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On research and development in a model of Schumpeterian economic growth in a creative region☆

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ABSTRACT

We analyze the nature of research and development (R&D) that leads to Schumpeterian economic growth in a region that is creative in the sense of Richard Florida. The engine of economic growth in our creative region is process innovations that lead to *quality* improvements in the machines that are used to produce a final consumption good. We accomplish two main tasks. First, we show that in the so called balanced growth path (BGP) equilibrium, growth is unbalanced because R&D takes place *only* on the machine line with the highest quality. Second, we show how a policymaker can alter the basic model so that the resulting equilibrium has balanced growth in the sense that there is R&D across *all* the different machine lines.

1. Introduction

1.1. Aim and rationale

The urbanist Richard Florida has now successfully popularized the twin concepts of the *creative class* and *creative capital* to economists and to regional scientists.[1] In this regard, Florida (2002, p. 68) helpfully explains that the creative class "consists of people who add economic value through their creativity." This class is composed of professionals such as doctors, lawyers, scientists, engineers, university professors, and, notably, bohemians such as artists, musicians, and sculptors. From the perspective of regional economic growth and development, these people are significant because they possess creative capital which is the "intrinsically human ability to create new ideas, new technologies, new business models, new cultural forms, and whole new industries that really [matter]" (Florida, 2005a, p. 32).

As noted by Florida on numerous occasions, the creative class deserves to be studied in detail because this group gives rise to ideas, information, and technology, outputs that are important for the growth and development of cities and regions. Hence, in this era of globalization, cities and regions that want to be successful need to do all they can to draw in and retain members of the creative class because this class is the primary driver of economic growth.

The above discussion raises the following question: how is the notion of creative capital different from the concept of human capital? To answer this question, first observe that in empirical work, the concept of human capital is typically measured with education or with education based indicators. Even so, Marlet and Van Woerkens (2007) have rightly pointed out that the accumulation of creative capital does *not* have to be dependent on the acquisition of a formal education. What this means is that even though the creative capital accumulated by some members of Florida's creative class (doctors, engineers, university professors) does depend on the completion of many years of formal education, the same is not necessarily true of other members of this creative class (artists, painters, poets). People in this latter group may be innately creative and thus possess raw creative capital despite having very little or no formal education.

Given this situation, Marlet and Van Woerkens (2007) are surely right when they say that there is little or no difference between the concepts of human and creative capital when the accumulation of this

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[1] See Florida (2002, 2005a, 2005b) and Florida et al. (2008).

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creative capital is a function of the completion of many years of conventional education. In contrast, there can be a lot of difference between the concepts of human and creative capital when the accumulation of this creative capital does not have to be a function of the completion of a conventional education. Because creative capital is of two types, it is a *more* general concept than the notion of human capital.

Let us now emphasize three points. First, the work of Eversole (2005), Baumol (2010), Batabyal and Nijkamp (2013), and Siemiatycki (2013) tells us that in regions where the creative class is a dominant part of the overall workforce, there is a definite link between *innovations*, the creative class, and regional economic growth and development. Second, innovative activities and processes are essentially *competitive* in nature and that this competitive aspect is related to the insight of Joseph Schumpeter who contended that growth processes are marked by *creative destruction* in which "economic growth is driven, at least in part, by new firms replacing incumbents and new machines and products replacing old ones" (Acemoglu, 2009, p. 458). Finally, the preceding two points notwithstanding, there are *no* theoretical studies of research and development (R&D) that leads to Schumpeterian economic growth in a region that is creative in the sense of Richard Florida. Hence, in this paper, we provide the *first* theoretical analysis of the ways in which R&D affects Schumpeterian economic growth in a region that is creative *a la* Richard Florida. Now, before we discuss the specifics of our paper, let us first briefly survey the related literature on R&D and Schumpeterian economic growth.

1.2. Review of the literature

In a prescient paper, Leahy and McKee (1972) noted that change in generic regional economies can be appropriately understood by adopting a "Schumpeterian view" of the underlying economy. In spite of the appearance of this statement more than four decades ago, economists and regional scientists have begun to utilize the ideas of Schumpeter to look at the nexus between innovation and economic growth in generic regions only since the early 1980s. Therefore, there is now a fairly sizeable empirical and case study based literature that has analyzed different aspects of Schumpeterian economic growth in generic regional economies.

In his survey article on R&D in creative regions, Malecki (1987) points out that regions that expect to become major areas of what he calls spin-off and creativity are likely to be constrained by the joint preferences of R&D workers, venture capital investors, and high-tech employers. Hodgkinson (1999) concentrates on Illawara, Australia and shows that what she calls "creative milieu factors" are salient determinants of R&D in Illawara. Malecki (2007) notes that although sophisticated policies are now in place to attract creative workers who comprise the core of the knowledge economy, it is important for policy makers to comprehend the nature of place competition and the critical role that knowledge plays in the strategies of the most competitive places.

Dewick et al. (2006) model creative destruction and its impacts on industrial structure in the European Union, the United States, and China. They show that as a result of the development and the diffusion of future biotechnologies and nanotechnologies, some industries grow, others decline, and some new ones emerge. Quatraro (2009) maintains that Schumpeter's views about innovation and business cycles can be used to comprehend the diffusion of innovation capabilities in various Italian regions. Aghion et al. (2009) point out that there is empirical support for the idea that more intense competition enhances innovation among what they call "frontier" firms but that this kind of intense competition may actually discourage innovation in "non-frontier" firms. Focusing on major high-tech industries in the United States, Bieri (2010) finds considerable support for some of Richard Florida's ideas in his empirical study. Specifically, he shows that the mix of creativity and diversity as proxied by his "Florida measure" is a key driver of the location choices of new high-tech firms.

Concentrating on 2645 counties in the United States, Hodges and Ostbye (2010) find support for a Schumpeterian growth model because, in their empirical model, bigger firms are needed to carry out effective R&D which then leads to higher economic growth in the localities being studied. Carillo and Papagni (2014) utilize a Schumpeterian growth model and make the point that the incentive structure confronting an economy's science sector greatly influences both the development of science and the economy itself. Finally, Batabyal and Beladi (2014) use a theoretical model to first derive the equilibrium level of creative capital that is allocated to the R&D sector in a creative region and then show how this level is affected by changes in the parameters of the model.

There are only three theoretical studies that are loosely connected to the basic issue we study—see Section 1.1—in this paper. Batabyal and Nijkamp (2012) have analyzed a one-sector, discrete-time, Schumpeterian model of growth in a general region and have shown that the region being studied experiences bursts of unemployment followed by periods of full employment. Batabyal and Nijkamp (2014) have used a Schumpeterian growth model to study the circumstances in which there is either too much or too little innovation first in a generic region and then when this region is part of an aggregate economy of $N \geq 2$ regions. Batabyal and Beladi (2016) have analyzed the effects of probabilistic innovations on Schumpeterian economic growth in a creative region. This last paper also studies whether there is too much or too little innovation in a particular creative region. In contrast to these three papers, we focus on the nature of R&D *per se* and the Schumpeterian economic growth that the conduct of R&D gives rise to in a creative region. There is no overlap between the questions analyzed by the above three papers and the question we study in the present paper.

The remainder of this paper is organized as follows. Section 2 describes our theoretical model of a creative region that is adapted from Aghion and Howitt (1992) and Acemoglu (2009, pp. 459–472). The engine of economic growth in our creative region is *process* innovations that lead to *quality* improvements in the inputs or machines that are used to produce a final consumption good. Section 3 describes the balanced growth path (BGP) equilibrium and then shows that in this equilibrium, R&D takes place only on the machine line with the *highest* quality. Section 4 shows how our model can be altered by a policymaker so that the resulting equilibrium has R&D across all the different machine lines. Finally, Section 5 concludes and then offers two suggestions for extending the research delineated in this paper.

2. The theoretical framework

2.1. Preliminaries

Consider an infinite horizon, stylized region that is creative in the sense of Richard Florida. The representative creative class household in this region displays constant relative risk aversion (CRRA) and its CRRA utility function is denoted by $\int_0^\infty \exp(-\rho t)[\{C(t)^{1-\theta} - 1\} / (1-\theta)]dt, \theta \neq 1$, where $C(t)$ is consumption at time t, $\rho > 0$ is the constant time discount rate, and $\theta \geq 0$ is the constant coefficient of relative risk aversion.[2] Following Aghion and Howitt (1992, p. 327), in what follows, we suppose that the representative creative class household is risk-neutral and hence this means that $\theta = 0$.

At any time t, the creative region under study possesses *creative capital* which we denote by $R(t)$. The total available creative capital at any time t or $R(t)$ either produces the final consumption good ($R_F(t)$) or is involved in R&D ($R_D(t)$). There is no growth in the stock of creative capital over time and hence we can write $R(t) = R, \forall t$. This creative capital R is supplied inelastically. The market for creative capital in our region is competitive and it clears. Hence, the market clearing condition $R_F(t) + R_D(t) = R$ holds.

[2] See Acemoglu (2009, pp. 308–309) for additional details on the properties of the CRRA utility function.

The aggregate resource or budget constraint in our region at time t is given by

$$C(t)+X(t)+I(t)\leq O(t), \tag{1}$$

where $C(t)$ is consumption, $X(t)$ is total spending on machines, $I(t)$ is total spending on R&D, and $O(t)$ is the output of the competitively produced single final good for consumption that we shall think of as a knowledge good such as a camera or a smartphone. The price of this final good is normalized to unity at all time points and hence $O(t)$ denotes both the output and the value of the final good. Note that the machines we have just referred to can also be thought of as inputs or as intermediate goods.

There is a continuum of machines that is used to produce the single final good $O(t)$. Each machine line or variety[3] is described by ν where $\nu\in[0,1]$. As noted in Section 1.2, the source of economic growth in our creative region is *process innovations* that improve the *quality* of existing machines. To this end, let $q(\nu,t)$ be the quality of the machine of line ν at time t.

The single final good for consumption (the knowledge good) in our creative region or $O(t)$ is produced competitively. The production function for this good is

$$O(t)=\frac{1}{1-\beta}\left[\int_0^1 q(\nu,t)x(\nu,t;q)^{1-\beta}d\nu\right]R_F(t)^{\beta}, \tag{2}$$

where $R_F(t)$ is the creative capital input that is producing the final good at time t, $q(\nu,t)$ is the quality of the machine of line ν at time t, $x(\nu,t;q)$ is the total amount of the machine of variety ν and quality q that is used at time t, and $\beta\in(0,1)$ is a parameter of the production function. Let $w>0$ denote the wage paid to the creative capital input $R_F(t)$ and let $r>0$ denote the interest rate. Since the representative creative class household in the region under study is risk-neutral, we can tell that $r=\rho$.[4]

Notice that for a given machine line ν, only the machine with the *highest* or *cutting edge* quality is used to produce the single final good in equilibrium. This feature is the source of *creative destruction* in the sense of Joseph Schumpeter. In general, what this means is that when R&D leads to the invention of a higher quality machine of a particular line, the previous lower quality machine of the same line is replaced or *destroyed*. Our next task is to explain how new machines in our creative region are first invented and then produced.

2.2. Machine invention and production

In our model, new machine varieties are invented as a result of the conduct of R&D and this R&D builds on the knowledge about existing machines. More specifically, the R&D in our creative region gives rise to innovation and this innovation advances the existing knowledge about the qualities of the various machine lines. There is free entry into R&D. Therefore, any firm can carry out research on the existing machine lines. Once invented, a machine of quality $q(\cdot,\cdot)$ can be produced at the constant marginal cost ζ in terms of the final consumption good.[5] The innovation possibilities frontier[6] in our creative region involves the use of some creative capital units—the $R_D(t)$—for the conduct of R&D. In this regard, note that each creative capital unit employed in R&D gives rise to a flow rate η of a new machine. Now, when the machine currently used in production has quality $q(\cdot,\cdot)$, the new machine has quality $\alpha q(\cdot,\cdot)$, where $\alpha>1$ denotes a proportional increase in quality.

The firm that generates an innovation receives a perpetual patent on the new machine it has invented. As such, this successful innovator has *monopoly* power in the market for machines.[7] The cost of undertaking R&D is assumed to be the same for the incumbent monopolist and for new firms (potential entrants). The existing patent system does not preclude other firms from undertaking research based on the newly invented machine just mentioned.

Now, with this theoretical framework in place, our next task is to first delineate the so called balanced growth path (BGP) equilibrium[8] and then to show that in this equilibrium, R&D takes place *only* on the machine line with the *highest* quality. While undertaking this exercise, we shall adapt some of the results in Peters and Simsek (2009, pp. 250–253) to our analysis of Schumpeterian economic growth in a creative region.

3. The BGP equilibrium with unbalanced R&D

We begin with some notation. Let $p(\nu,t;q)$ denote the price of machine x of variety ν and quality q at time t. Let the function $V(\nu,t;q)$ denote the time t net present discounted *value* of a monopolist with a machine of variety ν and quality q. Finally, let $i(\nu,t;q)$ denote the flow rate at which new innovations occur for a machine of variety ν.

We know that the production function for the final consumption good is given by Eq. (2). Modifying the discussion in Acemoglu (2009, p. 469) to our case, we deduce that conditional on the quality q, the demand function for a machine x of line ν at time t is given by

$$x(\nu,t;q)=p(\nu,t;q)^{-1/\beta}q(\nu,t)^{1/\beta}R_F(t). \tag{3}$$

Recall our earlier stipulation that once invented, a machine of quality $q(\cdot,\cdot)$ can be produced at the constant marginal cost ζ in terms of the final consumption good. This stipulation, the form of the demand function in Eq. (3), and our normalization $\zeta=1-\beta$ (see footnote 5) together tell us that the optimal price of a machine of line ν at time t is.

$$p(\nu,t;q)=\frac{\zeta}{1-\beta}=1. \tag{4}$$

Eqs. (3), (4), and the normalization $\zeta=1-\beta$ tell us that the profit function for machine producers is

$$\pi(\nu,t;q)=\beta q(\nu,t)^{1/\beta}R_F(t). \tag{5}$$

The market for creative capital units is competitive. In addition, from Eqs. (3) and (4), we can tell that the equilibrium demand for machines is given by $x(\nu,t;q)=q(\nu,t)^{1/\beta}R_F(t)$. Therefore, differentiating the right-hand-side (RHS) of Eq. (2) with respect to $R_F(t)$, we know that the wage paid to the creative capital units that are producing the final good must be equal to the marginal revenue product obtained from the $R_F(t)$ input. This gives us

$$\frac{\partial O}{\partial R_F(t)}=\frac{\beta}{1-\beta}\left\{\int_0^1 q(\nu,t)x(\nu,t;q)^{1-\beta}d\nu\right\}R_F(t)^{\beta-1}=w(t). \tag{6}$$

[3] We shall use the words "line" and "variety" interchangeably in the remainder of this paper.

[4] If, instead, this household were risk-averse then we would have $\theta>0$ and the relationship of equality between the time discount rate and the interest rate would cease to hold. As such, we would have to work with a standard consumption Euler equation of the form $\dot{C}(t)/C(t)=(1/\theta)\{r(t)-\rho\}$ in our analysis.

[5] We shall use the normalization $\zeta=1-\beta$ to simplify aspects of our subsequent mathematical analysis.

[6] Since we are working with a model of endogenous technology, firms and individuals in our creative region must ultimately have a choice between different kinds of technologies and, in this regard, greater amounts of R&D ought to lead to the invention of better technologies. These features tell us that there must exist a meta production function or a "production function over production functions" which tells us how new technologies are generated as a function of various inputs. Following Acemoglu (2009, p. 413), we refer to this meta production function as the "innovation possibilities frontier."

[7] Note though that the value of a patent is independent of the machine variety ν at time t.

[8] Since the notion of a BGP equilibrium is a standard concept in economic growth models, we omit a detailed description of this concept. See Batabyal and Beladi (2016) for an elaborate discussion of the properties of a BGP equilibrium.

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The left-hand-side (LHS) of Eq. (6) can be simplified further. This gives us

$$\frac{\beta}{1-\beta}\left\{\int_0^1 q(\nu,t)^{1/\beta}d\nu\right\} = w(t). \tag{7}$$

From the innovation possibilities frontier described in Section 2.2, we know that each creative capital unit generates a flow rate η of innovations. This tells us that the free entry condition into R&D is given by

$$\eta V(\nu,t;\alpha q) \leq w(t), \textit{with equality if } i(\nu,t;q) > 0. \tag{8}$$

To comprehend this condition, note that free entry requires that when the current machine quality is q, the wage in R&D or $w(t)$ should equal the flow benefit from this same R&D. Now, the flow benefit is equal to $\eta V(\nu,t;\alpha q)$. Why? This is because when the current machine quality is q, one more creative capital unit in R&D leads to the discovery of a new machine of quality αq at the flow rate η.

As in Batabyal and Beladi (2016, p. 227), the value function $V(\nu,t;\alpha q)$ in Eq. (8) solves a Hamilton-Jacobi-Bellman equation given by

$$r(t)V(\nu,t;q) - \dot{V}(\nu,t;q) = \pi(\nu,t;q) - i(\nu,t;q)V(\nu,t;q), \tag{9}$$

where $\dot{V}(\nu,t;q)$ is the time derivative of the $V(\nu,t;q)$ function. We now look for a BGP equilibrium in which two conditions are satisfied. First, the amount of creative capital that is employed in the production of the final good is *constant* or $R_F(t) = R_F^{BGP}$. Second, the flow rate at which new innovations occur or $i(\nu,t;q)$ is also *constant*.

We know that the creative class households in the region under study are risk-neutral and therefore $r(t) = \rho$. Using this last result and Eq. (5) to look for a solution to the HJB equation in Eq. (9), we get[9]

$$V(\nu,t;q) = \frac{\beta q(\nu,t)^{1/\beta} R_F^{BGP}}{\rho + i(\nu,t;q)}. \tag{10}$$

We now claim that the free entry condition in Eq. (8) and the solution to the HJB equation in Eq. (10) together imply that R&D will be conducted—or equivalently that R&D expenditures will be directed—only on the machine with the *highest* quality.

To verify the above claim, we proceed with a proof by contradiction. As such, suppose that our claim is false and that there exists a machine line $\hat{\nu}$ with quality $\hat{q} = q(\hat{\nu},t) < q^{highest} = max_{\nu}\{q(\nu,t)\}$ and that the flow rate of innovation $i(\hat{\nu},t;\hat{q})$ is positive. If this is true then the free entry condition in Eq. (8) above tells us that $\eta V(\nu,t;\alpha\hat{q}) = w(t)$. Now, note that for a given $i(\nu,t;q)$, the value of a machine blueprint is increasing in its quality q. So, keeping this last point in mind, Eq. (10) tells us that $i(\nu^{highest},t;q^{highest}) > i(\hat{\nu},t;\hat{q}) > 0$ because if this last set of inequalities did not hold then the free entry condition for machine line $\nu^{highest}$ would not hold.

This means that in any BGP equilibrium in which more than one machine line experiences a positive amount of R&D, what we may think of as the "innovation schedule' or $i(\nu;q)$) is an *increasing* function of quality q. Since we are analyzing a BGP equilibrium in which $i(\nu;q)$ is *not* a function of time, the "increasing in quality" attribute of the innovation schedule $i(\nu;q)$ means that the total amount of creative capital allocated to R&D or $\int R_D(\nu,t)d\nu$ is itself *increasing* over time. This happens because as the distribution of machine qualities increases over time, the only way to sustain more innovation in the different machine lines is by increasing the amount of creative capital allocated to these lines. However, this increase in the allocation of creative capital *contradicts* our maintained assumption that we are in a BGP equilibrium in which the amount of creative capital allocated to the production of the final good or $R_F(t) = R - \int R_D(\nu,t)d\nu$ is constant. Hence, a BGP equilibrium in which there is R&D in more than one machine line does *not* exist.

The last finding in the preceding paragraph effectively tells us that for any initial (time $t = 0$) distribution of qualities that we can represent by $\{q(\nu,0)\}_{\nu=0}^{\nu=1}$, the only machine line in which there is R&D is given by $\nu^{highest} = argmax_{\nu}\{q(\nu,0)\}$. In other words, in the BGP equilibrium that we are studying, R&D is conducted only on the machine line with the *highest* quality. Note that our analysis thus far also tells us that the machine line that will experience positive R&D is determined fundamentally by the *initial* conditions that prevail in our creative region.

Let us now pause to consider the nature of future R&D in our creative region. Our analysis thus far implies that

$$q\left(\nu^{highest},t\right) \geq q\left(\nu^{highest},0\right) \geq q(\nu,t) = q(\nu,0), \forall t, \forall \nu \neq \nu^{highest}. \tag{11}$$

The inequalities in Eq. (11) tell us that the machine line $\nu^{highest}$ will be the only line that will experience R&D at time $t = 0$ and in the future (time $t > 0$). Since no R&D will be conducted on other machine lines, we can also tell that no creative capital units will be employed in these other machine lines. Therefore, the quality of these other machine lines will remain constant over time and these lines will atrophy. In other words, from a R&D perspective, the only thriving machine line in our creative region is the one that had the highest quality at time $t = 0$.

The dramatically uneven fortunes of the different machine lines and the creative capital units employed in these machine lines tell us that at least from the standpoint of R&D, economic growth in our creative region will be *unbalanced*. In turn, this unbalanced growth is likely to lead to the uneven development of our creative region.[10] Note that even though this finding of possible "uneven development" is consistent with Florida's (2005b, p. 172) observation that "the creative economy generates…externalities" such as "uneven regional development" the finding itself shows that a potential role exists for activist policy by an apposite policymaker in our creative region.[11] Such a policymaker would want to know whether there is something that (s)he can do to ensure that the equilibrium in our creative region has *balanced* R&D across the various machine lines. We now proceed to analyze this question.

4. The BGP equilibrium with balanced R&D

Recall that the value function in Eq. (10) is increasing in quality q. This tells us that the unbalanced R&D result in Section 3 arises because even though the benefit from R&D is higher for machine lines with high quality, the cost of this same R&D is *independent* of the quality of a machine line. In turn, this independence result arises because as shown in Eq. (7), the equilibrium wage depends on a simple transformation of the *mean* quality associated with the various machine lines. Therefore, for a BGP equilibrium to have balanced R&D across all the machine lines, a policymaker must ensure that the cost of conducting R&D is *proportional* to the benefit.

One way of getting this proportionality is to alter the innovation possibilities frontier mentioned in Section 2.2. To this end, consider the machine line ν with quality $q(\nu,t)$. Now, remembering the result in Eq. (7),

[9] It is possible to give a *spatial* interpretation to the equation (10) result for the value of a monopolist with a machine of variety ν and quality q. To see this, suppose that our creative region is made up of J distinct spatial units and that the total creative capital that produces the final good or R_F^{BGP} is resident in each of these distinct units. Suppose also that the final consumption good is produced at a single location in our creative region. Then, we can think of the creative capital units that produce the final good transporting themselves to the location in question either by commuting or by migrating to this location. In addition, it is easy to see that the individual spatial units can be ranked in terms of the number of creative capital units that they send to the single location to help produce the final good. Finally, in this spatial interpretation, note that as the creative capital contribution of a particular spatial unit increases, so does the value of a monopolist given in Eq. (10).

[10] A similar result has also been obtained by Batabyal and Nijkamp (2011). The reader should note that this unbalanced growth may also lead to income inequality—a much discussed topic in contemporary times—in the creative region under study.

[11] See Beladi and Oladi (2014) for a discussion of uneven impacts caused by potentially immiserizing technical progress.

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suppose that the employment of a creative capital unit in this machine line gives rise to a flow rate of innovation given by

$$\frac{\eta \int q(\nu,t)^{1/\beta} d\nu}{q(\nu,t)^{1/\beta}}. \tag{12}$$

Despite the above change in the flow rate of innovation, the entire structure of production in our creative region remains unchanged from what we had in Sections 2 and 3. Therefore, the value of a monopolist with a machine of variety ν with quality q or, equivalently, the value of owning a patent on machine line ν with quality q is still given by Eq. (10).

Given the last point in the preceding paragraph, the free entry condition in Eq. (8) can now be written as

$$\frac{\beta}{1-\beta}\int q(\nu,t)^{1/\beta} d\nu = \left\{\frac{\eta \int q(\nu,t)^{1/\beta} d\nu}{q(\nu,t)^{1/\beta}}\right\} V(\nu,t;\alpha q) = w(t). \tag{13}$$

Using Eq. (10) to substitute for $V(\nu,t;\alpha q)$ in Eq. (13), this equation can be rewritten as

$$\left\{\frac{\eta \int q(\nu,t)^{1/\beta} d\nu}{q(\nu,t)^{1/\beta}}\right\}\left[\frac{\beta\{\alpha q(\nu,t)\}^{1/\beta} R_F^{BGP}}{\rho + i(\nu,t;q)}\right] = w(t). \tag{14}$$

We now focus on a BGP equilibrium in which the flow rate of innovation—or the rate at which machine producing monopolists are replaced—is *constant* so that we have $i(\nu,t;q) = i^{BGP}$. Using this constancy condition in Eq. (14), we get

$$\frac{1}{1-\beta} = \frac{\eta \alpha^{1/\beta} R_F^{BGP}}{\rho + i^{BGP}}. \tag{15}$$

We now want to derive an explicit expression for the constant flow rate of innovation i^{BGP}. To do so, we use Eq. (12) and adapt the discussion in Acemoglu (2009, p. 469) to our case. This gives us.

$$i^{BGP} = \left\{\frac{\eta \int q(\nu,t)^{1/\beta} d\nu}{q(\nu,t)^{1/\beta}}\right\} R_D(\nu,t). \tag{16}$$

Rewriting Eq. (16) to isolate the creative capital in R&D, we get

$$R_D(\nu,t) = \frac{i^{BGP} q(\nu,t)^{1/\beta}}{\eta \int q(\nu,t)^{1/\beta} d\nu}. \tag{17}$$

Finally, recall that because the competitive market for creative capital in our region clears, we have $R = R_F(t) + R_D(t)$ which can also be written as $R = R_F(t) + \int R_D(\nu,t) d\nu$. Now, substituting from Eq. (17) into this last market clearing condition and then simplifying, we get

$$R = R_F^{BGP} + \frac{i^{BGP}}{\eta}. \tag{18}$$

Eqs. (15) and (18) can be solved simultaneously to obtain values of R_F^{BGP} and i^{BGP} as functions of exogenous variables and the parameters of the problem under study. After several steps of algebra, we get.

$$R_F^{BGP} = \frac{\rho + \eta R}{\eta\{(1-\beta)\alpha^{1/\beta} + 1\}} \text{ and } i^{BGP} = \frac{(1-\beta)\alpha^{1/\beta}\eta R - \rho}{(1-\beta)\alpha^{1/\beta} + 1}. \tag{19}$$

Inspecting Eq. (19), it is clear that consistent with what we seek, the equilibrium values of both R_F^{BGP} and i^{BGP} are *constant*. In other words, if a policymaker is able to use measures to alter the innovation possibilities frontier so that the flow rate of innovations in our creative region is proportional to the mean quality of the machines—see Eq. (12)—then (s)he will be able to lead the region to a BGP equilibrium in which there is balanced economic growth. In the setting of our paper, balanced means that the amount of creative capital used to produce the final consumption good or R_F^{BGP} is constant and every machine line experiences R&D and the same and constant replacement rate given by i^{BGP}. This concludes our study of the nature of R&D in a model of Schumpeterian economic growth in a creative region.

5. Conclusions

In this paper, we analyzed the nature of R&D that led to Schumpeterian economic growth in a region that was creative in the sense of Richard Florida. The engine of economic growth in our creative region was process innovations that led to quality improvements in the machines that were used to produce a final consumption good such as a smartphone. First, we showed that in the BGP equilibrium, growth was unbalanced because R&D took place only on the machine line with the highest quality. Second, we demonstrated that in principle, our model could be altered by a policymaker so as to generate balanced growth in the sense that the resulting equilibrium had R&D across all the different machine lines.

The analysis in this paper can be extended in a number of different directions. Here are three suggestions for generalizing the research described here. First, it would be interesting to study exactly what kinds of policies a policymaker will need to put in place to alter the innovation possibilities frontier in the manner described in Section 4. Second, it would be instructive to study whether it is possible for the creative region under study to alter the innovation possibilities frontier by engaging in trade in inputs or in the final output with other regions. Finally, it would also be useful to analyze a multi-region model of Schumpeterian economic growth to determine what kinds of spatial interactions between different creative regions can be studied in a theoretically meaningful manner. Studies that incorporate these aspects of the problem into the analysis will increase our understanding of the connections between R&D and Schumpeterian economic growth in one or more creative regions.

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