Economic Modelling 37 (2014) 23–31

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

Long-term growth driven by a sequence of general purpose technologies[☆]

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ARTICLE INFO

Article history:
Accepted 1 October 2013

JEL classification:
O11
O33
O41

Keywords:
Schumpeterian growth
Research and development
General Purpose Technologies

ABSTRACT

We present a Schumpterian model of endogenous growth with General Purpose Technologies (GPTs) that captures two important historical stylized facts: First, from the beginning of mankind until today GPTs are arriving at an increasing frequency and, second, all GPTs heavily depended on previous technologies. In our model, the arrival of GPTs is endogenous and arises stochastically depending on the currently available applied knowledge stock. This way of endogenizing the arrival of new GPTs allows for a model which is more in tune with the historical reality than the existing GPT models.

1. General Purpose Technologies and long-term growth

A small number of ground-breaking inventions arriving in ever decreasing time intervals can be identified as important drivers of long-term economic growth: In early human history millennia lay between transforming innovations such as the domestication of plants and animals or the Bronze Age and the Iron Age. Later, the era of the industrial revolution witnessed the rise of the steam engine and production in large-scale factories, followed by the birth of railways and the steam ship in the course of only one century. Finally, current levels of welfare would hardly be possible without the introduction of personal computers and the rapid spread of the Internet usage within a few decades.

The view that such breakthrough technologies or "General Purpose Technologies", or GPTs, can be seen as true "engines of growth" has been shaped by Bresnahan and Trajtenberg (1995): They characterize GPTs as being radical innovations in the sense that they are "… characterized by the potential for pervasive use in a wide range of sectors and by their technological dynamism. As a GPT evolves and advances it spreads throughout the economy, bringing about and fostering generalized productivity gains." Furthermore they emphasize that GPTs are "enabling technologies", which give rise to new opportunities instead of offering complete, final solutions. As a matter of illustration, they present a static model where a monopolistic owner of the GPT interacts with corresponding application sectors.[1]

In the course of this paper we present a model where long-run growth is driven by a sequence of GPTs. Our model captures two stylized facts, which looking at the evolution of GPTs in history, immediately spring to mind: First, the time interval between the arrival of new GPTs has become ever shorter. This point can of course, at least partly, be seen as a result of the ever increasing pool of accumulated knowledge. Second, new GPTs are usually based on previously invented technologies and existing knowledge. Taking the Internet as an example, its invention would not have been possible without a multitude of previous inventions ranging from the computer to electricity. We achieve in modeling these stylized facts by extending our own model of Schumpeterian growth and GPTs, as presented in Schiess and Wehrli (2008). While in our previous model long-term growth is driven by

☆ We thank Lucas Bretschger, Maik Schneider, Thomas Steger, and two anonymous referees for their helpful comments and constructive suggestions.

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[1] In this model the assumption that the GPT is provided by a monopolist can, not surprisingly, result in too little research being performed in the sectors applying this technology.

0264-9993/$ – see front matter
http://dx.doi.org/10.1016/j.econmod.2013.10.014

exogenously arriving new GPTs, we now endogenize the arrival of new GPTs. Specifically, the probability that a new GPT arrives depends on the amount of previously accumulated applied knowledge. This allows us to model long-term growth as driven by a sequence of GPTs which, due to the rising stock of applied knowledge, arrive at ever shorter time intervals. Furthermore, we model economic cycles within the lifetime of a single GPT, assuming that the economic impact of such a new technology decreases over time.

Before we elaborate on the empirical regularities in the arrival of new GPTs which we address in our model, we turn to a brief survey of the previous literature on GPTs.

1.1. Previous literature: Short-term cycles caused by GPTs

While GPTs are widely seen as a main driving force of long-term economic growth, a majority of the literature on GPTs is concerned only with the lifetime of a single GPT, with a strong focus on the first phase after its introduction. This tendency is without doubt motivated by the goal of finding an explanation for the Solow paradox, according to which initially the already ubiquitous computers did not have any impact on productivity statistics. The phenomenon of a new GPT taking decades before having a major impact on economic aggregates is stated for example by David (1990), taking the example of electricity and the computer. Basu et al. (2006) show in an empirical study, that while technological improvements are beneficial in the long run, they can have contractionary effects in the short run. Similarly, Jacobs and Nahuis (2002) present a model whereby the introduction of a new GPT leads to a decrease in output in the short run. This is caused by high-skill workers being drawn away from output production due to the sudden increase in research productivity induced by the new GPT. According to Helpman and Trajtenberg (1998a) a new, exogenously arriving GPT cannot be put to a productive use in the final goods sector until a sufficient number of complementary components needs to be invented first (for example software in the case of computers). As this process requires resources to be moved from the final goods sector to the R&D sector, this results in a temporary decline in measured output. As soon as a sufficient number of components has been developed, the new GPT can be used in the production of the final good, leading to output growth picking up speed again.[2] At this point it is also important to note that the hypothesis of productivity slowdowns after the arrival of new GPTs is not that strong. Carlaw and Lipsey (2011), p. 566 state: "The introduction of a new GPT is sometimes, but not always, associated with a slowdown in the rates of growth of productivity and national income".

1.2. Previous literature: GPT models of long-term growth

Despite the fact that GPTs are widely seen as a main driving force of economic growth, models on GPT-driven long-term growth are relatively scarce: Aghion and Howitt (1998b) present a Schumpeterian model where long-term growth is driven by a sequence of innovations with an arrival rate which is proportional to the amount of labor devoted to research. While this model does not directly apply the concept of GPTs it is nevertheless a starting point when trying to explain growth driven by an endogenously created series of innovations.

Explicitly modeling GPTs, Carlaw and Lipsey (2006) developed a model with a sequence of GPTs arriving one after the other, with only one being active in any given period. In their model the arrival of a new GPT is governed by a constant random variable, hence the expected time interval between two GPTs remains always the same. Meanwhile, there is a variation in the size of the impact of a new GPT rising from the endogenously created pool of basic knowledge.

Van Zon et al. (2003) present a model where again long-term growth is driven by the arrival of new GPTs. While the expected time interval between the arrivals of new GPTs is again fixed, their model allows for different GPTs being active simultaneously. In a further refinement of their baseline model, van Zon and Kronenberg (2006) evaluate different tax policy measures in a scenario where long-run growth is driven by GPTs which are based either on carbon fuels or on non-carbon fuels. The probability of arrival of these GPTs is governed by the amount of currently performed basic R&D and they furthermore allow for various GPTs existing simultaneously.

1.3. Stylized Fact 1: Decreasing time intervals between GPTs

While the question which technologies qualify as a GPT cannot be answered in a conclusive way,[3] the fact that such transforming technologies arrive at an ever faster pace seems to be undeniable. Taking the list of historical GPTs compiled by Carlaw and Lipsey (2006) as shown in Table 1 as a point of reference, it becomes clear that the interval between the arrival of individual GPTs has steadily decreased in the course of history. This general trend is described by Carlaw and Lipsey (2006, p. 131–133) as follows: human existence has been accompanied by the introduction of new GPTs but the rate of innovation of new GPTs has been accelerating drastically in the 20th century. In the 18th century there are two important GPTs, four in the 19th century, and seven in the 20th.

Despite this strong empirical pattern of an acceleration in the arrival rate of new GPTs in the course of history, none of the previously mentioned models considers this fact: On the one hand, the models on the impact of new GPTs on the course of a single economic cycle are by definition not concerned with a sequence of GPTs. On the other hand, the presented models on long-term growth driven by a sequence of GPTs either assume either fixed time intervals between the arrival of new GPTs or a stochastic pattern with no long-term trend in either direction.

1.4. Stylized Fact 2: GPTs based on current stock of applied knowledge

Sir Isaac Newton is frequently quoted, for example by Scotchmer (1991), to illustrate that even the greatest minds in history depend on already existent knowledge: "If I have seen far, it is by standing on the shoulders of giants." Just as non-radical inventions more often than not build on previously existing knowledge, all GPTs had its origins to a certain extent in already present technologies.

Even a cursory glance at some of the GPTs in the past shows this very clearly: The invention of moveable type printing by Johannes Gutenberg in the second half of the 15th century dramatically changed the way how both secular and religious knowledge was disseminated.

Gutenberg made the huge step away from previous methods of reproduction of written information (such as woodblock printing and the production of manuscripts on parchment) by combining a multitude of existing technologies, instead of starting from scratch: The moveable types were derived from stamps used by jewelers to mark their products, while the printing press itself was modeled on the wine press. Paper already existed in his time and while not suited very well for hand-written volumes, turned out to be ideal for this new application.

The same reasoning holds true for the steam engine, which was invented by James Watt towards the end of the 18th century. Previously steam has already been used to drive atmospheric engines, such as the

[2] In Helpman and Trajtenberg (1998b) they additionally model how the diffusion of a new GPT to the various sectors of the economy can prevent it from having an immediate impact on output growth. Eriksson and Lindh (2000), argue that based on Helpman and Trajtenberg (1998a), the initial adverse impact of a new GPT can be mitigated, if components that were built for the old GPT can partially be used even after the arrival of a new GPT. Aghion and Howitt (1998a) retain a component building phase, but add a template-building phase coming into effect immediately after the arrival of a new GPT: As these templates are designed by specialized labor without any other uses, there is no measured impact on output during this initial phase. See Wehrli and Saxby (2008) for a more in-depth literature review.

[3] See Lipsey, Carlaw and Bekar (1998) for further elaborations.