The effects of disruptive innovations on productivity

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1. Introduction

Improvements in productivity have mainly arisen due to technological changes. According to Christensen (1997), a technological change is either disruptive or sustaining. Disruptive innovations are associated with new technologies that cause a shift in the technological paradigm and business routines; they create new products that eventually lead to the demise of existing products. Sustaining innovations reinforce the technological paradigm and business routines; they do not lead to the creation of new products, but rather the development of the existing ones.

The literature on disruptive innovation has principally focused on its effects on firms, industries, and markets (Adner and Zemsky, 2005; Christensen and Raynor, 2003; Daneels, 2004; Henderson, 2006; Momeni and Rost, 2016). A key notion in the literature on disruptive innovations is the displacement of established firms in favor of new firms. In order to progress faster, established firms are forced to focus on the traditional mass market. Disruptive innovation creates an opportunity for new firms to occupy emerging market niches. Over time, the new technology itself improves, and potentially occupy an ever-larger share of the market, thus driving the established firms into a shrinking and, ultimately, profitless corner.

In this paper, we use a macroeconomic perspective to measure the effects of disruptive innovations on total factor productivity (TFP). The effects of technological change can be distinguished by the level of aggregation (Assink, 2006). Indeed, at the micro and meso level, the displacement of established firms is clearly visible, but at the macro level it is only perceptible as a change in productivity. Reinterpreting these dynamics of productivity according to the seminal paper of Olley and Pakes (1996), we can explain why the displacement of established firms in favor of new firms at the micro and meso level appears as a change in productivity at the macro level. The restructuring of firms, industries and/or markets caused by disruptive innovations impacts the displacement of established and less productive firms in favor of new and more productive firms, as assessed at the micro and meso level of analysis. However, the exit of less productive firms from the market in favor of the entry of more productive firms impacts productivity at the macro level. In other words, the reallocation of factors toward more productive (and new) firms affects overall productivity.

Only a few studies focused on the impact of disruptive innovation at the macro level are present in the literature; nevertheless, the effects of disruptive innovation on productivity growth are clear. Scholars agree that at the macro level an additional and consolidated feature of disruptive innovations is a shift in the technological paradigm (Walsh and Linton, 2000; Kostoff et al., 2004; Ho and Lee, 2015; Kaal, 2016). While the effects of sustaining innovation on overall productivity are almost always positive, disruptive innovation can also have a negative impact on productivity. Indeed, the overall value of the effects of disruptive innovation depends on the difference between the positive effect, given by the expansion of new firms, and the negative effect, given by the reduction of established firms (Leipziger and Dodev, 2016). The market share of the established and new firms depends on the factor endowment; therefore, the same disruptive innovation could produce a positive effect in some areas, but a negative effect in others (Figueiredo, 2010).

Two macroeconomic effects of disruptive innovations are implicitly described in the literature: crowding-out; and substitution effect (Kostoff et al., 2004; Manyika et al., 2013). The former describes how production reacts to a new technological paradigm (Kassiech and Rabal, 2007). It is positive when the factor endowment is coherent with the disruption innovation, i.e. when the innovation improves the productivity of the most abundant factor in the economy; when factor endowment is incoherent with disruption innovation, the crowding-out effect is negative. The substitution effect regards the reaction of factors to the new technological paradigm (Frey and Osborne, 2017). It is always negative because it modifies the status quo of the economy and factor endowment is therefore forced to undergo multiple changes in order for production to become efficient again.

In this paper, we provide a new measure of TFP to capture all of the effects of disruptive innovations on GDP previously described. We do this in two steps. In the first step, we observe how the standard measure of TFP does not consider the effect of disruptive innovations; thus, we propose a method for measuring TFP that takes this new effect into account. In the second step, in order to separate out the crowding-out and substitution effects of disruptive innovations, we compare the previously published (and incomplete) methods used in the literature to measure the effects of technological changes on TFP with our proposed method. The result is a new measure of TFP that dissociates the
sustaining innovations effects, the crowding-out effects of disruptive innovations, and the substitution effects of disruptive innovations on productivity growth.

Using the KLEMS database for the years spanning 1973 to 2005, we measure the three effects of technological change for the countries examined: the Republic of Korea, the United States, and Italy. We observe that the effects of disruptive innovations on productivity growth had potentially relevant but different impacts in these countries and across time. Specifically, the effects were positive and high in Korea; the effect of disruptive innovations on the technological paradigm was significantly less in the United States, being close to zero; and in Italy, disruptive innovations had a negative and substantial effect on the economy. The heterogeneity of the production function, not only regards the country, but also the time element, and in particular the speed of innovation. Finally, we found that the three countries were subject to innovations at different times and that the crowding-out effects of these disruptive innovations were almost always more relevant than the substitution effects.

Few scholars have measured disruptive innovations and even less have quantified their effects (for a survey see Colombo et al., 2015). To the best of our knowledge, the only study of the effects of disruptive innovations on TFP is by Amaïzo (2012), who, beginning with Solow’s (1957) formulation, tried to add the impact of disruptive innovations to the production function. However, there were two limitations to this study. First, the author classified the technological paradigm shifts into five arbitrary and discrete segments on the technology ladder. Second, this innovative methodology measured the size of the innovation shift on the unchanged technological paradigm.

The implications of this paper are also relevant in other branches of innovation economics; in particular, in relation to the notions of biased technological change and of technology trajectory. Acemoglu (1998) stated that technological change is biased if it affects the productivity of factors in different ways and changes the technological paradigm. On the other hand, technological change is neutral if it affects the productivity of all factors in the same way, resulting in a technological paradigm that is unchanged, but used in a more efficient way (Solow, 1957). Our proposed measure reinterprets the effects of biased technological change on TFP (Zuleta, 2012; Feder, 2015, forthcoming; Antonelli, 2016) within the framework of disruptive innovation and, in particular, we show that disruptive innovation coincides with biased technological change.

In the words of Henry Ford, “If I had asked people what they wanted, they would have said faster horses”. The effects of this action would have been an example of sustaining innovation or, viewed from an alternative perspective, neutral technological change. Conversely, production of the Ford Model T in 1908 completely transformed the available technical choices by replacing horses with cars and constitutes an example of disruptive innovation or biased technological change. Similarly, even production of the Personal Computer by IBM in 1981 led to a change in technical choice, as it replaced people with computers.

Biased technological change is formally described as a change in the output elasticity of factors (Acemoglu, 2015), and it has both direct and indirect effects on the growth of productivity. On the one hand, variation in output elasticity directly changes production growth and is the crowding-out effect of disruptive innovation. On the other hand, variation in output elasticity modifies the amount of factors that firms use, which indirectly changes production growth and is the substitution effect of disruptive innovation. In contrast, a neutral technological change only has direct effects on productivity growth because sustaining innovation does not affect the technical choice.

The time element is highly relevant for studies into disruptive innovation. Indeed, the direction of technological changes within a technology paradigm is described by technology trajectories (Dosi, 1982); as such, disruptive innovations modify the technology trajectory (Bower and Christensen, 1995). However, disruptive innovation is not an event but is a process (Christensen and Raynor, 2003). The notion of disruptive innovation confirms that the innovation process is path dependent (and not simply past dependent). Indeed, past and current technology trajectories help to identify the probably future innovations, but technological paradigm shifts can modify these expectations (Momeni and Rost, 2016). Using the KLEMS database, we observe that a small shift in technology in an initial period can impact the direction of futures innovations, but that it does not constitute a strict constraint.

The remainder of this paper is organized as follows. Section 2 illustrates the proposed method used to measure the effects of sustaining and disruptive innovations on TFP. Section 3 compares our method with others in order to distinguish the crowding-out and substitution effects of disruptive innovations on TFP. Section 4 reports the empirical implementation of the method and our conclusions are discussed in Section 5.

2. The effects of disruptive innovations on TFP

Each technological change can be described as a shift in the map of isoquant. A neutral technological change corresponds to a parallel shift in the map of isoquant, and a biased technological change corresponds to a change in the slope of the map of isoquant. Using the modern textbook representation of TFP, where $K$ is capital and $L$ is labor, Fig. 1 describes the perfect correspondence between neutral technological change and sustaining innovation and between biased technological change and disruptive innovation. In the left quadrants, we describe a parallel shift of the isoquant that produces the same quantity $Q$ from time 0 to time 1. The isoquant shifts along the isotechnique (dotted line), representing a sustaining innovation. Indeed, it strengthens the technological paradigm because the same labor-capital-saving technology is used. In other words, the country continues to use the same technical choice ($K/L$), but in a more efficient way. In contrast, the change in slope shifts the isoquant of the isotechnique (right quadrant), and represents a disruptive innovation because it affects the technological paradigm. In other words, the new technology modifies the technical choice in the country, and, as shown in the figure, a more labor-saving technology is used.\(^1\)

It is generally acknowledged that Solow (1957) addressed each kind of shift in the production function (Antonelli and Quatraro, 2014). Here, we show that he did not perfectly capture all of the effects of disruptive innovation on TFP. Solow started by assuming a generic aggregate production function at time $t$ of the form:

$$Q = F(K, L, i).$$

(1)

He measured the generic percentage change of output over time, differentiated Eq. (1) with respect to time (the dot is the derivative),

\(^1\) A technological change may also arise in the form of a change in returns to scale. However, in the paper we do not investigate its effect on the TFP any further because it does not modify the effect of disruptive innovations. Indeed, a change in returns to scale is described by an increase or decrease in the distance between isoquants along the same technological paradigm.
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