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

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Keywords: Water, Land Use Patterns, Regional Migration, Amenities

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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.

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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 (McDonald *et al.* (2014)).

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 (Roback (1982), Rappaport (2006), (2008)). 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 (1971)). 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 of water content (Reimer (2012)). 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 (Krugman (1991), Fujita *et al.* (1999), Baldwin *et al.* (2002)). 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 (1998), 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.* (2013) 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 (1954) 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 Behrens *et al.* (2009) and Behrens and Picard (2011)) 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" (Samuelson, (1954)).

Water loss in interbasin water transfers come largely from evaporation, seepage and carriage water use. For instance, Ma *et al.* (2016) 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 (DSEWPAC, 2010). 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 (FAO, 2008). While carriage water, which is the additional water needed to maintain quality, is estimated to between 0-35% of the transfer (Hollinshead and Lund (2006), ACWA (2016)). While we maintain the iceberg assumption to ease the analysis more intricate transport specifications have been developed in the spatial literature.

Rogers and Martin (1995) and Martin (1999) 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 (2000) and De Cara *et al.* (2017) 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 Nijkamp and Verhoef (2002), Regnier and Legras (2017))

There is a long literature on agricultural productivity as summarized in Christensen (1975) and Ball *et al.* (1997). 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 (USDA ERS(2015a)). 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 (US Census,(1990), (2000), (2011)). 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 (USDA ERS(2015b)). 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 (USDA ERS(2015b)).

A number of papers in the NEG literature have aimed to integrate land use into the core-periphery model (Helpman (1998), Tabuchi (1998), Pflüger and Süedekum (2007), Pflüger and Tabuchi (2010)). However, the analysis is often restricted to urban areas. One of the key features of this model is how variations in agricultural productivity and amenities across regions affect the price of urban land and the extent to which they promote, or curtail, the concentration of households in a single region. Recent research suggests that all land is not, in fact, equal and that variations in land quality across regions have a significant effect on urban land costs (Burchfield *et al.* (2006), Saiz (2010)). Additionally, the uneven distribution of agricultural productivity can be a key determinant in the growth of a region (Matsuyama (1992)). Picard and Zheng (2005) integrated a more fully realized agricultural sector into the NEG framework, however their analysis did not focus on the competition for land between the urban and agricultural sector, which is one of the primary purposes of this research.

An important question to ask is when water is costly to transport while agricultural goods are freely traded between regions, why would the arid region not simply import the agricultural good? Our model suggests than when the agricultural productivity in the arid region is sufficiently high the output from importing water, taking into account any water loss, is greater than if agricultural production were left solely in the water rich region. However, if the amenity level in the arid region is high, households would prefer the land developed for urban use. Therefore, the results hinge critically on the relative agricultural productivity and amenity levels between regions. More generally, our results show that when one region is endowed with both a higher level of amenities and agricultural productivity relative to the other region, these features push households to migrate in opposite directions. A higher degree of local amenities increases the local population, while greater agricultural productivity promotes migration toward the less productive region leaving the more productive region for agricultural use. It follows that when amenities and productivity are sufficiently close to one another there is some level of population dispersion between the two regions. When economies of scale are introduced in the manufacturing sector, if they are sufficiently high, the wage premium generated by the concentration of households in a single region dominates any benefit from a more even distribution of households between both regions. However, if scale economies are high and either amenities or productivity dominates the other, only one of the concentrated equilibria is stable.

The paper is presented as follows. Section 2 develops the model, providing a discussion of both the short-run and the long-run equilibrium and some results. Section 3 discusses the equilibrium prices, population distributions and urban and agricultural land use as well as the conditions for different equilibrium configurations. Section 4 provides a numerical simulation of the model using US data on household consumption and agricultural productivity. Section 5 concludes and offers some suggestions for future research.

2 The Model

Insert Table 1 Here

Table 1 provides an index of notation for the model. Consider two regions that are populated by a mass, N, of identical households, with N_i the number of households in region $i = 1, 2$. There is a single source of water with a finite supply, W, located in region 2. It is costless to transport water within region 2. To supply water in region 1, there are iceberg transport costs that require $\tau > 1$ units to be ordered to supply 1 unit, with $\tau - 1$ units lost in transit.

Each region contains a Central Business District (CBD), which holds an urban manufacturing sector. All local households provide an inelastic supply of labor to the local manufacturing sector and receive the wage y_i. Households demand 1 unit of land, which implies that the size of the city in each region is equivalent to the local population. Each region is assumed to have a fixed quantity of land N. Therefore, in the case that all households concentrate in a single region, all land is used for household consumption.

A household that lives the distance x_i from the city faces commuting costs tx_i, where t is the units of the numeraire good required to travel a unit of distance. It is assumed that interregional commuting is not possible and that all land rent accrues to absentee landlords. [1] Utility is derived from household consumption of the numeraire manufactured good, m_i, and the agricultural good, a_i, which are both freely traded with respective prices 1 and p^a. Additionally, households in each region consume urban water, w_i^u, and face the regional water price, p_i^w. The difference in regional water prices reflect transport costs in the distribution of water and is represented by the relationship $p_1^w = \tau p_2^w$. All households face the price p_2^w. But for a household in region 1, to receive 1 unit of water they must order τ units so that the effective price that they pay is τp_2^w. Utility takes the Cobb-Douglas form and a household's problem in each region at location x_i is then

$$V_i(x_i) = \max_{a_i, m_i, w_i^u} \quad \phi_i a_i^{\alpha} (w_i^u)^{\gamma} m_i^{\eta}, \quad \alpha + \gamma + \eta = 1, \tag{1}$$

$$s.t.$$

$$y_i - r_i(x_i) - tx_i = p^a a_i + p_i^w w_i^u + m_i.$$

The parameter ϕ_i is a regional shift factor that represents each region's endowment of local natural amenities, such as climate or attractive landscape.

Utility maximization yields the following demand functions and indirect utility

$$a_i = \alpha \frac{y_i - r_i(x_i) - tx_i}{p^a}, \quad w_i^u = \gamma \frac{y_i - r_i(x_i) - tx_i}{p_i^w}, \quad m_i = \eta(y_i - r_i(x_i) - tx_i),$$

$$V_i(x_i) = \alpha^{\alpha} \gamma^{\gamma} \eta^{\eta} \left(\frac{y_i - r_i(x_i) - tx_i}{(p^a)^{\alpha} (p_i^w)^{\gamma}} \right). \tag{2}$$

In order for households to be indifferent across locations within a city, utility must be constant. By the assumption of unit lot sizes for households the size of the city in each region is simply N_i. The rent at the boundary of the city is equivalent

[1] While this assumption is chosen for simplification, it does not qualitatively affect the results. What changes is the mechanism whereby relative net incomes vary across regions. In the model with absentee landlords the net income of households within each region varies with the local rental price. When the model is adapted so that all rental income accrues back to households, the regional variation in net income enters through changes in the transfer payment. However, in both models, changes in parameters vary relative incomes in the same direction.

to the agricultural land rent, r_i^a, so that $r_i(N_i) = r_i^a$. Therefore, for utility to be constant it must be the case that $V_i(x_i) = V_i(N_i)$. Given common wages and prices within the city and using (2) the regional bid rent function can then be written as

$$r_i(x_i) = r_i^a + t(N_i - x_i). \tag{3}$$

Note that

$$r_i'(x_i) = -t. \tag{4}$$

This indicates that marginal rents must decline with the distance from the city in order to compensate households for the additional commuting costs they incur from being located further from the CBD.

Inserting (4) in to the budget constraint, the indirect utility can be rewritten as

$$V_i = \alpha^\alpha \gamma^\gamma \eta^\eta \phi_i \frac{(y_i - r_i^a - tN_i)}{(p^a)^\alpha (p_i^w)^\gamma}. \tag{5}$$

Notice that due to the assumption of an inelastic demand for land by households, the demand and indirect utility functions are independent of each resident's commuting distance from the CBD, x_i. Therefore the term x_i is dropped from the remainder of the paper.

2.1 Manufacturing

The manufacturing sector in each region contains a continuum of small firms, which produce outputs using labor with the aggregate linear production function $A_i N_i$. Firms take A_i as given; therefore, perfect competition drives profits to zero, implying $A_i = y_i$. However it is assumed that there are external benefits to production from the size of the local labor force. Therefore workers are paid their average rather than their marginal product with wages taking the form

$$y_i = A_i = A(1 + N_i)^\delta, \tag{6}$$

where δ is a measure of the external benefits to output from local labor supply and A is the marginal product of labor of an isolated worker. The functional form in (6) implies that there is a wage premium for the region with a larger population.

2.2 Agriculture

In each region the land available for agricultural production is the remainder not devoted to urban use, $N - N_i$. The agricultural good is produced using water and land with the intensive form function

$$2\beta_i\sqrt{w_i^a}, \tag{7}$$

where w_i^a is the quantity of agricultural water used per unit of land and β_i is a shift factor that measures the agricultural productivity of the region. The agricultural sector faces the water price p_i^w and the agricultural land rent r_i^a and receives p^a for each unit of the agricultural good sold. The profit function per unit of land is then given by

$$p^a 2\beta_i\sqrt{w_i^a} - p_i^w w_i^a - r_i^a. \tag{8}$$

Profit maximization and perfect competition yield the agricultural water demand and land rents

$$w_i^a = (\frac{p^a\beta_i}{p_i^w})^2, \quad r_i^a = \frac{(p^a\beta_i)^2}{p_i^w}. \tag{9}$$

Note that the ratio of agricultural rents is constant with

$$\frac{r_1^a}{r_2^a} = B, \quad B \equiv \frac{1}{\tau}(\frac{\beta_1}{\beta_2})^2. \tag{10}$$

B, which measures the marginal rate of transformation between each region's agricultural land. This reflects the water weighted productivity of agricultural land in the arid region. Note that when water transport costs increase, relative productivity between region 1 and 2 falls so that households face a lower opportunity cost for urban land in region 1 increasing disposable income.

3 Equilibrium prices and population distributions

3.1 Short-run equilibrium

In the short run, the population share in each region is assumed to be fixed. It is useful to rewrite terms in share form. Define $\lambda \equiv N_1/N$, with $1-\lambda \equiv N_2/N$. In equilibrium the revenue generated from the sale of agricultural goods and water, respectively, must equal the household expenditure on the respective goods. The equilibrium conditions are then given by

$$p^a \left(2(1-\lambda)N\beta_1\sqrt{w_1^a} + 2\lambda N\beta_2\sqrt{w_2^a}\right) = p^a\left(\lambda N a_1 + (1-\lambda)N a_2\right), \tag{11}$$

$$p_2^w W = p_2^w((1-\lambda)N w_2^u + \lambda N w_2^a) + p_1^w(\lambda N w_1^u + (1-\lambda)N w_1^a). \tag{12}$$

Inserting (2),(9) and (10) into (11) and (12) yields short-run prices as function of λ

$$r_2^a = \frac{\alpha}{2}\left(\frac{\lambda(A(1+(\lambda N))^\delta - t\lambda N) + (1-\lambda)(A(1+(1-\lambda)N)^\delta - t(1-\lambda)N)}{(1-\lambda)(B+\frac{\alpha}{2}) + \lambda(1+B\frac{\alpha}{2})}\right), \tag{13}$$

$$\begin{aligned} p_2^w =& \frac{N}{W}\left(\frac{\lambda(A(1+(\lambda N))^\delta - t\lambda N) + (1-\lambda)(A(1+(1-\lambda)N)^\delta - t(1-\lambda)N)}{(1-\lambda)(B+\frac{\alpha}{2}) + \lambda(1+B\frac{\alpha}{2})}\right) \\ &\times (\gamma + \frac{\alpha}{2})(B(1-\lambda)+\lambda), \end{aligned} \tag{14}$$

$$\begin{aligned} p^a =& \left(\frac{\lambda(A(1+(\lambda N))^\delta - t\lambda N) + (1-\lambda)(A(1+(1-\lambda)N^\delta) - t(1-\lambda)N)}{(1-\lambda)(B+\frac{\alpha}{2}) + \lambda(1+B\frac{\alpha}{2})}\right) \\ &\times \sqrt{\frac{N}{W}\frac{\alpha}{2}(\gamma+\frac{\alpha}{2})(B(1-\lambda)+\lambda)}, \end{aligned} \tag{15}$$

with $p_1^w = \tau p_2^w$ and $r_1^a = B r_2^a$.

3.1.1 Short-run comparative statics

Insert Table 2 Around Here

This section considers the effects of the parameters on the short-run prices. Table 2 provides the signs of the comparative statics. An increase in the parameter α, which is the household expenditure share for agricultural goods, leads to an increase in all prices. As households increase their demand for food there is greater demand for factors of production, namely water and land, driving up both input and output prices. An increase in households demand for water, γ, raises the price of water and thus the price of agricultural goods, but has no effect on agricultural land rents. Conversely, an increase in the available supply of water, W, reduces the price of water and the agricultural good but has no effect on rents. While an increase in the population, holding the water supply fixed, raises the prices for both water and agricultural good. When B increases so that agricultural sector in region 1 is relatively more productive than region 2, region 2 rents fall. It is straightforward to show that agricultural rents rise in region 1 with increases in B. Conversely, an increase in τ would reduce B, raising the relative productivity of the agricultural sector in region 2 and the land rents. The comparative statics on the remaining (short-run) parameters are ambiguous. To understand the intuition it is useful to begin with λ. In each price there is a common term in the numerator, which is the sum of the disposable income net of agricultural land rents for workers in each city multiplied by their respective population share. Suppose that $\lambda = 1/2$ so that disposable income net of agricultural land rents are equal for households in both regions. Consider an increase in λ, which would raise the wages of workers in region 1 and lower the wages for workers in region 2. However, it would also increase commuting costs in region 1 while reducing such costs in region 2. Therefore, disposable income increases only if the marginal wage increase outweighs the additional marginal commuting cost. Now consider the common denominator of each of the prices. The denominator is decreasing in λ if $B > 1$. Intuitively, when λ increases and the agricultural sector in region 1 is sufficiently more productive than region 2, there is a productivity loss due to the transition of land from agricultural to urban use, putting upward pressure on prices. We can then say that if the external benefits of agglomeration exceed the commuting costs and $B > 1$, p_2^w and p^a increase with λ. A similar argument holds in the case of N. Prices rise with the total population provided that the wage increase from agglomeration economies offset additional commuting costs.

Finally, we can show the following

$$\frac{\partial p_2^w}{\partial B} > 0, \quad \frac{\partial p^a}{\partial B} > 0 \iff \lambda < 1/2$$
$$\frac{\partial p_2^w}{\partial \tau} < 0, \quad \frac{\partial p^a}{\partial \tau} < 0 \iff \lambda < 1/2$$

This is a curious result, given that we would expect productivity increases to lead to reductions in factor and output prices. Recall that an increase in B raises land rents in region 1 and lowers rents in region 2. Therefore, when $\lambda < 1/2$, an increase in B raises disposable income for a greater segment of the population and increases overall expenditure on water and agricultural goods, thus raising their respective prices.

3.2 Long-run equilibrium

In the long run, households locate in the region where they receive the higher utility. The migration equation is standard from the literature (Baldwin *et al*, 2003) and is assumed to take the form

$$\dot{V}(\lambda) = \lambda(1-\lambda)(V_1 - V_2). \tag{16}$$

where $V_1 - V_2$ is simply the utility gap between regions. When $V_1 - V_2 > 0$ households migrate toward region 1 and when $V_1 - V_2 < 0$ households migrate toward region 2. An equilibrium is characterized by $\dot{V} = 0$. There are solutions at $\lambda = 0, \lambda = 1$, and $\lambda \in (0, 1)$ such that $V_1 = V_2$. A concentrated equilibrium is stable if $\dot{V}|_{\lambda=0} \leq 0$, $\dot{V}|_{\lambda=1} \geq 0$, while an interior equilibrium is stable if $V|_{\lambda^* \in (0,1)} = 0$ and $\frac{\partial \dot{V}}{\partial \lambda}|_{\lambda^* \in (0,1)} < 0$, where λ^* denotes an interior equilibrium. Inserting (13) into (5) and noting the fixed ratio between each region's agricultural land rents and water prices, an interior solution implies

$$V_1 - V_2 =$$

$$\phi_1 \frac{(A(1+(\lambda N))^\delta - r_1^a - t\lambda N)}{(p^a)^\alpha (p_1^w)^\gamma} - \phi_2 \frac{(A(1+(1-\lambda)N)^\delta - r_2^a - t(1-\lambda)N)}{(p^a)^\alpha (p_2^w)^\gamma}$$

$$= \frac{1}{(p^a)^\alpha (p_1^w)^\gamma} \times$$

$$\Bigg(A\left(\Phi(1+(\lambda N))^\delta - (1+(1-\lambda)N)^\delta\right) - t\left(\Phi\lambda N - (1-\lambda)N\right) - (B\Phi - 1)\frac{\alpha}{2}$$

$$\times \left(\frac{\lambda(A(1+(\lambda N))^\delta - t\lambda N) + (1-\lambda)(A((1+(1-\lambda)N)^\delta) - t(1-\lambda)N)}{(1-\lambda)(B+\frac{\alpha}{2}) + \lambda(1+B\frac{\alpha}{2})} \right) \Bigg) = 0$$

$$. \qquad (17)$$

The term $\Phi \equiv \frac{\phi_1}{\phi_2}\frac{1}{\tau^\gamma}$ measures the water cost weighted relative amenity level for locating in the arid region. Thus when transport costs are higher, from (1), amenities are weighted down in region 1 relative to region 2. There is an incentive for concentration through the wage premium, where household income is higher in the region with the larger population. However, concentration raises local urban rents by increasing both commuting costs and the agricultural land rent. The proceeding section will focus on the interplay of these competing features of the model.

3.3 Results

Given the assumption of iceberg transport costs the distribution of the population is independent of the water supply, W, as p_2^w can be factored out of the utility gap. However, the true quantity of water available in the economy must take into account any water loss from interbasin water transfers. The water loss is a function of the size of the urban population and the agricultural sector in the arid region. In terms of households, demand is driven by the number of residents in the arid region, λN, which in turn is determined by the relative amenity level between regions, Φ, the share of expenditure on own water consumption, γ, and the expenditure share on the agricultural good, α. For the agricultural sector, water demand in the arid region is driven by the availability of agricultural land, $(1-\lambda)N$ and the relative productivity of land between regions, B. And of course, interacting with these terms is τ which defines the extent of the water loss from regional transfers. This section begins by analyzing the equilibrium population distributions, λ. We then consider how changes in the parameters effect the long-run equilibrium.

In order to understand the competing roles of regional amenities and agricultural productivity in the household location decision, it is useful to consider the model with no agglomeration economies, i.e. $\delta = 0$.

Proposition 1. *When there are no scale economies in the urban manufacturing sector, there is a unique interior equilibrium when*

$$\frac{A - r_2^a}{A - tN - r_1^a} = \frac{A(1-\frac{\alpha}{2}) + \frac{\alpha}{2}(AB + tN)}{(A - tN)} > \Phi > \frac{(A - tN)B}{AB(1-\frac{\alpha}{2}) + \frac{\alpha}{2}(A + tN)} = \frac{A - tN - r_2^a}{A - r_1^a}. \tag{18}$$

Proof. See Appendix A

The inequalities in (18) ensure that $\dot{V}(0) > 0$ and $\dot{V}(1) < 0$ so that an interior equilibrium exists. The term on the left is the ratio of the disposable income of an isolated worker in region 2 to a worker in region 1 when the population is concentrated. Conversely, the term on the right is ratio of disposable income for workers when they are concentrated in region 2 compared to an isolated worker in region 1. These inequalities simply guarantee that the opportunity cost of concentrating in a single region is sufficiently high so that the population is divided between regions. The intuition is that if ϕ_1 is large relative to ϕ_2, households receive a greater benefit from concentrating in region 1, leaving the land in region 2 for agricultural use. Conversely, if β_1 is sufficiently greater than β_2, all households locate in region 2 to allow for the more productive land in region 1 to be used for agricultural production. Therefore, in order for the population to be divided between the two regions, the relative amenity and productivity levels must be similar in magnitude.

Suppose that the parameters are such that an interior equilibrium exists. Consider how changes in B and Φ affect the equilibrium prices, utility and population share. In the short run, an increase in B raises agricultural output reducing the agricultural price and increasing the price of water. In region 2, in order for the zero-profit condition to hold, agricultural rents fall to accommodate the loss in revenue, while the agricultural rents rise in region 1 due to the increase in productivity. The overall effect is to raise net income, and thus utility, in region 2 relative to region 1, leading to a reduction in λ.

An increase in Φ has no short-run effects. In the long run, increasing amenities in region 1 raises the local utility level, generating migration toward region 1. This increases the demand for urban land in region 1, which drives up r_1^a and raises p^a. The increase in the agricultural price raises revenue for the agricultural sector in region 2, increasing r_2^a. In addition, an increase in p^a lowers the demand for agricultural goods and thus the water inputs needed for agricultural production, reducing p_i^w.

We now introduce urban agglomeration economies. It is helpful to define the following terms.

$$\Phi_1 \equiv \frac{A(1+\frac{\alpha}{2}(B-(1+N)^\delta))+\frac{\alpha}{2}tN}{(A(1+N)^\delta - tN)}. \tag{19}$$

$$\Phi_2 \equiv \frac{B(A(1+N)^\delta - tN)}{A(B-\frac{\alpha}{2}(B-(1+N)^\delta))+tNB\frac{\alpha}{2}}, \tag{20}$$

Φ_1 mirrors (18) and represents the ratio of the opportunity cost of deviating toward region 2 relative to the disposable income of a worker when $\lambda = 1$. Conversely, Φ_2 represents the ratio of the disposable income of a worker in region 2 when $\lambda = 0$ relative to the opportunity cost of deviating toward region 1. This yields the following result.

Proposition 2. *When there are external scale economies in the manufacturing sector, the parameter space can be divided into four cases:*

Case 1: If

$$\Phi_2 < \Phi < \Phi_1, \tag{21}$$

there is a stable interior equilibrium and no stable concentrated equilibria.

Case 2: If

$$\Phi_2 > \Phi > \Phi_1, \tag{22}$$

both concentrated equilibria are stable with an unstable interior equilibrium.

Case 3: If

$$\Phi > \max\{\Phi_2, \Phi_1\}, \tag{23}$$

$\lambda = 1$ *is a stable equilibrium,* $\lambda = 0$ *is unstable. Any interior equilibria come in pairs and alternate between stable and unstable.*

Case 4: If

$$\Phi < \min\{\Phi_2, \Phi_1\}, \tag{24}$$

$\lambda = 0$ *is a stable equilibrium,* $\lambda = 1$ *is unstable. Any interior equilibria come in pairs and alternate between stable and unstable.*

Proof. See Appendix B

Figure 1 provides graphical examples of Proposition 2 in $\{\Phi, \beta_1\}$, $\{\Phi, \delta\}$ and $\{\Phi, \tau\}$ space, respectively as well as three dimensional plots in $\{\Phi, \beta_1, \tau\}$ space and $\{\Phi, \beta_1, \delta\}$ space.

Insert Figure 1 Here In Color

Case 1: When neither the Φ nor B dominates and both scale economies and transport costs are low, there is a stable dispersed equilibrium. This is due to two factors. First, when scale economies are low, the wage premium generated by household concentration in a single region is not sufficient to offset the additional commuting costs from a single large city. Second, the moderate levels of both Φ and B, relative to one another, ensure that land in each region is devoted to both urban and agricultural use. This is an interesting result as in general lower transport costs tend to generate agglomeration in NEG models. In this case, lowering transport costs reduces the costs of locating in the arid region generating more competition for land between the agricultural and urban sectors leading to dispersion.

Case 2: In the case Φ and B are relatively close to one another and both scale economies and transport costs are high, the wage premium is dominant, leading to concentration in either region. The competition for land between the urban and agricultural sectors and the higher urban costs from from longer commutes, are not sufficiently strong to counter the wage premium generated from household concentration in a single region.

Case 3: There is a tendency toward concentration in region 1 driven by both the wage premium and higher level of amenities in region 1. This effect is more pronounced as τ increases, given that in the example, households consume less water per unit of land than agricultural production making it more economical in terms of water use for workers to concentrate in the arid region.

Case 4: In contrast to *Case 3*, when B dominates and there are strong economies of scale, all households locate in region 2 collecting the full agglomeration wage, $A(1+N)^{\delta}$, leaving the more fertile land in region 1 for agricultural production. This outcome becomes less likely as transport costs increase due to the excessive water loss in providing water to the agricultural sector in the arid region.

Insert Figure 2 Here

Up to this point in the analysis, the focus has been on the determinants of the equilibrium. In order to shed some light on how the population distribution changes with the parameters, Figure 2 provides bifurcation diagrams for β_1, ϕ_1, N, τ, α, γ, t and δ.

In Figure 2(a) at low values of β_1, the high amenities in region 1 dominate leading all households to locate in that region. As the land in region 1 becomes relatively more productive households migrate toward region 2 to allow the more fertile land to be employed in agricultural production, until the whole of the population is concentrated in region 2. Similarly, in Figure 2(b), for relatively low levels of ϕ_1, B dominates and the population is concentrated in region 1. As ϕ_1 increases, both a stable and an unstable equilibrium emerge in the interior, up to a critical level after which all households are concentrated in region 1.

Figure 2(c) provides the effect of changes in the total population, N. An increase in the population leads to an increase in the wage rate through the external economies, pushing households toward the more populous region. However, the rise in income increases the demand for the agricultural good, which is more easily satisfied by using the more productive region for agriculture. Therefore, a second stable, concentrated equilibrium emerges in region 2 for higher values of N. In Figure 2(d) when $\tau = 1$, B dominates as all land is devoted to agriculture in region 1. As τ increases both B and Φ decline; however, the effect on Φ is less significant as it is dampened by the exponent γ. Therefore increases in transport costs reduce the benefit of agricultural production to a greater degree than urban development in the arid region. As τ becomes exceedingly high, the whole population locates in region 1. Intuitively, households consume less water than the agricultural sector, therefore water loss is minimized when region 2 is solely dedicated to agriculture and households in the arid region simply import their food.

Figure 2(e) provides the simulation for α, which determines household demand for the agricultural good. When α is small there is less need for the more productive agricultural land in region 1 and the higher amenities dominate, leading to concentration of all households in the region. As α increases the population begins to divide itself between regions as the higher productivity of land in region 1 begins to dominate the amenities until the whole of the population is located in region 2.

In Figure 2(f) , when household demand for water is low, so is the water loss from household consumption leading households to locate in the arid region. However, as household demand for water increases the population begins to shift toward region 2. In Figure 2(g), when commuting costs are low, there exist multiple equilibria, with both concentrated equilibrium stable and an unstable interior equilibrium. As commuting costs increase, a stable interior equilibrium emerges from $\lambda = 1$ and tends to evenly divide the population between regions. Intuitively, as commuting costs take up a larger portion of income, households move to minimize those costs by distributing themselves into two smaller cities.

In Figure 2(h) when there are no scale economies, i.e $\delta = 0$, the population share, and thus the wage, are slightly higher in region 1. Therefore, as δ increases the wage differential between regions 1 and 2 grows, leading to further increases in λ up to a stable concentrated equilibrium at 1. A second unstable arm emerges along with a stable concentrated equilibrium at $\lambda = 0$ as the wage premium from household concentration becomes dominant. Notice that the simulations for δ and

t are almost mirror images of each other, reflecting the trade-off of agglomeration between higher wages and higher commuting costs

4 Numerical Example: An Application to US Data

The above model has provided a broad view of the tension between amenity and productivity levels on regional land use patterns and household location choice. This section provides a numerical example of the model that is calibrated using stylized facts from US data on household consumption and agricultural production. Table 2 gives the parameter values employed in the simulation. In the case of the productivity premium, an index of total factor productivity (TFP) by state in 2004 ranges from a low of 0.5712 for Wyoming to a high of 1.7979 for California, implying the following upper and lower bounds, $B \in (0.3177, 3.1475)$. β_2 is set at 1 and $\beta_1 = \{1, 1.5, 2\}$. Estimates of interregional unit water transport costs show a great deal of variation between regions, largely due to differences in distance and topography. We then set τ to 1.2 and 1.6, to represent high and low transport costs, consistent with ACWA (2016) , Hollinshead and Lund (2006) and DSEWPC(2010). This yields for low transport costs $B = \{.83, 1.87, 3.33\}$ and for high transport costs $B = \{.63, 1.41, 2.5\}$. Consistent with estimates of per-capita water use of 1 acre/ft per person in California (USGS, 2010) we set $W = 1$ and $N = 1$ so that regional population is described in share form.

The model is considered both with and without scale economies in production. The value of δ is set at 0.21 which reflects a 7% increase in average productivity with a doubling of employment density, consistent with empirical estimates. When $N = 1$, t reflects not only the commuting cost per unit of distance, but also the cost of commuting from the boundary of the region. Therefore a worker commuting from the boundary spends roughly 20% of gross income on commuting (AASHTO, 2013). Finally, the value of $\Phi = 1.1$ represents an empirically modest, though as we will see not insignificant, amenity premium for region 1.

Insert Table 3 Here

Tables 4 provides the results of the simulation when transport costs are low. Conceptually, this is consistent with a situation where the water transport technology is better able to reduce water loss and thus more effectively take advantage of regional variations in productivity. The first set of columns represent the case where agricultural productivity is equivalent in each region but, given the transport costs for water, region 2 is effectively more productive in agricultural while region 1 provides greater amenities. In the case when there are no scale economies, 72% of the population reside in region 1 and roughly 65% of region 1's agricultural demand is imported. When scale economies are introduced all households locate in region 1 and all food is imported. Additionally, scale economies uniformly raise prices and utility due to higher household income. The concentration of the population implies that only region 2 produces the agricultural good. Therefore agricultural water use increases in region 2 and urban water use increases in region 1. In this case, household concentration shifts agricultural production to the more productive region generating higher total agricultural output and a lower level of water loss. Notice that average urban land rent, which is calculated by integrating the rent function over the city and dividing by the local population, is increasing in region 1 and decreasing in region 2 when productivity is held fixed and scale economies are introduced.

The second set of columns in Table 4 represents the case where the agricultural sector in region 1 is moderately more productive. Given the higher productivity of land in region 1, when there are no scale economies, the population is more evenly divided with a 63% share in region 1. However, only 13% of region 1's agricultural demand is imported. When scale economies exist, again region 1 is solely used for housing and there is a similar effect on prices and utility from an increase in δ. However, note that there is an increase in the land rent in region 1 and decrease in region 2 in relation to the case where region 2 was more productive. Note that water loss falls by nearly 50% as all agricultural land in region 1 is taken out of production when households concentrate. However there is also a 13% decline in total agricultural output.

The third set of columns denotes the case where region 1 is significantly more productive than region 2. In this case, while scale economies do continue to push more workers toward region 1, 28% of the land remains available for agricultural production. When there are no scale economies, region 1 is a net exporter of agricultural goods, however, when δ is increased, the loss of available land for agriculture makes it so that the region becomes again a net importer. While there is a reduction in water loss it is much smaller than in the previous case, roughly 10% compared to nearly 50%. This occurs due to the fact the region 1 continues to produce the agricultural good. Given that land used for housing utilizes less water than if used for farming, the fact that workers don't fully concentrate in region 1 as before means a significant amount of water continues to be lost through transfers to region 1 for agricultural production. However, the fact that region 1 continues to produce output reduces the loss to total agricultural output. It is worth noting that total urban water use, taking into account water loss, stays roughly constant over each example. Finally, average urban land rents appear to rise at a slower rate in region 1 and fall at a slower rate in region 2 when scale economies are introduced as productivity increases in region 1. In addition, the share of income devoted to housing on average in region 1 goes from roughly 10% when there are no scale economies and $\beta_1 = 1$ to nearly 17% when $\beta_1 = 2$ with scale economies. While in region 2 with the same parameter changes the income share falls from 7.5% to 5.5%.

Table 5 gives numerical results for the model when transport costs are high. In contrast to the results in Table 4, this example highlights a situation where the water transport technology is less effective. In this case, greater productivity in the arid region is ultimately diminished by the large water loss associated with the water transfer. Qualitatively, the results are largely the same. However, when both regions have the same productivity, so that region 2 is effectively more productive, once scale economies are introduced, land rents fall. This is due to the fact that the scale economies push households toward region 1, generating less competition for land in the more productive region. As would be expected, water loss is higher and agricultural output is lower than in the case with lower transport costs, while urban water use remains largely unchanged. When there are no scale economies, total agricultural water use is lower with high transport costs compared to low transport costs, however the quantity of water used by the agricultural sector in region 2 is higher as the region generates a greater share of the agricultural output. Interestingly, the population shares with no scale economies are largely the same in the case of both high and low transport costs. However, when $\beta_1 = 2$, when scale economies are introduced there is stronger shift by households toward region 1 when there are high transport costs, with a 36% increase in the population compared to 26% when there are low transport costs. The larger transition of agricultural land to urban use in region 1 generates a greater decline in agricultural output relative to the case of low transport costs.

Insert Table 4 and 5 Around Here

4.1 A discussion of the numerical results in light of US migration patterns

Can the results in Tables 4 ad 5 be used to describe migratory patterns in the US? Of course a linear two-region model cannot fully account for the migration patterns across households in fifty states. We nevertheless feel that it is capable of qualitatively reproducing many features in the data. Consider a relatively small region such as Southern California where the productivity of the land is relatively homogenous over the region, while the area closer to the coast has more amenable weather compared to the much warmer regions further inland. In the early 1900s the land in Southern California was largely devoted to agriculture. Presently, the region is completely urbanized from Ventura County to the Mexican border and well inland through Los Angeles County, Riverside County, Orange County and San Diego County. The eastern portion of Southern California that buttresses Arizona and Nevada remains largely agricultural containing two of the most productive regions in the country, the Imperial Valley and Coachella Valley. This result would be consistent with the first set of columns in Tables 4 and 5 where the agricultural productivity in region 1 is low and the amenities dominate. Similarly, we can compare Florida, which ranked 2nd in US agricultural TFP in 2004 and grew from the 33rd most populous state to the 4th between the years 1900 and 2000 (Hobbs and Stoops, 2002), to Iowa which ranked 3rd in TFP and fell in population rank from 10th to 30th between 1900 to 2000. This is consistent with a specification where B is relatively low as both regions have similar productive capabilities, while Φ would favor Florida with its warmer climates and coastal amenities.

Finally, consider California in relation to Texas. Both offer warm weather and face water supply concerns, yet California ranked 1st in agricultural TFP in 2004 while Texas was ranked 43rd. In 1960 California farm output was 50% greater than that of Texas and by 2004 it was 100% larger, while over the same time period both Houston and the Dallas-Fort Worth areas entered into the top 10 of the most populous US cities. This is consistent with a more dominant agricultural sector in California. Both California and Texas have significant urban sectors, while the agricultural sector is larger and growing at a faster pace in California.

5 Conclusion and Future Research

This paper has developed a two-region economic geography model to explore the interplay of agricultural productivity and amenities in arid regions when water is a mobile factor and there are economies of scale in the urban manufacturing sector. When scale economies are sufficiently low, it was shown that amenities and agricultural productivity drive land-use patterns in opposite directions. Amenities encourage the development of land for urban use, while greater productivity supports land use for agricultural production. For moderate levels of both amenities and productivity, there is a stable and dispersed equilibrium. If economies of scale in the manufacturing sector are high and neither the productivity or amenity levels dominate the other, the wage premium generated from all households concentrating in a single region overwhelms the benefits of a more even distribution of the population. When either the amenities or agricultural productivity dominates the other and there is a high degree of scale economies, only one of the concentrated equilibria is stable. The parameter space was explored in order to define the conditions for stable and unstable equilibrium configurations, and bifurcation diagrams were shown numerically for key parameters. Finally, the model was calibrated to reflect US data on household consumption and agricultural production patterns.

While this paper has developed a coherent framework to explore how competing urban and agricultural interests vie for water and land, in the interests of tractability a number of realistic features have been excluded. Iceberg transport costs provide a convenient way to conceptually model freight costs; however, they focus solely on the marginal cost of distribution associated with the loss of water. For carriage water, the iceberg specification is appropriate however to consider evaporation and leakage a distance based measure would be more appropriate. Additionally, it would be important to consider additional marginal costs, for instance, the energy costs associated with pumping water. Zhou and Tol (2005) find that water is relatively inexpensive to transport horizontally but becomes exceedingly costly to transport vertically. In practice water distribution networks, both intra- and interregionally, have significant fixed costs, particularly in the development of the network linking communities to an outside water source. Such networks require financing from local, state and federal governments. The economies of scale and public financing of interregional water transfers should be further explored in order to gain a more robust understanding of the effect of water transfers on migration and land use.

Our model assumed that the agricultural good is produced using solely water and land with no labor inputs used. For a country like the United States where less than 1% of the population is employed in agricultural production, this assumption is less onerous. However, in countries where agricultural employment is high it would be useful to consider how variations in productivity effect agricultural employment across regions. Additionally, it would be interesting to consider a situation in which agricultural workers face not only a choice between regions but between remaining in the agricultural sector or switching to urban employment. Furthermore, our specification of the technology for the agricultural sector as simply a Cobb-Douglas aggregation of water and land implies unitary elasticity of substitution which is higher than empirical estimates which range from 0-0.5. (Luckman *et al.* (2014), Graveline and Merel (2014)). Therefore, if the model were to be extended for policy analysis more sophisticated functional forms would need to be employed.

Additionally, while our model is able to qualitatively capture some long-run macro trends in the location of agricultural production the model ignores the possible use of different production technologies which allow for adaptation to different climates and geography. Moreover, our model does not deal explicitly with varieties of agricultural goods which could allow for regional specialization in distinct varieties of output.

Due to the assumption of iceberg transport costs, the available supply of water plays no role in the long-run distribution of households. It would be useful to introduce a more intricate specification in which the availability of water played an explicit role in the household and agricultural producers location decision. In addition, an important issue is the reliability of water supply, in particular for agriculture. For example, while households can be relatively flexible in their water use (by reducing irrigation, taking shorter showers) almond farmers can not in the short run as easily adapt without losing a significant share of their crop. Therefore introducing a dynamic, stochastic water supply that takes into account the likelihood of wet, average or dry years would help to better understand agricultural producers planting decisions.

This model has provided a competitive framework where water is allocated to its best use through the price system. However, water transfers are often dominated by a Byzantine set of rules, where water prices vary not only by city or region, but by consumers within cities and rural areas as well. A portion of agricultural land in certain regions may be allocated water rights that are not available to the remaining shares of land. Therefore, an understanding of the institutional factors that define water-use patterns, often over-and-above the market structure, are crucial in gauging the future development of arid regions and the ability to sustain future growth in population and agricultural production.

Finally, high amenity cities tend to have higher rents. Households respond to these higher prices by reducing the quantity of living space they consume, presumably offsetting the loss through the additional benefits they receive from the local amenities. Relaxing the assumption of inelastic demand for land by households can provide a more realistic portrait of land distribution in a region with both high productivity and amenities. In particular, it would allow for the possibility of a large share of the population residing in a single region on a relatively small share of the land.

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Appendix

A Proof of proposition 1

Setting $\delta = 0$ in [17] implies that there is a quadratic solution in n_1 for $\dot{V} = 0$. This further implies that the slope of $\dot{V}$ changes signs at most once. It follows that solving for Φ in $\dot{V}|_{n_1=0} > 0$ and $\dot{V}|_{n_1=1} < 0$ ensures a single crossing through the x-axis.

B Proof of proposition 2

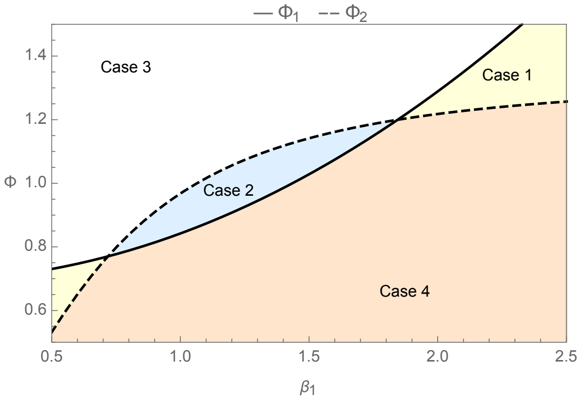
The conditions for each case are the following: case 1 requires $\dot{V}|_{n_1=0} > 0$ and $\dot{V}|_{n_1=1} < 0$, case 2 requires $\dot{V}|_{n_1=0} < 0$ and $\dot{V}|_{n_1=1} > 0$, case 3 requires $\dot{V}|_{n_1=0} > 0$ and $\dot{V}|_{n_1=1} > 0$ and case 4 requires $\dot{V}|_{n_1=0} < 0$ and $\dot{V}|_{n_1=1} < 0$. Solving for Φ in each case yields the result.

For regions $i = 1, 2$			
a_i	demand for agricultural good	α	agricultural good expenditure share
m_i	demand for manufacturing good	β_i	agricultural total factor productivity
r_i^a	agricultural land rent	γ	household water expenditure share
$r_i(x_i)$	urban land rent at location x_i	δ	scale economies in manufacturing sector
t	per unit commuting costs	η	manufacturing good expenditure share
w_i^a	agricultural water demand	λ	regional share of total population
w_i^u	urban water demand	ϕ_i	regional amenity shift factor
x_i	household commuting distance	τ	water transport costs
y_i	household wage	Φ	relative regional amenities
A	productivity of isolated worker		
B	relative regional productivity		
N_i	regional population		
N	total population		
W	total supply of water		
V_i	indirect utility		

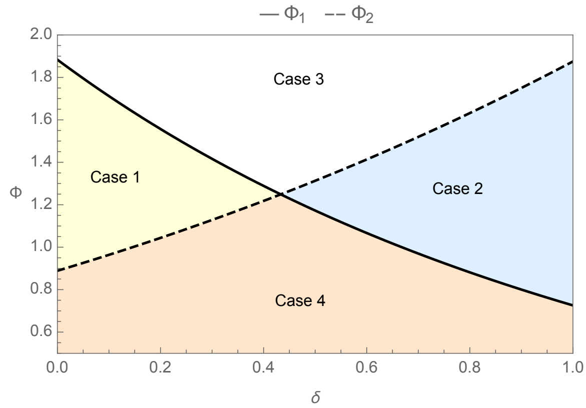
Table 1: Notational Glossary

	α	γ	B	N	W	λ
r_2^a	+	0	-	?	0	?
p_2^w	+	+	?	?	-	?
p^a	+	+	?	?	-	?

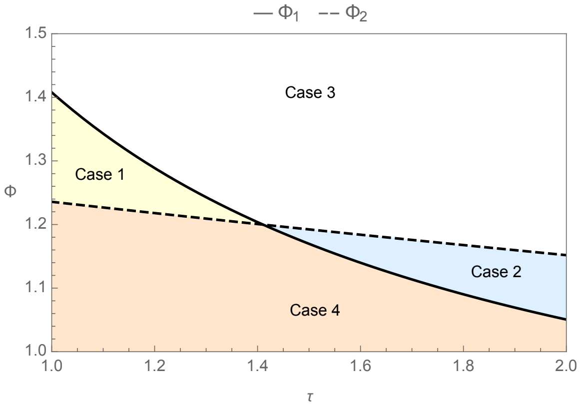
Table 2: Short run comparative statics



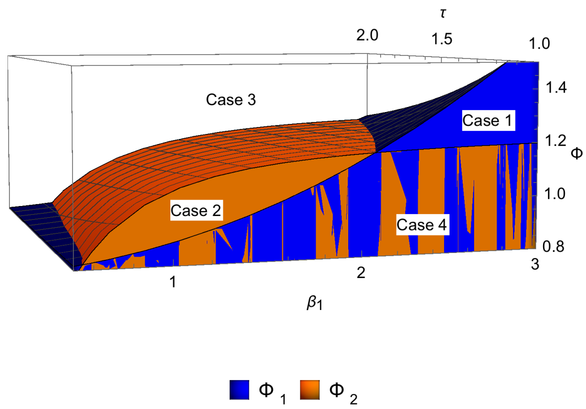
(a) $\{\Phi, \beta_1\}$ space



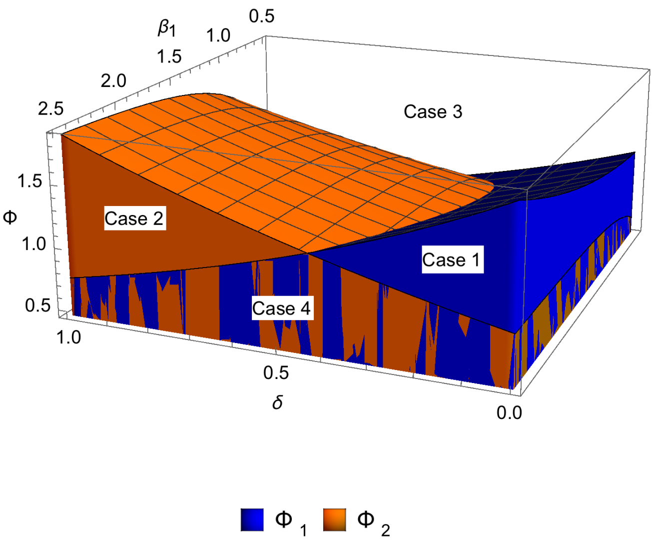
(b) $\{\Phi, \delta\}$ space



(c) $\{\Phi, \tau\}$ space



(d) $\{\Phi, \beta_1, \tau\}$ space



(e) $\{\Phi, \beta_1, \delta\}$ space

Figure 1: Equilibrium regions in parameter space. Note: A=10, t=2, $\alpha = .4$, $\tau = 1.2$, $\beta_1 = 2$, $\beta_2 = 1$, $\phi_2 = 1$.

$t = \$10,000$	(AASHTO, 2013)
$A = \$50,000$	(US Census, 2016)
$B = \{0.63, 0.83, 1.41, 1.87, 2.5, 3.33\}$	(USDA ERS, 2015a)
$W = 1$	(USGS, 2010)
$\alpha = .1$	(USDA ERS, 2016)
$\delta = .21$	(Ciccone and Hall, 1996)
$\gamma = .02$	(Hawk, 2013)
$\tau = \{1.2, 1.6\}$	(ACWA, 2016), (Hollinshead and Lund, 2006), (DSEWPC, 2010)
$\Phi = 1.1$	(Rappaport, 2008)

Table 3: Parameter values

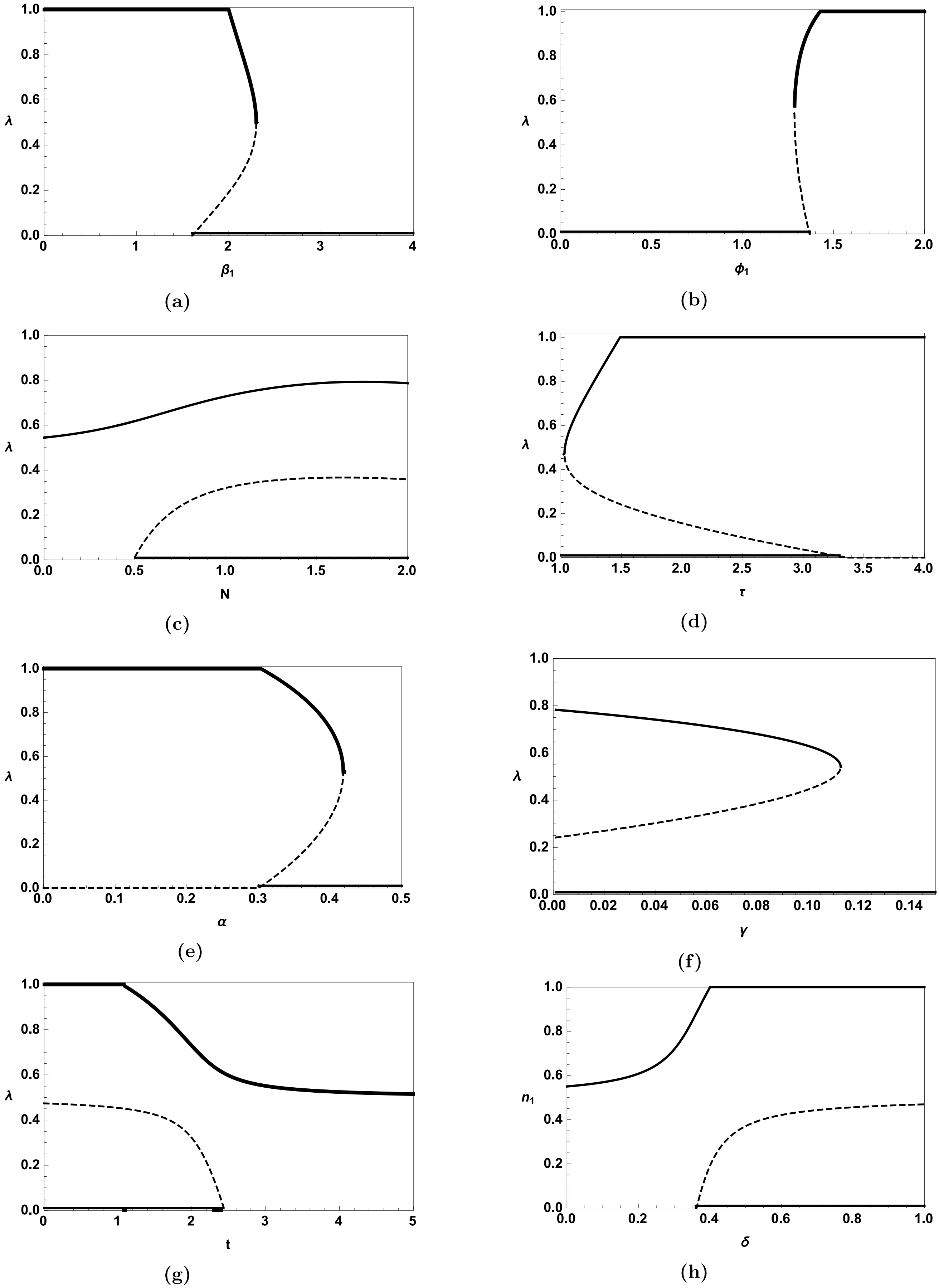


Figure 2: Equilibrium population shares due to changes in β_1, ϕ_1, N, τ, α, γ, t and δ. Solid lines are stable and dashed lines are unstable long-run equilibria. Note: A=10, $\delta = .4$, $B = 4$, t=2, $\Phi = 1.3$, α=.4, $\gamma = .05$

$\Phi = 1.1$									
$\tau = 1.2$									
	$\beta_1 = 1$			$\beta_1 = 1.5$			$\beta_1 = 2$		
	$\delta = 0$	$\delta = .21$	$\%\Delta$	$\delta = 0$	$\delta = .21$	$\%\Delta$	$\delta = 0$	$\delta = .21$	$\%\Delta$
λ	0.72	1.00	39.81	0.63	1.00	59.73	0.57	0.72	26.16
p_2^w	2948.80	3214.47	9.01	2955.43	3061.40	3.59	2969.43	3179.56	7.08
r_1^a	1842.69	1913.38	3.84	2982.31	4100.09	37.48	3536.54	4587.83	29.73
r_2^a	2211.23	2296.05	3.84	1590.56	2186.72	37.48	1060.96	1376.35	29.73
p^a	2553.53	2716.72	6.39	2168.13	2587.36	19.34	1774.95	2091.93	17.86
Utility	11473.70	12747.90	11.11	11592.00	12212.20	5.35	11821.80	12608.90	6.66
Agricultural Water 1	0.15	0.00	-100.00	0.31	0.00	-100.00	0.42	0.34	-21.17
Agricultural Water 2	0.54	0.71	33.18	0.34	0.71	112.00	0.20	0.31	52.85
Urban Water 1	0.17	0.24	43.63	0.14	0.24	65.47	0.13	0.17	27.93
Urban Water 2	0.09	0.00	-100.00	0.11	0.00	-100.00	0.13	0.08	-34.02
Water Loss	0.06	0.05	-24.19	0.09	0.05	-48.05	0.11	0.10	-9.62
Agricultural Demand 1	1.15	1.69	47.17	1.18	1.69	43.63	1.31	1.53	16.22
Agricultural Demand 2	0.50	0.00	-100.00	0.77	0.00	-100.00	1.08	0.65	-40.06
Agricultural Output 1‘	0.41	0.00	-100.00	1.03	0.00	-100.00	1.71	1.22	-28.38
Agricultural Output 2	1.24	1.69	36.46	0.92	1.69	84.02	0.68	0.95	38.87
Total Agricultural Output	1.65	1.69	2.46	1.95	1.69	-13.20	2.39	2.17	-9.15
Average Urban Land Rent 1	5442.69	6913.38	27.02	6132.31	9100.09	48.40	6386.54	8187.83	28.20
Average Urban Land Rent 2	3611.23	2296.05	-36.42	3440.56	2186.72	-36.44	3210.96	2776.35	-13.54

Table 4: Simulation results with low transport costs

	$\Phi = 1.1$								
	$\tau = 1.6$								
	$\beta_1 = 1$			$\beta_1 = 1.5$			$\beta_1 = 2$		
	$\delta = 0$	$\delta = .21$	$\%\Delta$	$\delta = 0$	$\delta = .21$	$\%\Delta$	$\delta = 0$	$\delta = .21$	$\%\Delta$
λ	0.73	1.00	37.16	0.65	1.00	54.77	0.59	0.80	36.39
p_2^w	2956.97	3246.94	9.81	2956.91	3128.44	5.80	2967.98	3153.60	6.25
r_1^a	1469.37	1449.53	-1.35	2596.80	3142.41	21.01	3267.55	4323.60	32.32
r_2^a	2350.99	2319.24	-1.35	1846.61	2234.60	21.01	1307.02	1729.44	32.32
p^a	2636.62	2744.17	4.08	2336.72	2644.01	13.15	1969.57	2335.37	18.57
Utility	11436.00	12787.40	11.82	11491.20	12375.80	7.70	11670.50	12404.70	6.29
Agricultural Water 1	0.08	0.00	-100.00	0.19	0.00	-100.00	0.29	0.17	-39.44
Agricultural Water 2	0.58	0.71	23.23	0.40	0.71	77.02	0.26	0.44	69.85
Urban Water 1	0.13	0.18	40.50	0.11	0.18	59.68	0.10	0.14	38.95
Urban Water 2	0.08	0.00	-100.00	0.11	0.00	-100.00	0.12	0.06	-50.46
Water Loss	0.13	0.11	-15.47	0.18	0.11	-41.66	0.23	0.19	-18.98
Agricultural Demand 1	1.17	1.69	44.78	1.13	1.69	49.31	1.21	1.51	24.52
Agricultural Demand 2	0.43	0.00	-100.00	0.68	0.00	-100.00	0.94	0.42	-55.60
Agricultural Output 1‘	0.30	0	-100.00	0.79	0.00	-100.00	1.38	0.75	-45.73
Agricultural Output 2	1.30	1.69	30.01	1.02	1.69	65.52	0.78	1.18	52.20
Total Agricultural Output	1.60	1.69	5.50	1.81	1.69	-6.50	2.15	1.93	-10.39
Average Urban Land Rent 1	5119.37	6449.53	25.98	5846.80	8142.41	39.26	6217.55	8323.60	33.87
Average Urban Land Rent 2	3700.99	2319.24	-37.33	3596.61	2234.60	-37.87	3357.02	2729.44	-18.69

Table 5: Simulation results with high transport costs