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Interbasin water transfers and the size of regions: An economic geography example

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ABSTRACT

A two-region, spatial economic model is developed to explore the implications of interregional water transfers on household migration and the intraregional distribution of land between urban and agricultural use when there are agglomeration economies in urban production. A particular example is considered where an arid region lacks water resources but has differing levels of amenities and agricultural productivity relative to a water rich region. The conditions for the stability of both the dispersed and concentrated equilibria are found. Numerical simulations provide a graphical example of the set of stable equilibria in the parameter space. Finally, the model is calibrated using data on household consumption and agricultural production patterns in the US.

1. Introduction

The growth of the American West over the last fifty years can be thanked in no small part for its ability to draw on additional water resources beyond the local available supply. The California State Water Project and the Colorado River Aqueduct both provide Southern California households and agricultural producers with water from the northern portion of the state and the Colorado River, respectively, while the Central Utah Project and the Central Arizona Project both significantly supplement their respective region's local water resources. More generally, a recent study found that arid regions globally are increasingly reliant on imported water for both urban use and agricultural irrigation [1].

Given the significant constraint that limited water resources place on a region's economic viability, why have such large cities and farming communities emerged in these arid locations? In regards to cities, the urban economics literature has focused on local amenities as a driver of household growth in arid regions [2–4]. With the decline of moving costs, households are drawn to regions with agreeable weather or physical beauty. As for agriculture, provided that there is sufficient water for irrigation, the moderate climates and a lack of unpredictable weather create highly productive and year-round growing conditions.

This paper develops a spatial economic model to explore how interbasin water transfers affect interregional migration and water use and the intraregional distribution of land between agricultural and urban use. The primary contribution of this paper is in integrating the tools of spatial and regional economics in order to gain insight on how access to interregional water transfers in the long run play a role in the location choice of households and agricultural production. There has been little theoretical research on the economic implications of regional water transfers (an important exception is Howe and Easter [5]). The international trade literature has focused on 'virtual water', which allows arid regions to reduce the amount of water needed for irrigation by importing goods embedded with a high degree

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of water content [6]. While in the short run this is a viable alternative to maintaining a local agricultural sector for a country facing water scarcity, this strand of the literature ignores the possible productivity benefits from locating agricultural production in highly fertile but arid regions.

In order to explore the interplay between natural amenities and agricultural productivity on household migration and land use patterns, a novel synthesis of the monocentric city framework and the two-region trade models associated with the New Economic Geography (NEG) is developed. The monocentric city model has been the workhorse model in urban economics for the last 40 years, for its capability in analyzing the tradeoffs between the scale economies in urban concentration and the diseconomies of scale in commuting within an intraregional setting. The NEG, in contrast, has provided a class of models designed to explore the impact of interregional trade costs on population migration when there are scale economies in a monopolistically competitive manufacturing sector [7–9]. This paper combines these models in a tractable framework while making a couple of modifications.

The model consists of two regions of equal size whose land can be used for urban or agricultural use (or both). Each region is naturally endowed with differing degrees of natural amenities, which are valued by households, and agricultural total factor productivity, which determines regional agricultural output. Households work in an urban manufacturing sector and live in the city where production is located. The manufacturing sector in each region has external scale economies associated with the size of the local population. The number of residents in each city defines the proportion of each region's land that is developed for urban use, with any remaining land in the region devoted to agricultural production. There is then an opportunity cost to urban land in lost agricultural production, which is increasing in the total factor productivity of the regions agricultural sector. Agricultural producers compete with urban households for both water and land. The agricultural good is assumed to be freely traded between regions as introducing trade costs requires considering different trade regimes (autarky, incomplete specialization and specialization) depending on the relative levels of regional agricultural productivity. Therefore, this assumption, consistent with Helpman's specification [10], allows us to simplify the analysis and focus on the interregional distribution of water and the intraregional distribution of land. Transport costs in agricultural goods are nonetheless important. For instance, Volpe et al. [11] show how gasoline prices, which effect freight rates, are a primary driver in the regional variation in prices for agricultural goods. However, casual empiricism suggests that there is less regional (and seasonal) variation in available produce varieties than in the past, suggesting a decline in transport costs for agricultural goods over time.

In the model we assume that there is a fixed supply of water, which is solely located in a single region, with the other region assumed to be arid. The arid region can import water but there are transports costs associated with shipment, which take the iceberg form, where the costs of transport are paid with the water itself. Therefore the actual available supply of water is dependent on the number of households and the scale of agricultural production in the arid region. Since Samuelson [12] developed the specification of iceberg transport costs it has been widely used in the international trade and spatial economics literature due to the large gains in tractability that the specification provides. While recently the assumption of constant parametric transport costs has come under scrutiny for its lack of realism (see Refs. [13] and [14] we argue that with regards to water, the parametrization of transport costs in this manner is apt and consistent with Samuelson's notion that "… just as only a fraction of ice exported reaches its destination as unmelted ice" [12].

Water loss in interbasin water transfers come largely from evaporation, seepage and carriage water use. For instance, Ma et al. [15] find that 8.57% of the water diversion from the Middle Route of China's South-North Water Transfer Project was lost to evaporation. A report by the Australian government finds that transferring water interregionally through canals would require double the amount of water than would be consumed [16]. While the Food and Agriculture Organizations of the United Nations finds that only 40% of water transfers for agricultural irrigation actually reach the agricultural products, with the remaining portion lost in transit. However, much of the water loss is returned through acquifier recharge and can be used for other purposes at later dates [17]. While carriage water, which is the additional water needed to maintain quality, is estimated to between 0 and 35% of the transfer [18,19]. While we maintain the iceberg assumption to ease the analysis more intricate transport specifications have been developed in the spatial literature. Rogers and Martin [20] and Martin [21] retain the iceberg specification but allow the transport costs to be endogenously determined by the level of public infrastructure, with a greater quantity of infrastructure reducing transaction costs. Konishi [22] and De Cara et al. [23] consider a transport network where goods are collected from their point of origin at common hub and then redistributed out to different markets. Additionally, distance based measures have been applied to pollution costs due to transport to study urban location patterns and densities (see Refs. [24,25]).

There is a long literature on agricultural productivity as summarized in Christensen [26] and Ball et al. [27]. In our model we focus on the regional variation in agricultural productivity, which can be seen in the total factor productivity measures that have been published by the US Department of Agriculture since the 1960's [28]. We consider a simple, but tractable, production function where output is solely produced using water and land and where relative output between regions is simply a function of relative productivity and transport costs. While the model abstracts from many of the important inputs in agricultural production, it is able to provide insights into the spatial variation in agricultural production. We do not consider labor inputs in the agricultural sector, therefore the model is indicative of more developed economies where the share of labor devoted to agricultural production is low. Furthermore, our analysis does not take into account the possibility of adjusting technology or varying the types of crops grown in order to better suit the local environment. These issues are considered in the conclusion by motivating future research. Conceptually the results of our model can be described as a long-run outcome for the location centers for households and agricultural production. For example, empirically in the US the warmer southern and western states have had an increasing share of the US population since the 1960's, while the northern Midwest and the Northeast have seen a declining population share [48–50]. Additionally, the share of total US agricultural output in the southern Pacific and Atlantic regions, particularly in the water stressed regions of California and Florida, has been persistently increasing since 1960 [29]. Meanwhile, the Great Lakes region, often referred to as the "breadbasket of America", has shown a steady decline in population, however continues to produce a sizable share of US agricultural output [29].