New Technological Knowledge, Rural and Urban Agriculture, and Steady State Economic Growth

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New Technological Knowledge, Rural and Urban Agriculture, and Steady State Economic Growth[1]

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1

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2

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Abstract

We analyze the growth effects over space arising from the adoption of new agricultural technology in a rural-urban setting. We use a dynamic model to study the impacts of technology and learning on the steady state growth rates of rural and urban regions that produce agricultural goods. New applications of agricultural technologies are tested and adopted in the rural region and they are gradually learned by the urban region. Our analysis leads to four results. First, we determine the steady state growth rate of agricultural output per worker in the rural region. Second, we define an urban to rural region agricultural technology knowledge ratio, analyze its stability properties, and then use this ratio to compute the steady state growth rate of agricultural output per worker in the urban region. Third, for specific parameter values, we study the ratio of agricultural output per worker in the urban to the rural region when both regions have converged to their balanced growth paths. Finally, we discuss the policy implications of our analysis.

Keywords: Economic Growth, Learning, Rural Region, Technology, Urban Region

JEL Codes: O18, Q16, R11

1. Introduction

1.1. Preliminaries and objective

The rural versus urban distinction has accurately delineated the economic landscape for much of human history. Indeed, as noted by Irwin *et al.* (2010), the Industrial Revolution gave rise to a number of technological innovations in production and transportation that resulted in production moving out of homes and into large factories. In addition, labor-saving technologies in agriculture and scale economies in manufacturing led to the movement of large numbers of people and to the emergence of industrial cities.

With the passage of time, cities and urban regions more generally have grown to dominate the economic landscape in most nations of the world. As such, urban regions now are generally considered to be dynamic, they display relatively rapid rates of economic growth, they are industrial, and they are often technologically more advanced. In contrast, rural regions are generally viewed as being not as dynamic, they are frequently agricultural, they display slow economic growth rates, and they are technologically backward.

Regional scientists have been interested in studying rural and urban regions in Europe at least since the seminal works of Christaller (1933) and Losch (1954). However, when studying this topic in contemporary times, they have pointed frequently to rural-urban disparities in metrics such as education (Jordan *et al.* 2014), health (Hall *et al.* 2006), and income (Yamamoto 2008). This focus has led regional scientists to address questions pertaining to the viability of rural regions as independent entities in the face of ever increasing urbanization and the above noted rise of cities.[5]

Even though regional scientists have historically conceptualized rural regions as frequently stagnant and more backward than urban regions, it is important to understand that at least in many of the so called Organization for Economic Cooperation and Development (OECD) countries, this conceptualization is *flawed*. In fact, the work of Ward and Brown (2009), Korpela *et al.* (2010), and Skelhorn *et al.* (2014) clearly tells us that in many OECD nations, rural regions are energetic and vibrant places because of, *inter alia*, a low population density, a re-profiling as dynamic tourist centers, an abundance of natural landscapes, the influx of less conventional people, and a clean, healthy, and safe environment.

Despite the energy and the vibrancy of rural regions, Ward and Brown (2009, p. 1237) are surely right when they point out that "[r]arely are rural and urban areas, and the complex flows and relationships which bind them together, considered in an integrated and holistic way." Given this state of affairs, we would now like to emphasize two points. First, to the best of our knowledge, there are *virtually no theoretical* studies that have examined one or more linkages between rural and urban regions in an analytically meaningful manner Second, we are also unaware of *any theoretical* studies that have modeled rural regions as active and economically thriving areas and not as "lagging regions."[6]

5

See Alberto and Glaeser (1995), Bettencourt (2013), and Kourtit *et al.* (2015) for additional details on this point.

6

Three recent studies have addressed rural-urban-spatial economic interactions. Hodge and Midmore (2008) point out that the spatial diversity of rural economies and the high level of dependence of the countryside on urban economic activity call for appropriate and comprehensive modeling efforts. They offer several examples of how such efforts might proceed. Next, Mayer *et al.* (2016) argue that rural entrepreneurs with linkages to urban areas may act as a countervailing force to economic polarization in cities. Finally, Tacoli (2003) claims that rural-urban linkages have become an essential part of livelihoods and production

Given this lacuna in the literature, our basic objective in this paper is to use a dynamic model to analyze the effects of new technological knowledge adoption and learning on the steady state or long run growth rates of rural and urban regions that produce agricultural goods. We use agriculture as the economic activity that connects the rural and the urban regions. We explain why we focus on agriculture specifically in section 1.2 below. New applications of or innovations in agricultural technological knowledge are developed in the rural region and these technologies are gradually learned or copied by the urban region.[7] Our analysis leads to four results. First, we derive the steady state growth rate of agricultural output per worker[8] in the rural region. Second, we define an urban to rural regional agricultural technology knowledge ratio, examine its stability properties, and then use this ratio to ascertain the steady state growth rate of agricultural output per worker in the urban region. Third, for specific parameter values, we study the ratio of agricultural output per worker in the urban to the rural region when both regions have converged to their balanced growth paths (BGPs). Finally, we discuss the policy implications of our analysis.

1.2. The focus on agriculture

Recall that our primary goal in this paper is to conduct a dynamic analysis of rural-urban linkages when the source of this linkage is the gradual transmission of new technological

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systems to such an extent that the resulting economic landscape is neither rural nor urban. We stress that there is no overlap between these three studies and our paper.

7

We are using the term "agricultural technological knowledge" in a generic sense. Depending on the context, this term can encompass a whole host of practical applications of technologies and farming methods including but not limited to different methods of irrigation, fertilizer application, fruit picking technologies, and precision crop management. In this regard, the reader should note that the new applications or innovations we have referred to in the text of the paper concern these methods and processes. For instance, in the case of precision crop management, the new applications or innovations could be about new and/or different ways of using remote sensing by satellite or unmanned aerial vehicles to deliver spatial data in a timely manner via the internet to farmers.

8

In the remainder of this paper, we shall use the words "laborer" and "worker" interchangeably.

knowledge about the production of a certain good from the rural to the urban region. We know from the work of Irwin *et al.* (2010) and others that rural regions in OECD countries now produce a whole variety of goods. However, it is *not* possible to obtain analytic results with a dynamic model in which there are a large number of goods. Therefore, in the interest of analytical tractability, we have decided to focus on *one good* that is produced in both the rural and in the urban regions of our stylized aggregate economy.

The next question involves determining what kind of good we ought to be working with. In this regard, note that even though rural regions in OECD countries are now diversified in the sense that they typically produce many goods in addition to agricultural goods, agriculture continues to be a *salient activity* in many of these regions. In fact, a recent OECD research report (OECD, 2010, p. 8) clearly states that "[w]hile there are differences among OECD countries in the economic contribution of agriculture in rural areas, in most cases the sector remains the principal user of rural land." More specifically, this point has been emphasized for the disadvantaged southern regions of Italy by Capitanio *et al.* (2011), for rural regions in Hungary by Nemeth (2004), and for rural areas in Romania by Bucur (2015). Given this overwhelming recognition of the importance of agriculture in the rural regions of OECD and other European nations and because there is now a burgeoning literature that documents the increasing significance of agriculture in a variety of urban regions,[9] we have decided to focus on an agricultural good in our dynamic model of an aggregate economy consisting of stylized rural and urban regions. Put differently, if one has to work with a single good on grounds of analytical tractability then we claim that it is eminently reasonable to work with an agricultural good.

9

See Barthel and Isendahl (2013), Draus *et al.* (2014), Opitz *et al.* (2016), and Grebitus *et al.* (2017) for a more detailed corroboration of this claim.

The remainder of this paper is organized as follows. Section 2 describes our theoretical model of a rural and an urban region that is adapted from Krugman (1979), Grossman and Helpman (1991), and Batabyal and Nijkamp (2014). Section 3 derives the steady state growth rate of agricultural output per laborer in the rural region. Section 4 first specifies an urban to rural region agricultural technology knowledge ratio, then examines this ratio's stability properties, and finally uses this ratio to ascertain the steady state growth rate of agricultural output per laborer in the urban region. Section 5 first provides values for certain parameters in our model and then this section uses these values to analyze the ratio of agricultural output per laborer in the urban region to agricultural output per laborer in the rural region when both regions have converged to their BGPs. Finally, section 6 concludes and then discusses possible extensions of the research described in this paper.

2. The Theoretical Framework

The aggregate economy of interest in this paper is made up of a rural and an urban region. We index these two regions with the subscript i where $i = R, U$. The subscript R denotes the rural region and the subscript U denotes the urban region. The two essential factors of production or inputs in each of the two regions at any time t are environmental capital $E_i(t)$ and labor $L_i(t)$. These two factors of production are used either in the *agricultural technology* sector or in the *final good* sector. As noted in section 1, the final good in both the rural and the urban region is an agricultural good.[10] To keep the subsequent mathematical analysis manageable, we suppose that there is no growth in the stock of labor $L_i(t), i = R, U$. The present knowledge

10

In addition to input from workers or laborers, the production of agricultural goods requires, *inter alia*, land, soil, water, and micro-organisms in the air and in the soil. Together, these items constitute what Dasgupta (1996, pp. 389-390) calls the "environmental resource-base." He has pointed out that "the environmental resource-base should be seen as a gigantic capital stock" (Dasgupta, 1996, p. 390). It is this idea that we are utilizing here when we refer to the first factor of production as environmental capital.

about the agricultural technology available in the two regions at any time t is denoted by $A_i(t)$. The proportion of the stock of labor in the rural region that is employed in the agricultural technology sector is denoted by a_{L_R}. Therefore, $(1 - a_{L_R})$ is the proportion employed in the agricultural final good sector.

Before we proceed further, let us briefly discuss whether it is true that there is very little innovation in agriculture that flows out of rural areas. Garcia *et al.* (2013, p. 2) address this question in their study of the Valencia region in Spain. These researchers state clearly that "rural areas are not a handicap for innovation but improved access to training services and technological institutes have a significant influence on innovation." Second, focusing on economic activity in OECD nations in general, a research report (OECD, 2007, p. 2) states that "rural areas are re-inventing their role in the global economy and their capacity to innovate is fundamental." Third, Fieldsend (2013, p. 177) discusses agricultural knowledge and innovation systems in rural areas. He points out that the so called ADER project in the United Kingdom has effectively encouraged entrepreneurship and innovation and that such a project can be used to encourage "agricultural innovation in other farming situations…in eastern and central Europe." Finally, a recent OECD policy note about rural regions (OECD, 2018) contends that rural regions are to be viewed as "engines of national prosperity" (p. 4) in part because technological breakthroughs are likely to lead to "product innovations in agriculture, forestry, mining…" (p. 6). Given these findings in the extant literature, we conclude that innovations of all kinds, including agricultural innovations, have and can continue to flow out of rural regions.

The production functions denoting the outputs of the agricultural final good in each of the two regions are given by

$$O_i(t) = E_i(t)^{\theta}\{A_i(t)\left(1 - a_{L_i}\right)L_i\}^{1-\theta}, \qquad (1)$$

where $O_i(t)$ denotes the output and the value of the agricultural final good in region i, $\theta \in (0, 1)$ is a parameter of the production function, and $i = R, U$. The equation of motion describing the temporal evolution of the stock of environmental capital in the two regions under study is given by

$$\frac{dE_i(t)}{dt} = \dot{E}_i(t) = s_i O_i(t), \tag{2}$$

where $s_i \in (0, 1)$ is the time-independent savings rate in region i and $i = R, U$. The reader will note that consistent with the contents of footnote 10, equation (2) treats the stock of environmental capital like a stock of physical capital that is a key part of many traditional economic growth models.

Glasser (2018) points out that although there are some exceptions, the emergence of agriculture in the urban regions of many countries is generally considered to be a recent phenomenon. Therefore, relative to urban regions, rural regions that frequently have a long agricultural history are typically the *more* dominant source of knowledge about the applications of agricultural technology. To model this idea, we suppose that applications of or knowledge about agricultural technologies are developed in the rural region---also see footnote 7---in accordance with the equation of motion given by

$$\dot{A}_R(t) = B a_{L_R} L_R A_R(t), \tag{3}$$

where $B > 0$ is a time-independent shift variable. The urban region does not develop knowledge about new agricultural technologies by itself. Instead, improvements in the technology possessed by the urban region are the result of learning or copying from the existing technology of the rural region. We model this idea by assuming that the stock of knowledge about agricultural technology in the urban region evolves over time in accordance with the equations of motion given by

$$\dot{A}_U(t) = \zeta a_{L_U} L_U \{A_R(t) - A_U(t)\}, if\ A_R(t) > A_U(t) \tag{4}$$

and

$$\dot{A}_U(t) = 0, if\ A_R(t) \leq A_U(t), \tag{5}$$

where $\zeta > 0$ is a parameter and a_{L_U} is the proportion of the stock of labor in the urban region that is engaged in learning or copying the agricultural technology of the rural region. From this description, it should be clear to the reader that $(1 - a_{L_U})$ is the proportion of the stock of labor in the urban region that is employed to produce the agricultural final good. Finally, observe that because there is no growth in the stock of labor in our model, L_R and L_U are time-invariant. With this theoretical framework in place, we now proceed to determine the steady state growth rate of agricultural output per worker in the rural region.[11]

3. Output Growth in the Rural Region

The model of the rural region that we have just delineated in section 2 can be thought of as a variant of the regular Solow growth model[12] that has been comprehensively discussed in textbooks such as Romer (2012, pp. 6-48). Therefore, we deduce from equation (3) that the growth rate of knowledge about agricultural technology in the rural region is given by

11

Given our primary objective (see section 1.1), the theoretical framework we have just discussed is appropriate because of four reasons. First, this framework allows us to capture a salient technological linkage between a rural and an urban region in a straightforward manner. Second, this linkage and the underlying framework explicitly recognize the fact that the rural region of interest is *not* a lagging region. Third, this linkage and the way in which we model the evolution of knowledge about the relevant agricultural technology in the two regions permit us to obtain an analytic solution. Finally, this analytic solution allows us to shed light on the policy implications of our research. It is this kind of theoretical framework and analysis that is missing in the existing literature in regional science.

12

A related model is described in Batabyal and Beladi (2017).

$$\frac{\dot{A}_R(t)}{A_R(t)} = Ba_{L_R}L_R, \qquad (6)$$

which is time-invariant. Now, adapting a well-known result from the Solow model---see Romer (2012, p. 19)---to our problem, it is straightforward to confirm that the steady state growth rate of the output of the agricultural good per worker in the rural region is equal to the growth rate of knowledge about the agricultural technology and this is given by equation (6). Our next task has two parts to it. First, we stipulate an urban to rural region agricultural technology knowledge ratio and then study this ratio's stability properties. Second, we utilize this ratio to determine the steady state growth rate of the output of the agricultural final good per worker in the urban region.

4. Agricultural Technology Knowledge Ratio and Output Growth in the Urban Region

Let us define $\mathrm{P}(t) \equiv A_U(t)/A_R(t)$ to be the urban to rural region agricultural technology knowledge ratio that we wish to study. In order to examine the stability properties of this ratio, it will be necessary to first find a mathematical expression for $\dot{\mathrm{P}}(t)$ as a function of the ratio $\mathrm{P}(t)$ and the parameters of our model. To do so, we begin by differentiating the defining expression for $\mathrm{P}(t)$ with respect to time t. We get

$$\dot{\mathrm{P}}(t) = \frac{A_R(t)\dot{A}_U(t) - A_U(t)\dot{A}_R(t)}{A_R(t)^2}. \qquad (7)$$

Let us now substitute the expressions for $\dot{A}_R(t)$ and $\dot{A}_U(t)$ from equations (3) and (4) in equation (7) and then simplify the ensuing expression. This gives us

$$\dot{\mathrm{P}}(t) = \left[\zeta a_{L_U} L_U \left\{1 - \frac{A_U(t)}{A_R(t)}\right\}\right] - \left\{\frac{A_U(t)}{A_R(t)}\right\}\left\{B a_{L_R} L_R\right\}. \quad (8)$$

The next step is to substitute the definition $\mathrm{P}(t) \equiv A_U(t)/A_R(t)$ in equation (8) and to then simplify the ensuing expression. This process gives us an equation for $\dot{\mathrm{P}}(t)$ as a function of the ratio $\mathrm{P}(t)$ and the parameters of the model. Specifically, the equation we seek is

$$\dot{\mathrm{P}}(t) = \zeta a_{L_U} L_U - \left\{\zeta a_{L_U} L_U + B a_{L_R} L_R\right\}\mathrm{P}(t). \quad (9)$$

Now, to examine equation (9) in greater detail, it will be necessary to draw the phase diagram implied by this equation. We do this in figure 1. Inspection of figure 1 leads to four

Figure 1 about here

results. First, we see that the mathematical relationship between $\dot{\mathrm{P}}(t)$ and $\mathrm{P}(t)$ is *linear*. Second, the intercept term on the vertical or $\dot{\mathrm{P}}(t)$ axis is $\zeta a_{L_U} L_U > 0$. Third, the slope of this linear relationship is negative and equal to $-\left\{\zeta a_{L_U} L_U + B a_{L_R} L_R\right\}$. Finally, observe that equation (9) and the phase diagram in figure 1 are *not* relevant when $1 \leq \mathrm{P}(t)$. This is because equation (5) clearly tells us that $\dot{A}_U(t) = 0$ whenever $A_R(t) \leq A_U(t)$.

Figure 1 tells us that the graph of equation (9) intersects the horizontal or $\mathrm{P}(t)$ axis at the point P^* which is clearly positive. When $\mathrm{P}(t) < \mathrm{P}^*$ we get $\dot{\mathrm{P}}(t) > 0$. This means that when the agricultural technology knowledge ratio $\mathrm{P}(t)$ begins to the left of P^*, this ratio *increases* over time to the value P^*. In contrast, when $\mathrm{P}(t) > \mathrm{P}^*$ we get $\dot{\mathrm{P}}(t) < 0$. In other words, when the agricultural technology knowledge ratio $\mathrm{P}(t)$ starts to the right of P^*, this ratio *decreases* over time to the P^* value. From this line of reasoning, it should be clear to the reader that the urban to rural region agricultural technology knowledge ratio in our model does converge to the *time-invariant* and *stable* value given by P^*.

It is possible to calculate the actual value of P^*. To do so, let us first set the value of $\dot{\mathrm{P}}(t)$ in equation (9) equal to zero and then simplify the resulting expression. This gives us

$$\mathrm{P}^* = \frac{\zeta a_{L_U} L_U}{\zeta a_{L_U} L_U + B a_{L_R} L_R}. \tag{10}$$

Observe that the ratio in the right-hand-side (RHS) of equation (10) is made up of terms that are all time-invariant and therefore, consistent with our observation in the preceding paragraph, it follows that P^* itself is time-invariant.

Let us now use equation (10) to determine the steady state growth rate of agricultural output per worker in the urban region. The time-invariance of the urban to rural region agricultural technology knowledge ratio tells us that in the steady state, knowledge about agricultural technology $A_U(t)$ in the urban region must be growing at the *same* rate as the knowledge about agricultural technology $A_R(t)$ in the rural region. This result and the fact that our theoretical framework is a modified version of the Solow growth model together indicate that in the steady state, the agricultural economy of the urban region is also a Solow type economy in which the learned or copied knowledge about agricultural technology grows at the time-invariant rate given by $Ba_{L_R}L_R$. Comparing this last finding with equation (6), we see that the steady state growth rate of agricultural output per worker in the urban region is *identical* to the analogous growth rate in the rural region.

The discussion and particularly the last result in the previous paragraph lead to two noteworthy policy implications. First, this result indicates that even though the urban region is technologically less adept than the rural region, from the standpoint of economic growth, patience on the part of policymakers in the urban region will yield dividends. What we mean by this statement is that in the steady state, both regions grow at the same rate and hence *no* growth enhancing policies will be required to improve the efficiency of urban agriculture in the long run. Second, the proportion of the stock of labor in the urban region that is responsible for learning or copying the agricultural technology of the rural region or a_{L_U} has *no* effect on the steady state growth rate of the urban region. Hence, attempts by policymakers in the urban region to stimulate economic growth by moving workers from the agricultural final good sector to the sector responsible for enhancing knowledge about the urban region's agricultural technology by learning or copying the technology of the rural region, will be futile.

We now proceed to our final task in this paper. To this end, we first provide specific values for certain parameters in our model. Then, we use these values to analyze the ratio of agricultural output per worker in the urban region to agricultural output per worker in the rural region when both regions have converged to their BGPs.

5. Agricultural Output per Worker Ratio and Balanced Growth

Let us begin by stipulating the particular values that we shall be using for some of the parameters in our model. The specific values are

$$a_{L_R} = a_{L_U} \text{ and } s_R = s_U. \tag{11}$$

The first parametric stipulation in equation (11) indicates that the proportion of the stock of labor in the rural region that produces agricultural technology knowledge is the same as the corresponding proportion in the urban region that is responsible for learning or copying the agricultural technology knowledge of the rural region. The second parametric stipulation in equation (11) informs us that the savings rates in the rural and in the urban regions under study are equal. There are two reasons for making these parametric stipulations. We want to keep the following mathematical analysis tractable and, in addition, we want to obtain definite results.

To continue the analysis, let us think of the expression $A_R(t)L_R$ as technologically enhanced labor in the rural region. Next, let us divide the production function for the agricultural final good in the rural region given in equation (1) by the above described expression for technologically enhanced labor. This gives us

$$\frac{O_R(t)}{A_R(t)L_R} = \left\{\frac{E_R(t)}{A_R(t)L_R}\right\}^{\theta} \left\{\frac{A_R(t)(1-a_{L_R})L_R}{A_R(t)L_R}\right\}^{1-\theta}. \quad (12)$$

To express equation (12) in a more compact manner, let us make use of the following two definitions. First, let $o_R(t) \equiv O_R(t)/A_R\,(t)L_R$ be the output of the final agricultural good per technologically enhanced laborer in the rural region. Second, let $e_R(t) \equiv E_R(t)/A_R\,(t)L_R$ denote the environmental capital stock per technologically enhanced laborer in the rural region. With the help of these two definitions, we can rewrite equation (12) as

$$o_R(t) = e_R(t)^{\theta}(1 - a_{L_R})^{1-\theta}. \quad (13)$$

We are now in a position to utilize the methodology delineated in Acemoglu (2009, pp. 26-71) to infer that on the BGP, the equality $e_R^* = e_U^*$ must hold. This equality implies that the equilibrium values of the environmental capital to the technologically enhanced labor ratios in the rural and in the urban regions must be the same. Let us now take the time derivative of the defining expression $e_R(t) \equiv E_R(t)/A_R\,(t)L_R$ and then substitute equation (2) for the rural region in the ensuing expression. After some steps of algebra, we get

$$\dot{e}_R(t) = \frac{s_R O_R(t)}{A_R(t)L_R} - \left\{\frac{\dot{A}_R(t)}{A_R(t)}\right\}\left\{\frac{E_R(t)}{A_R(t)L_R}\right\} = s_R o_R(t) - B a_{L_R} L_R e_R(t). \quad (14)$$

Next, let us substitute for $o_R(t)$ from equation (13) into equation (14). This gives us

$$\dot{e}_R(t) = s_R e_R(t)^{\theta}(1 - a_{L_R})^{1-\theta} - Ba_{L_R}L_R e_R(t). \tag{15}$$

Recall that the steady state growth rate of agricultural output in the urban region is given by $Ba_{L_R}L_R$. Using this piece of information and a process similar to that utilized in the derivation of equations (12) through (15) gives us the equation that is the equivalent of equation (15) for the urban region. The particular equation of interest is

$$\dot{e}_U(t) = s_U e_U(t)^{\theta}(1 - a_{L_U})^{1-\theta} - Ba_{L_R}L_R e_U(t). \tag{16}$$

We can now use the parametric stipulations given in equation (11) to express the differential equations in (15) and (16) differently. Doing this, we see that these two differential equations which delineate the evolution of environmental capital per technologically enhanced laborer or e in the rural and in the urban regions are the *same*. From this we infer that the BGP values of both e and o are *identical* in both the rural and in the urban regions. We can express this important result in symbols in the following manner

$$e_R^* = e_U^* \text{ } and \text{ } o_R^* = o_U^* \Rightarrow \frac{o_U^*}{o_R^*} = 1. \tag{17}$$

Let $o_U \equiv O_U(t)/A_U(t)L_U$. Then equation (17) and the definitions of o_R and o_U together suggest that

$$\frac{A_U}{A_R} = \frac{O_U/L_U}{O_R/L_R}. \tag{18}$$

Inspection of equation (18) reveals that the urban to rural region agricultural technology knowledge ratio on the LHS is *equal* to the urban to rural region ratio of agricultural output per laborer on the RHS.

The analysis in section 4 leads us to deduce that in the steady state, the urban to rural region agricultural technology knowledge ratio converges to the stable and time-invariant value P^* given in equation (10). Using equation (10) to substitute for the agricultural technology knowledge ratio A_U/A_R in equation (18), we obtain

$$\frac{\zeta a_{L_U} L_U}{\zeta a_{L_U} L_U + B a_{L_R} L_R} = \frac{O_U/L_U}{O_R/L_R}. \qquad (19)$$

The term $B a_{L_R} L_R$ in the denominator of the ratio on the LHS of equation (19) is clearly positive. Knowing this, it is straightforward to confirm that the entire ratio on the LHS is *less* than one. This result leads to three policy implications.

First, we see that in contrast with the result obtained in section 4, agricultural output per worker in the urban region is now always *less* than agricultural output per worker in the rural region. Second and once again in contrast with what we discovered in section 4, on the BGP, the urban to rural region agricultural output per worker *is* a function of a_{L_U} or the proportion of the labor stock in the urban region whose task is to ameliorate knowledge about the agricultural technology in this region by learning or copying the technology of the rural region. Finally, all other things being equal, the larger is the proportion a_{L_U}, the more closely aligned will the time-path of agricultural output per worker in the urban region be with the corresponding time-path in the rural region. This concludes our discussion of new technological knowledge, rural and urban agriculture, and steady state economic growth.[13]

6. Conclusions

In this paper, we used a dynamic model to study the impacts of agricultural technology on the steady state economic growth rates of a rural and an urban region. Applications of or knowledge about new agricultural technologies were developed in the rural region but improvements in agricultural technology applications in the urban region were the outcome of learning or copying from the rural region's technologies. Our analysis contributes to the extant literature in regional science in four ways. First, we ascertained the steady state growth rate of agricultural output per worker in the rural region. Second, we defined an urban to rural region agricultural technology knowledge ratio, examined its stability properties, and then utilized this ratio to figure out the steady state growth rate of agricultural output per worker in the urban region. Third, for particular parameter values, we analyzed the ratio of agricultural output per worker in the urban region to agricultural output per worker in the rural region when both regions had converged to their BGPs. Finally, we commented on the policy implications of our research.

The analysis in this paper can be extended in a number of different directions. Here are four suggestions for extending the research described here. First, consistent with an observation of Hodge and Midmore (2008) and Ward and Brown (2009) discussed in section 1, it would be useful to introduce at least one rural-urban linkage in addition to agriculture to determine the extent to which these additional linkages can be studied in an analytically meaningful manner.

13

To the best of our knowledge, the results and the policy implications we have discussed in the penultimate paragraph of section 4 and in the last paragraph of section 5 are *new*. Therefore, they cannot be directly compared to findings in the extant literature. In addition, the novelty of our results and the stated policy implications together mean that we do learn something that we did not already know.

Second, it would be helpful to study the ways in which land use changes in rural regions stemming from increasing urbanization in adjacent regions affects the sustainability of agriculture and other economic activities in rural regions. Third, following the work of Mayer *et al.* (2016), it would be meaningful to study spatial disparities between rural and urban regions that arise from different cultural attitudes between agro-economic entrepreneurs in rural regions and “hobby farmers” in cities. Finally, as noted in Meijer *et al.* (2015), it would be important to gain additional analytical insights into the role that technology diffusion, knowledge acquisition, and cultural attitudes play in impacting agricultural, institutional, and food production practices in rural and urban regions. Studies that incorporate these aspects of the problem into the analysis will increase our understanding of the connections between technology, learning, and the economic growth and development of rural and urban regions.

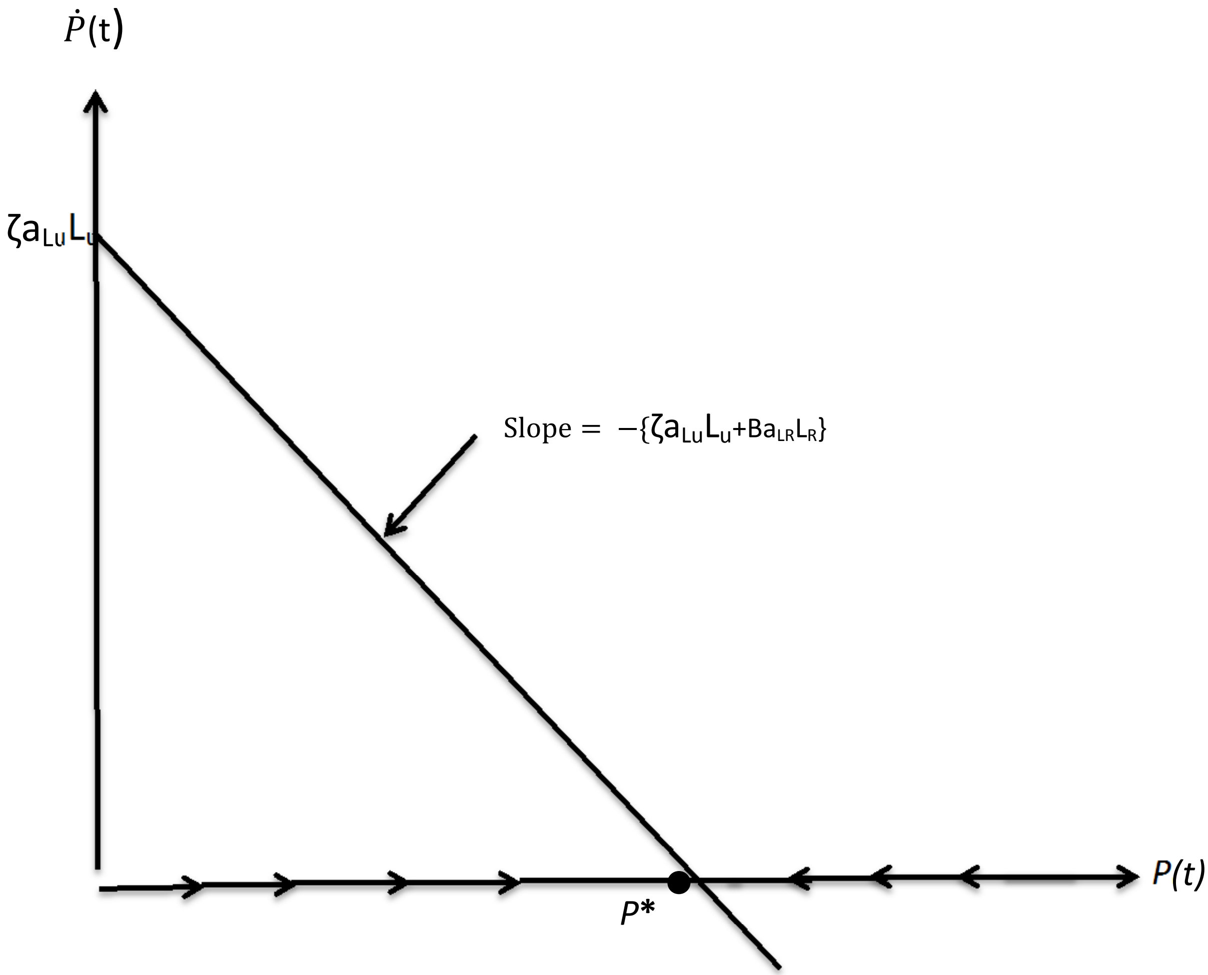

Figure 1: Phase diagram

References

Acemoglu, D. 2009. *Introduction to Modern Economic Growth*. Princeton University Press, Princeton, NJ.

Alberto, A.F., and Glaeser, E.L. 1995. Trade and circuses: Explaining urban giants, *Quarterly Journal of Economics*, 110, 195-227.

Barthel, S., and Isendahl, C. 2013. Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities, *Ecological Economics*, 86, 224-234.

Batabyal, A.A., and Beladi, H. 2017. Patent protection in a model of economic growth in multiple regions, *Networks and Spatial Economics*, 17, 255-268.

Batabyal, A.A., and Nijkamp, P. 2014. Technology, learning, and long run economic growth in leading and lagging regions, *Economic and Political Weekly*, 49, 92-96.

Bettencourt, L.M.A. 2013. The origins of scaling in cities, *Science*, 340, 1438-1441.

Bucur, S.L. 2015. Characteristics and temporal gaps of the rural space, *Agricultural Economics and Rural Development*, 12, 223-235.

Capitanio, F., Adinolfi, F., and Malorgio, G. 2011. What explains farmers' participation in rural development policy in Italian southern region? An empirical analysis, *New Medit: Mediterranean Journal of Economics, Agriculture, and Environment*, 10, 19-24.

Christaller, W. 1933. *Central Places in Southern Germany*. Fischer, Jena, Germany.

Dasgupta, P. 1996. The economics of the environment, *Environment and Development Economics*, 1, 387-428.

Draus, P., Roddy, J., and McDuffie, A. 2014. ‘We don’t have no neighborhood’: Advanced marginality and urban agriculture in Detroit, *Urban Studies*, 51, 2523-2538.

Fieldsend, A.F. 2013. Facilitating innovation in agriculture: Lessons from a European perspective, *Agricultural Economics and Rural Development*, 10, 177-190.

Garcia Alvarez-Coque, J.M., Lopez-Garcia Usach, T., and Sanchez Garcia, M. 2013. Territory and innovative behavior in agri-food firms: Does rurality matter? *New Medit: Mediterranean Journal of Economics, Agriculture, and Environment*, 12, 2-10.

Glasser, R. 2018. The farm in the city in the recent past: Thoughts on a more inclusive urban historiography, *Journal of Urban History*, 44, 501-518.

Grebitus, C., Printezis, I., and Printezis, A. 2017. Relationship between consumer behavior and success of urban agriculture, *Ecological Economics*, 136, 189-200.

Grossman, G.M., and Helpman, E. 1991. Endogenous product cycles, *Economic Journal*, 101, 1214-1229.

Hall, S.A., Kaufman, J.S., and Ricketts, T.C. 2006. Defining urban and rural areas in U.S. epidemiological studies, *Journal of Urban Health*, 83, 162-175.

Hodge, I., and Midmore, P. 2008. Models of rural development and approaches to analysis evaluation and decision-making, *Economie Rurale*, 5, 23-28.

Irwin, E.G., Isserman, A.M., Kilkenny, M., and Partridge, M.D. 2010. A century of research on rural development and regional issues, *American Journal of Agricultural Economics*, 92, 522-553.

Jordan, M.M., Chapman, D., and Wrobel, S.L. 2014. Rich districts, poor districts: The property tax equity impact of Arkansas school finance equalization, *Public Finance and Management*, 14, 399-415.

Korpela, K., Ylen, M., Tyrvainen, L., and Silvennoinen, H. 2010. Favorite green, waterside and urban environments, restorative experiences and perceived health in Finland, *Health Promotion International*, 25, 200-209.

Kourtit, K., Nijkamp, P., and Stough, R. Eds. 2015. *The Rise of the City*. Edward Elgar, Cheltenham, UK.

Krugman, P. 1979. A model of innovation, technology transfer, and the world distribution of income, *Journal of Political Economy*, 87, 253-266.

Losch, A. 1954. *Economics of Location*. Yale University Press, New Haven, CT.

Mayer, H., Habersetzer, A., and Meili, R. 2016. Rural-urban linkages and sustainable regional development: The role of entrepreneurs in linking peripheries and centers, *Sustainability*, 8, 745.

Meijer, S.S., Catacutan, D., Ajayi, G.O.C., Sileshi, W., and Nieuwenhuis, M. 2015. The role of knowledge, attitudes, and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa, *International Journal of Agricultural Sustainability*, 13, 40-54.

Nemeth, I. 2004. Hungarian agriculture at the dawn of EU accession, *EuroChoices*, 3, 6-11.

OECD. 2007. Innovative Rural Regions. https://www.oecd.org/cfe/regional-policy/Innovative-Rural-Regions.pdf. Accessed on 20 June 2018.

OECD. 2010. *Agricultural Policies and Rural Development: A Synthesis of Recent OECD Work*. https://www.oecd.org/agriculture/44561502.pdf. Accessed on 21 June 2018.

OECD. 2018. *Rural 3.0: A Framework for Rural Development*. https://www.oecd.org/cfe/regional-policy/Rural-3.0-Policy-Note.pdf. Accessed on 21 June 2018.

Opitz, I., Berges, R., Piorr, A., and Krisker, T. 2016. Contributing to food security in urban areas: Differences between urban agriculture and peri-urban agriculture in the global north, *Agriculture and Human Values*, 33, 341-358.

Romer, D. 2012. *Advanced Macroeconomics*, 4th edition. McGraw-Hill Irwin, New York, NY.

Skelhorn, C., Lindley, S., and Levermore, G. 2014. The impact of vegetation types on air and surface temperatures in a temperate city: A fine scale assessment in Manchester, UK, *Landscape and Urban Planning*, 121, 129-140.

Tacoli, C. 2003. The links between urban and rural development, *Environment and Urbanization*, 15, 3-12.

Ward, N., and Brown, D.L. 2009. Placing the rural in regional development, *Regional Studies*, 43, 1237-1244.

Yamamoto, D. 2008. Scales of regional income disparities in the USA, 1955-2003, *Journal of Economic Geography*, 8, 79-103.