters and propagate its further diffusion among society members. Finally, we argue that the *'critical penetration rate'* approximates the *'critical mass'* of new technology adopters, which precondition further spread of technology and force the emergence of the *'technological take-off'*.

Importantly to note is that following this procedure would yield rigid identification of the exact date when $\Phi_{i,y} = \Omega_{i,y}$. However to satisfy the later, daily data on new technology penetration rates would be required, which for obvious reasons is barely possible. To challenge this obstacle we decide 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 already mentioned, ones having passed the $Y_{crit,i,y}$ the new technology starts to diffuse at exponential rate which is exhibited through increasing values of $\Omega_{i,y}$. Finally, the process of diffusion slows down and inevitably heads toward the maturity phase when the desired saturation $(N_y)$ is achieved. During the slow down and maturity phase $\Phi_y \rightarrow 1$ and $\Omega_y \rightarrow 0$, which determines the termination of the diffusion process.

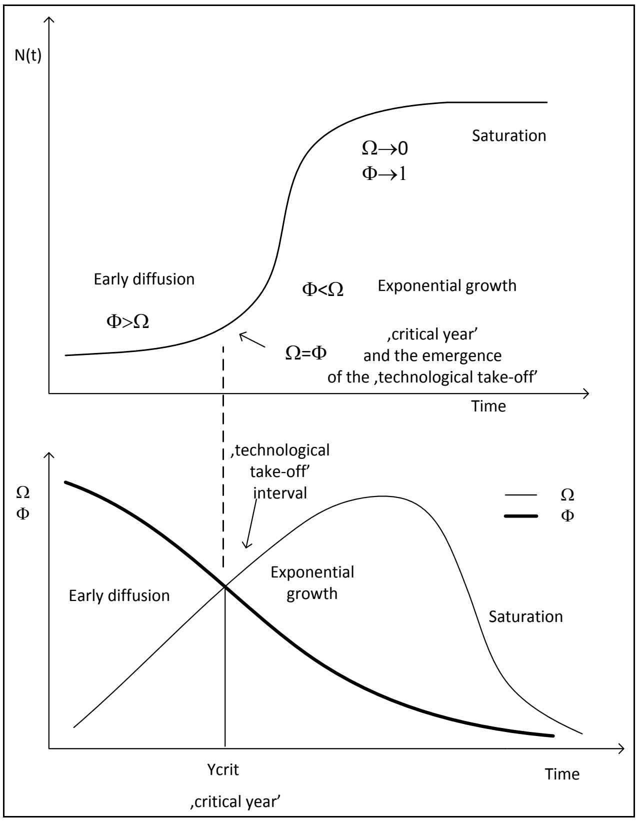


**Fig.2. Relationships between technology replication coefficient ($\Phi_{i,y}$), marginal growth in technology adoption ($\Omega_{i,y}$), critical year ($Y_{crit,i,y}$) along the S-shaped technology diffusion trajectory.**

Finally, we propose to label the 2-year interval, right after the $Y_{crit,i,y}$, as the *'technological take-off'*, which – as previously defined, denotes the time period when the nature of the diffusion process is 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.

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:

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

Following the Eq. (7) we argue that if $y$ stands for $Y_{crit,i,y}$, the *'technological take-off'* interval encompasses the period $< y+1; y+2 >$.

If the critical year ($Y_{crit,i,y}$) is not identified, henceforth the conditions specified in Eq.(7) are not satisfied, and this implies that the emergence of *'technological take-off'* has been held. Technically, it means that during the initial diffusion phase the replication was too weak, to assure gradual increases of $\Omega_{i,y}$, which would allows for closing the gap between $\Phi_{i,y}$ and $\Omega_{i,y}$ (see Fig.3). As result, the paths showing changes in $\Phi_{i,y}$ and $\Omega_{i,y}$ diverge instead of converge, and the critical year does not emerge. If the $\Phi_{i,y} = 1$ or $\Phi_{i,y} < 1$, the situation is similar, and the technology diffusion is impeded. Countries where the $Y_{Crit,i,y}$ has not been identified, are those where the process of entering exponential growth phase has been restrained and they remained virtually locked in 'technology-low-level' trap, becoming latecomers with this respect.

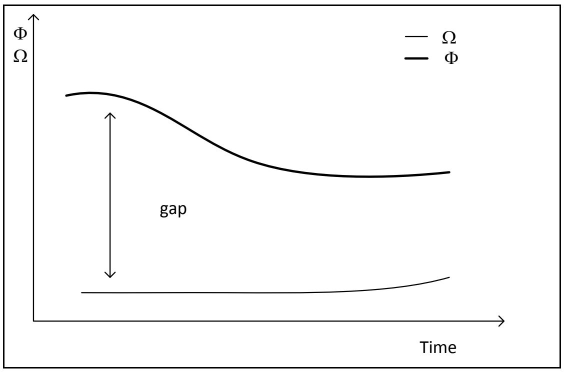


**Fig.3. The 'technology-low-level' trap. Source: Author`s elaboration.**

Finally, we strongly argue that the 'critical year', 'critical penetration rate' and and the *'technological take-off'* do not emerge unconditionally or in isolation, but they are heavily predetermined by multiple social, economic and instructional prerequisites. The *'technological take-off'* is preconditioned and induced by strong stimuli, which are usually well-established in the early diffusion phase. In this vein, we claim that the analysis of the '*critical mass*' should be considered in the broad context, which allows capturing a broad array of factors potentially fostering or impeding the *'technological take-off'*. We suggest that both identification of 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. Such approach places the purely numerical analysis in the broad macroeconomic perspective and is essential for capturing those factors, which potentially foster or hinder the emergence of the *'technological take-off'*. The proposed broadening of the *'critical mass'* analysis sheds light on socio-economic and institutional country`s characteristics, and situate the analysis in broad macroeconomic perspective. These preconditions generally combine institutional change, economic performance, political regimes, social norms and attitudes, and state of development of backbone infrastructure. In a broad sense, the *'technological take-off'* requires a society and an economy to 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 works of Baumol (1986), Perez and Soete (1988), or Verspagen (1991), that country`s ability to adopt new technologies is preconditioned by a wide array of factors. Societies assess and assimilate technological novelties relying upon 'intellectual` capital institutional, governmental and cultural conditions. Some empirical evidence show that the most prominent factor in country`s ability to adopt and use effectively new technologies are education and skills of labour force (Baumol et al. 1989). Countries experiencing significant lacks in these probably shall never be able to assure widespread of new technologies and use the full potential of technological change. As result they will never catch-up with richer countries, and remain as lagging behind and technologically disadvantaged regions.

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