Infrastructure and Urban Primacy:
A Theoretical Model

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Abstract

Cities in developing countries are often more primate than their counterparts in developed countries. Due to the high fixed cost of infrastructure provision, poorer countries are often forced to concentrate initial investment in infrastructure in one or two cities, causing primacy. In this paper, I develop a simple model that explains why primacy first increases then falls as income increases. Next, I investigate how various characteristics of a country's economy can affect primacy, and find that strong backward and forward linkage and high capital depreciation can augment the initial advantage the main city enjoys, and cause a sustained state of primacy.

Introduction

Urban primacy is characterized by a high concentration of a country's urban population in a city or urban agglomeration (United Nations, 2004, p. 97). A variety of explanations have been advanced for this trend, ranging from political bias (Ades & Glaeser, 1995), protectionist policies (Krugman & Elizondo, 1996), to low income levels that limit scale economies (Moomaw & Shatter, 1996).

Henderson (2002) suggested that countries with limited resources are forced to concentrate infrastructure investment on one or two cities causing urban primacy (p. 99). This argument makes intuitive sense: as infrastructure projects often involve very high fixed costs, and enjoy great scale economies, poorer countries can only efficiently invest in one or two cities. Infrastructure, in turn, attracts industry, creating employment that draws migrants, resulting in urban primacy. As the country develops and income rises, the government becomes able to invest in its hinterland regions, encouraging deconcentration. Indeed, Henderson showed that primacy first rises then falls with income.

In this paper, I will develop a model that explains the relationship between urban primacy and public investment in infrastructure, and accounts for factors such as external scale economies and depreciation.

Model Framework

I make several assumptions for the sake of simplicity. Firstly, infrastructure investment is cumulative and funded by taxes. Governments make investment decisions at the start of each period, and spend all available resources on investment in that period. Secondly, there are two locations in the country: location 1, the main city, and location 2, the hinterland or secondary city. Lastly, public infrastructure investment is the only type of investment, firms depend entirely on variable input, labor. These assumptions, while unrealistic, will not qualitatively affect the model's predictions.

In this model, infrastructure investment decisions are made to maximize immediate total income of the country. This is not entirely unrealistic, as short term gains can be quickly reinvested in infrastructure, which would, as investment is cumulative, contribute greatly to long-term gain. Furthermore, political factors, such as reelection and the need to demonstrate economic growth to donor countries, might encourage this behavior. Nonetheless, there is full centralization, and taxes collected in the main city can be invested in the main city, or in the hinterland, and vice versa. There need not be political bias toward the main city.

This model use the Dixit-Stiglitz model of monopolistic competition (1977), in which each firm produces a different product, and product diversity is desirable due to interaction of demand within and among industries. Production in location *i* takes the traditional Cobb-Douglas form, where production Y_i, depends on infrastructure K_i, and number of firms N_i.

$$Y_i = K_i^{\alpha} N_i^{1-\alpha} \tag{1}$$

Although (1) represents constant returns to scale of Y with respect to K and N, a well-established result of the Cobb-Douglas function, holding the number of firms constant, there are diminishing returns to investment, as fixed cost have not been factored in yet. However, it is worthwhile to note that scale is not as meaningful a concept in this context as it involves period-by-period decision-making, over which investment is cumulative, and there is little incentive to consider scale over the short term. Furthermore, the scale of production cannot be changed as the number of firms cannot be independently controlled by the government. Firm numbers are instead determined by an interaction of factors, which will be elaborated upon later in the paper.

As production is equal to income, with wage equalization within a location, wage rate for each worker is Y_i / L_i, where L_i is the size of the labor force. At the start of each period, the government makes its investment decisions, and labor markets adjust frictionlessly. Holding the number of firms constant, an increase in infrastructure investment increases the productivity of labor. Firms thus hire more workers to take advantage of increased productivity until the location achieves production level described in (1). With perfect labor mobility, individual wages equalize across locations, giving:

$$Y_1 / L_1 = Y_2 / L_2 \qquad (2)$$

Substituting this into (1), we get a very basic relationship between investment and population ratios:

$$L_1 / L_2 = (K_1^{\alpha} N_1^{1-\alpha}) / (K_2^{\alpha} N_2^{1-\alpha}) \qquad (3)$$

Thus, all other things constant, an increase in infrastructure development increases income, and thus labor and population in the location. Repeatedly investing in the main city while neglecting the hinterland would result in great differences in *K*, as it is cumulative, causing urban primacy.

The Basic Theoretical Model

Due to the nature of infrastructure, production, treated as exogenous from the perspective of firms, does not take the usual Cobb-Douglas form presented in (1). Instead, production also requires an initial investment β before the benefits of infrastructure can be reaped, a fairly realistic assumption. For instance, the initial investment could be construction of a power plant in a city or construction of a road connecting the location to domestic and international markets, without which any investment in infrastructure is ineffective.

Furthermore, each location has a base level of production γ_i that is not affected by levels of infrastructure or number of firms. For example, the basic agricultural economy is not affected by infrastructure investment, industrial production is.

Thus, the production function is

$$Y_i = \gamma_i + (K_i - \beta_i)^{\alpha} N_i^{1-\alpha} \quad (4)$$

The production function is represented graphically below.

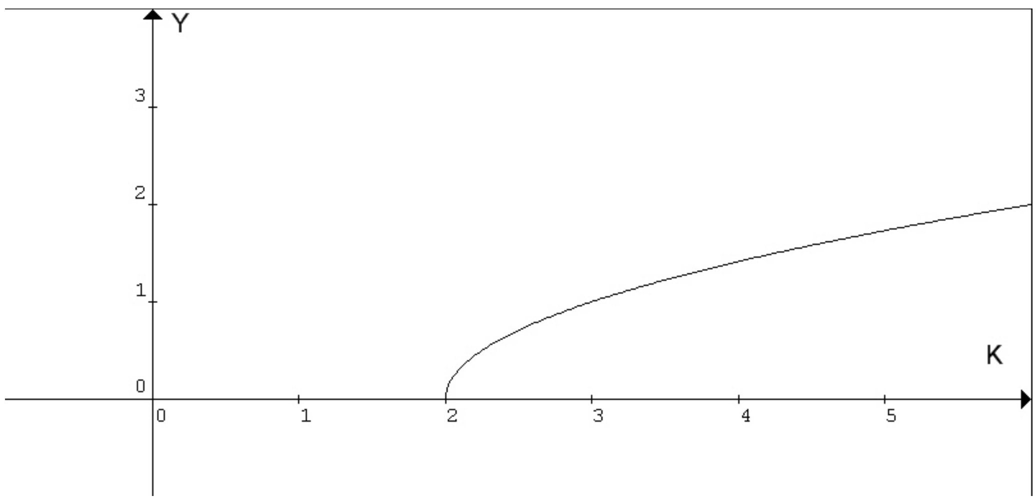

Figure 1: Production Y against infrastructure investment K, with $\alpha = 0.5$, $\beta = 2$, $\gamma = 0$, and $N = 1$.

The graph shows that these assumptions imply that scale economies in infrastructure exist and are significant when accumulated capital is approaching β. Conversely, with large values of K, these scale economies are not significant, as the fixed cost is spread out, and there are accompanying decreasing marginal returns to investment. Thus, as theory predicts, scale economies will be more important to countries with limited resources.

Even for locations with identical production functions (values of α and β) and initial endowments (K at time t_0), a government with limited resources that maximizes short run production will invest its funds entirely in one location, arbitrarily chosen as location 1. Due to the set up cost β_2, investment in the main city remains more productive for a period of time, and thus it draws investment and population away from the hinterland.

In this model, labor is normalized to

$$L_1 + L_2 = 1 \quad (5)$$

The government collects taxes and invests a percentage τ of income from the previous period $Y_{t\text{-}1}$ in infrastructure. Thus, as income grows, the government has more resources to invest in infrastructure. Nonetheless, governments will only invest in the hinterland if available spending C can cover fixed cost β_2 in one period, and the resultant changes in income in the hinterland is larger, $\Delta\ Y_2 \geq \Delta\ Y_1$. For simplicity, the government invests all available C in one location, and does not split investment between two locations in any time period.

This is illustrated in the table below.

Table 1: Investment Decisions, with $\alpha = 0.5$, $\beta = 2$, $\gamma = 1$, $N = 1$, $\tau = 0.5$

t	$C = \tau\ Y_{t\text{-}1}$	$Y = \gamma + (K_{t\text{-}1} + C_t - \beta)^{\alpha}\ N^{1\text{-}\alpha}$				$K = \Sigma\ K_t$		$Y = Y_1 + Y_2$	L_1	L_2
		ΔY_1	ΔY_2	Y_1	Y_2	K_1	K_2			
0	--	--	--	1	1	0	0	2	0.5	0.5
1	1	0*	0	1	1	1	0	2	0.5	0.5
2	1	0*	0	1	1	2	0	2	0.5	0.5
3	1	1*	0	2	1	3	0	3	0.67	0.33
4	1.5	0.58*	0	2.58	1	4.5	0	3.58	0.72	0.18
5	1.79	0.49*	0	3.07	1	6.29	0	4.07	0.75	0.25
6	2.04	0.44*	0.19	3.52	1	8.33	0	4.52	0.78	0.12
7	2.26	0.41	0.51*	3.52	1.51	8.33	2.26	5.02	0.70	0.30
8	2.51	0.46	1.16*	3.52	2.66	8.33	4.77	6.18	0.57	0.43
9	3.09	0.56	0.76*	3.52	3.42	8.33	7.86	6.94	0.51	0.49
10	3.47	0.61	0.63*	3.52	4.05	8.33	11.33	7.57	0.46	0.54
11	3.78	0.66*	0.57	4.18	4.05	12.11	11.33	8.23	0.51	0.49
12	4.12	0.59	0.61*	4.18	4.67	12.11	15.44	9.48	0.44	0.56

* indicates a larger return to additional resources and thus where investment will take place.

Columns ΔY_1 and ΔY_2 show the corresponding marginal returns to infrastructure investment, and columns Y_1 and Y_2, and K_1 and K_2, show the total income and cumulative infrastructure after the investment decision has been made based on ΔY_1 and ΔY_2. Column Y shows total income that results from short term maximization, while columns L_1 and L_2 show the resulting population distribution.

Due to its limited resources, the government concentrates infrastructure investment in location 1 until t_7, when returns to investment in location 2 are bigger than that of location 1. The concentration of resources in location 1, the main city, attracts population and causes primacy. As income increases and returns to investment in the main city decreases, investing in the hinterland becomes more attractive. The government's subsequent investment in the hinterland leads to population deconcentration, corresponding with $t_{7\sim9}$. Population is approximately equal and relatively stable after t_9. Thus, countries become increasingly primate as time progresses and income increases, but tend away from primacy after a certain income level.

Location Differences and Capital City Effects

Studies have consistently found that capital cities are more primate (Ades & Glaeser, 1995; Moomaw & Shatter, 1996; Henderson, 2002). The model does not yet fully explain this trend: if choice of initial investment is arbitrary, the main city is equally likely to be the capital city or any other location. The initial choice of investment at t_1 could be biased toward the capital city due to simple political bias of the government, or that oversight is more effective near to the seat of political power.

With this model, capital city effects can be explained by lower set up cost β_1 in the capital city, due to its better accessibility, as, historically, governments would have located their capitals on accessible land. Furthermore, locations chosen as capital cities due easy accessibility could have become the distribution center for imports and exports. Thus, β_2 would be higher as it would require infrastructure that connects the hinterland with the capital city, which is unnecessary for the capital city.

Alternatively, the capital city might posses higher initial infrastructure endowments K_1 at time t_0. As capital cities are usually founded and developed before other locations, its initial infrastructure K_1 is likely to be higher. Either or both of these factors could lead capital cities to be more primate. However, in equilibrium, two locations with similar production functions will have the same income and population. While the capital city is more primate during development, primacy is a temporary state.

Nonetheless, any of these reasons could create an initial impetus to develop the main city over the hinterland. As the model is further developed, the initial decision to develop the main city, location 1, over the hinterland, location 2 is assumed.

Prolonged Primacy

Although the number of firms N_i has been ignored for simplicity, it is an important determinant of production, and thus urban primacy. From (5), we can see that an increase in the number of firms will lead to an increase in production. As each firm produces a unique product, an increase in numbers of firms increases product diversity and contributes to output, consistent with the Dixit-Stiglitz model. Graphically, the curve representing Y_i and K_i will scale upward.

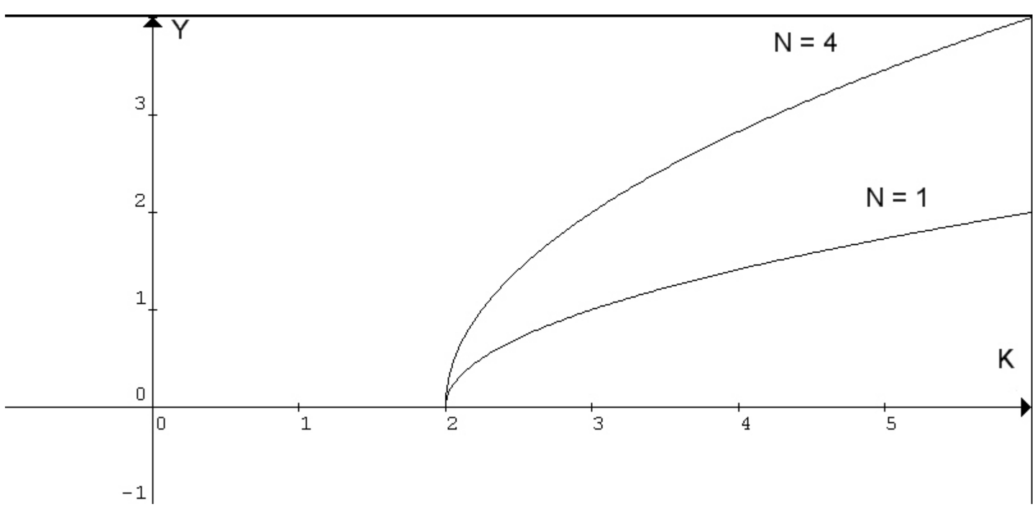

Figure 2: As with Figure 1 for $N = 1$ and $N = 4$, but with values $\beta = 1$, and $\gamma = 0$.

In the graph above, when N increases from 1 to 4, the production curve shifts up. Thus, for a given level of accumulated investment, K, an increase in the number of firms increases income Y and thus population. Furthermore, an increase in the number of firms also increases the returns to additional investment, as the production function becomes steeper, making the city more attractive to investment. Clearly, an increase in the number of firms can increase and prolong primacy.

To explain the determinants of number of firms, we turn to Hirschman's (1958) explanations of backward and forward linkages. In a populous location with high disposable income, a ready market would attract firms to supply consumer products. Similarly, the existence of firms that are not concerned with primary production would encourage firms to supply intermediate inputs, exhibiting backward linkages. On the other hand, firms that do not produce end products attract firms that use its products as intermediate inputs, creating forward linkages. Thus, the number of firms N depends on the income of the population Y and, in somewhat circular causation, the number of firms.

In this case, while labor is perfectly mobile in the short and long run, firms can only enter the market in the long run, at the start of any period. A firm that decides to enter the market at time t had previously decided against entering the market at time $t - 1$. Any decision to enter the market at a city implies that, between t and $t - 1$, determining factors N and Y must have changed in a manner that encouraged entry. Thus,

$$\Delta N_t = \mathrm{f}\,(\Delta N_{t\text{-}1}, \Delta Y_{t\text{-}1}) \qquad (6)$$

Notably, there is circular causation at work. An increase in either the number of firms or level of income will create a feedback loop that increase the number of firms. When viewed in context with (5), an increase in the number of firms increases production in the city that in turn increases the income, reinforcing the feedback loop. Circular causation is certainly possible and is an intuitively attractive explanation for urban primacy. Somewhat arbitrarily, I assign the function in (6) to be

$$\Delta N_t = \rho * (\Delta N_{t\text{-}1} + \Delta Y_{t\text{-}1}) \qquad (7)$$

This function, however, exhibits two vital characteristics. Firstly, a steady state for N, whether the initial or final state, can exist when there are no changes in N or Y ($\Delta N_t = 0$ when $\Delta N_{t-1} = 0$ and $\Delta Y_{t-1} = 0$). Secondly, with $\rho < 1$, ΔN decays exponentially, and, an external shock to N will allow it to reach equilibrium at t_∞. Thus, while a feedback loop exists, it is not a self-perpetuating function.

With (4), (5), and (7), I obtain these results:

Table 2: Investment Decisions, with $\alpha = 0.5$, $\beta = 2$, $\gamma = 0$, $\tau = 0.5$, $\rho = 0.5$.

t	C	N_1	N_2	ΔY_1	ΔY_2	Y_1	Y_2	K_1	K_2	Y	L_1	L_2
0	--	1	1	--	--	1	1	0	0	2	0.5	0.5
1	1	1	1	0*	0	1	1	1	0	2	0.5	0.5
2	1	1	1	0*	0	1	1	2	0	2	0.5	0.5
3	1	1	1	0*	0	2	1	3	0	3	0.67	0.33
4	1.5	1.5	1	1*	0	2.93	1	4.5	0	3.94	0.75	0.25
5	1.97	2.11	1	0.71*	0	4.07	1	6.47	0	5.08	0.80	0.20
6	2.53	2.80	1	0.89*	0.73	5.42	1	9.00	0	6.42	0.84	0.16
7	3.21	3.59	1	1.04	1.10*	6.01	2.10	9.00	3.21	8.11	0.74	0.26
8	4.06	3.98	1.55	1.35	1.49*	6.28	3.86	9.00	7.27	10.14	0.62	0.38
9	5.07	4.18	2.57	1.69*	1.47	8.10	4.68	14.07	7.27	12.78	0.63	0.37
10	6.39	5.12	3.08	1.86	1.96*	8.86	6.99	14.07	13.66	15.85	0.56	0.44
11	7.93	5.59	4.32	2.36*	2.10	11.58	8.09	22.00	13.66	19.67	0.59	0.41
12	9.83	7.01	4.93	2.62	2.71*	12.84	11.30	22.00	23.49	24.14	0.53	0.47
13	12.07	7.72	6.60	3.31*	2.97	16.73	12.91	34.07	23.49	29.64	0.56	0.44
14	14.82	9.73	7.43	3.69	3.79*	18.66	17.43	34.07	38.31	36.89	0.52	0.48
15	18.04	10.73	9.74	4.64*	4.20	24.19	19.81	52.11	38.31	44.00	0.55	0.45
16	22.00	13.55	10.90	5.20	5.32*	27.06	26.21	52.11	60.31	53.27	0.51	0.49
17	26.64	14.96	14.43	6.50*	5.94	34.89	29.71	78.75	60.31	64.60	0.54	0.46
18	32.30	18.92	15.75	7.32	7.47*	39.11	38.78	78.75	92.61	77.89	0.50	0.50
19	38.94	20.90	20.30	9.12*	8.39	50.17	43.89	117.7	92.61	94.06	0.53	0.47
20	47.03	26.45	22.57	10.3	10.5*	56.32	56.74	117.7	139.6	113.1	0.50	0.50

In this case, the population distribution is even, $L_1 \approx L_2$, after t_{15}, instead of t_9 from Table 2. Due to strong backward and forward linkages, investment in the main city increases the number of firms, which, in turn, increases the returns to investment. This attracts government investment in infrastructure, which further shifts the production function, shown in Figure 2, up, making it steeper.

Nonetheless, marginal returns are still decreasing along the curve. Although investment is concentrated in the main city from $t_{1\text{-}6}$, because of decreasing marginal returns in the main city, and increased resources C due to backward and forward linkages, the government diverts investment to the hinterland during $t_{7\text{-}8}$ as marginal returns are greater there. However, investment does not continue in the hinterland until an even population distribution, as it did in Table 1. Due to linkages, the main city in this case is still relatively attractive to investment. Furthermore, the head start the main city had gave it a cumulative advantage that prolonged primacy.

In this case, how prolonged the primacy is depends on the strength of forward and backward linkages, denoted by the ρ term. For instance, with $\rho = 0.25$ instead, primacy ceases at t_9, not significantly different from the case with no linkages. On the other hand, a value of $\rho = 0.75$ creates a permanent state of extreme primacy ($L_1 \approx 1$). Graphically, with higher values of ρ, any investment will cause the production function to shift upward and become steeper, as shown in Figure 2. The high value of ρ causes a sufficiently large shift such that returns to investment in the main city are always higher, and cause extreme primacy even if both locations have the same production function and linkages.

The following graph shows how different values of ρ affect whether and when the population stabilizes at an approximately even distribution. (The population is considered even at time t if the populations are approximately equal, $0.45 < L_i < 0.55$ in both locations, for three consecutive periods.)

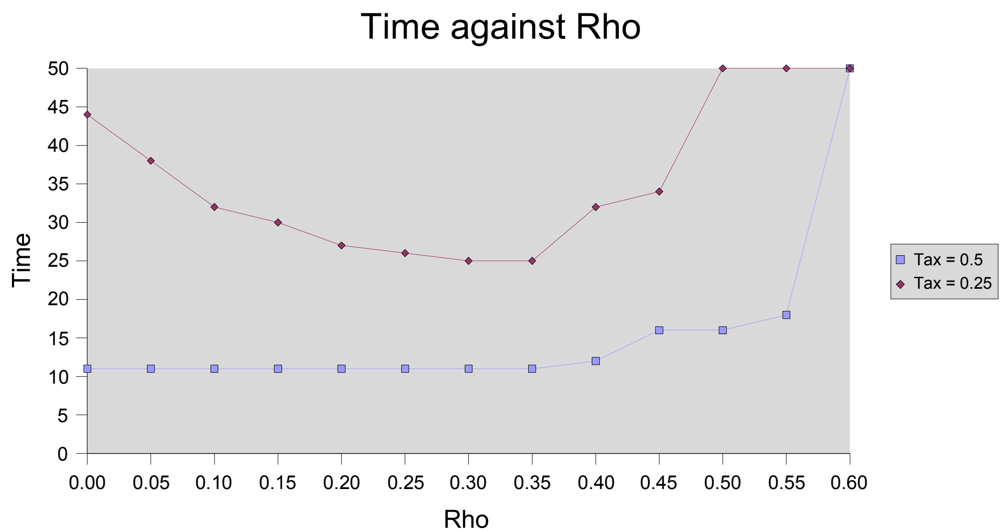

Figure 3: Time t against linkage strength ρ, with $\tau = 0.5$ and $\tau = 0.25$.

In the graph above, t_{50} represents extreme primacy, as the population does not converge toward an even distribution. This occurs with values of $\rho > 0.55$ for $\tau = 0.5$, and $\rho > 0.45$ for $\tau = 0.25$. The line representing $\tau = 0.5$ moves as expected from the results in Table 2. As ρ increases, time taken to reach equilibrium increases because stronger linkages emphasizes the initial advantage the capital city has.

On the other hand, the line representing $\tau = 0.25$ exhibits somewhat surprising behavior. It is reasonable that a lower tax rate would constrain resource and prolong primacy, and $\tau = 0.25$ is always above $\tau = 0.5$ as expected. However, the time taken to reach an even distribution first decreases before increasing, different from the increasing trend seen in $\tau = 0.5$. Examining the numbers generated by the model, it can be seen that higher values of ρ increases income, and allows for more investment in the hinterland, as resources are not as limited. This causes income to rise, which is augmented by linkages. For lower levels of τ, larger ρ might significantly increase resources available, that would be invested in the hinterland, offsetting the initial advantage of the capital city. This would has less impact for higher values of τ as the increase in income is as a result of linkages are not significant compared to resources available.

Thus, strong backward and forward linkages do not always prolong primacy, and the effect of linkages on resources available must be considered. However, high values of ρ, especially if ρ approaches one, invariably lead to extreme primacy.

Sustained Primacy

The model thus far has assumed that, for any single time period, the government would invest all its funds in one city, an assumption that has allowed clear conclusions to be drawn. However, it is more realistic that the government invests in both cities, dividing its resources to maximize total income. Thus the government chooses the amount of investment in location 1, ΔK_1 , to maximize total income Y, such that $\Delta K_1 + \Delta K_2 = C$.

Under these circumstances, there is less fluctuation in population levels, as locations are not alternately given or denied large sums of investment. This change does not affect the results obtained when backward and forward linkages were ignored (in table 1), and population reaches a steady, even distribution at t_{11}. However, if linkages are factored in, there are noticeable differences from table 2, and the population does not move toward an even distribution as quickly. These results are illustrated below.

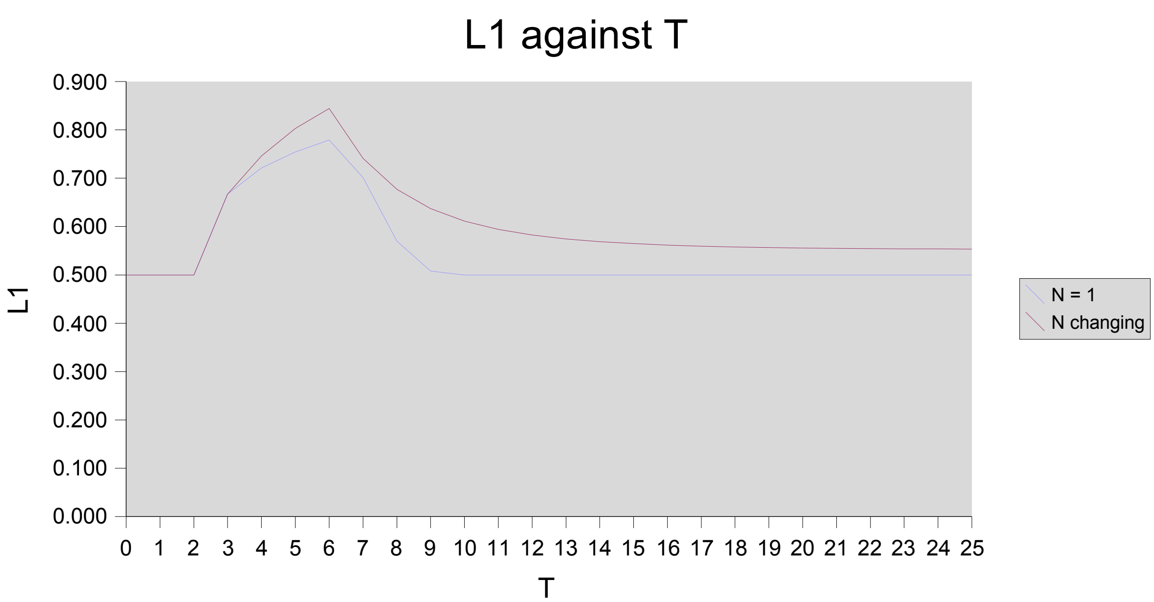

Figure 4: Time t against main city population L_1, with $\alpha = 0.5$, $\beta = 2$, $\gamma = 0$, $\tau = 0.5$, $\rho = 0.5$, for $N = 1$ and changing N

With a less restrictive model of decision making, linkages causes increased and more prolonged primacy than if the were no linkages, as shown in the graph above. These results agree qualitatively with those derived in table 1 and 2.

It is worth mentioning that, by allowing the government to divide funds between cities, there is a prolonged, almost permanent population imbalance shown in figure 4, different than the results obtained in table 2. In both cases, during the earlier time periods, investment is concentrated in the main city, giving it an advantage that is reinforced by linkages. However, this advantage is gradually lost due to decreasing marginal returns, and the hinterland becomes a relatively more attractive choice, corresponding with t_7 in table 2.

With the previous investment constraint, that all investment must be made in one city, all available resources will be directed to the hinterland for several time periods after t_7, while the main city is starved of investment. Together with linkages, such concentrated investment in the hinterland quickly erodes the advantage that the main city had. On the other hand, if the government is able to divide resources and invest in both locations, it will continue investing in the main city, albeit with a lower share of the total resources available. Backward and forward linkages reinforced the investment in the main city, and its advantage is not eroded as rapidly.

From figure 4, it seems as though, with more flexible investment decisions, linkages cause uneven population distribution at equilibrium. The graph below illustrates the population distribution at t_{50}, which I assume is close to equilibrium as rate of change is slow at later time periods.

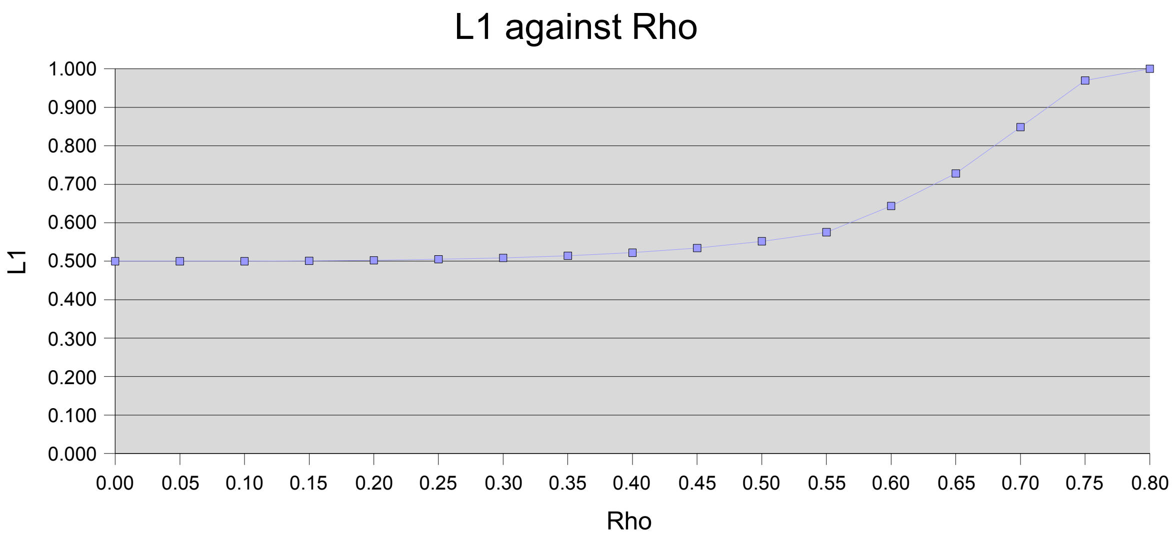

Figure 5: Equilibrium main city population L_1 against linkage strength ρ with $\tau = 0.5$

As expected, low values of ρ give a fairly even population distribution, while high values cause population concentration or even extreme primacy. The main city becomes increasingly primate as ρ grows, as the effect of linkages is cumulative, and, can be self-reinforcing.

Although it was relatively simple to see, with the previous decision-making process, that population would tend toward a relatively even distribution, it is not immediately clear why the population would stabilize at any particular uneven population distribution. In this two-sector model, the government seeks to maximize returns to investment, and will thus invest all its available funds such that returns to investment are equal in both cities. Due to linkages and the initial advantage given to the main city by diverting all resources to it, the main city would have a higher production function. In a static situation, the government faces these production curves,

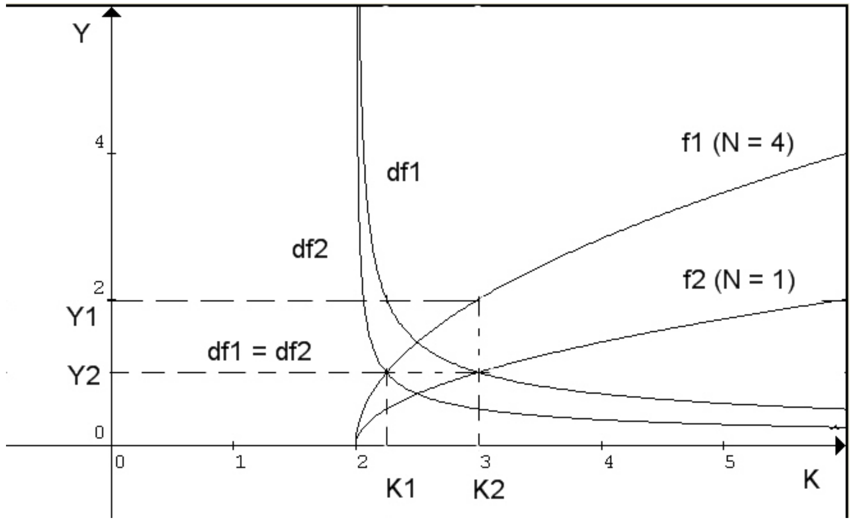

Figure 6: As with figure 2, but with derivatives of functions.

In the long term, the government will equate marginal returns to maximize income. In the graph, the main city is given some advantage in the early time periods due to fixed costs, and its production function is represented by f_1, while the hinterland is represented by f_2. The government equates marginal returns, df_1 and df_2, investing until K_1 and K_2 in the respective cities, resulting and uneven income, Y_1 and Y_2, and urban primacy. The distribution of income depends on the relative gradients of the production functions of both locations, and the higher the value of ρ, the larger the initial advantage to the main city and the more uneven the population distribution. The two production functions eventually reach an equilibrium state in which they draw a fixed portion of investment, and maintain the relative slopes of their production curves, leading to a steady state of primacy.

Due to linkages and the resultant advantage to the main city in the early periods, the curves are likely to vary, and there is no inherent reason that the population should converge to an even distribution. Instead, it converges to an equilibrium that depends on the slopes of the production functions. This, in turn, is determined to some extent in the early stages of investment, when all investment is directed to the main city due to the fixed cost of infrastructure investment. Stronger linkages create larger differences in early stages, which accumulate and cause stronger primacy.

Capital Depreciation

Although capital depreciation has been ignored so far, and it is likely play a role in determining primacy. As the countries concerned in this model are those that have limited resources, capital depreciation further limits resources and might be a significant factor determining primacy. Capital depreciates at a rate δ every time period, giving,

$$K_t = (1 - \delta)\, K_{t\text{-}1} \tag{8}$$

To understand the dynamics driving the model, we first compare it to the model without depreciation.

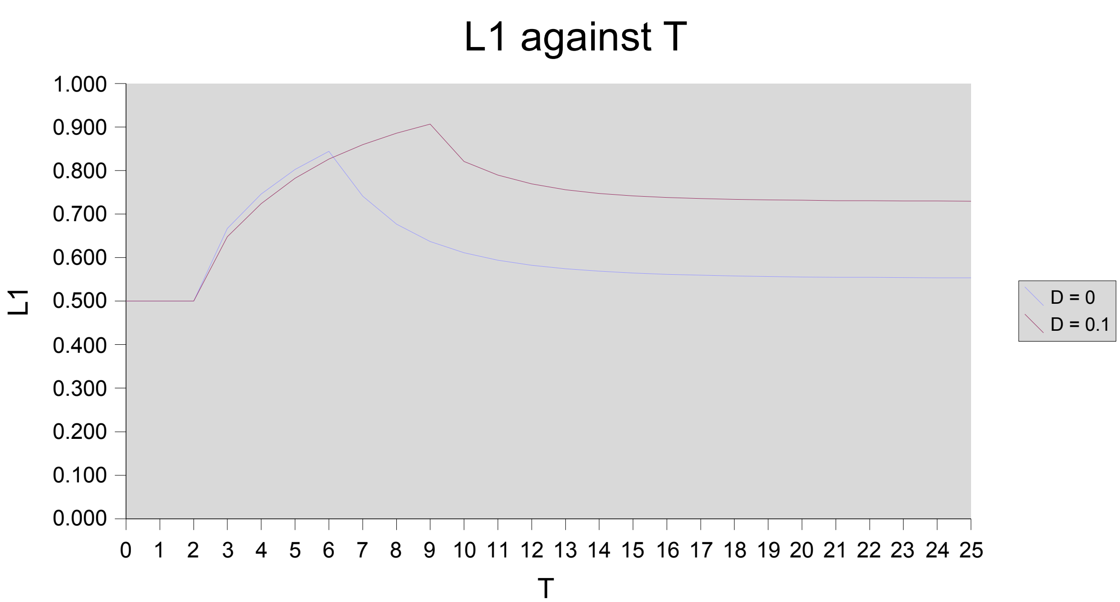

Figure 7: As with figure 4, time t against main city population L_1, with $\delta = 0$ and $\delta = 0.1$

From the graph, we can see that the line representing depreciating capital (D = 0.1) rises less rapidly than the line without (D = 0), but peaks later and at a higher value, and shows a less steep drop as well as more primacy in equilibrium. As depreciation reduces income, and all initial investment takes place in the main city, primacy increases faster if there is no depreciation. With depreciation, income rises less quickly, and the main city is less primate.

Without depreciation, the trend of increasing primacy is quickly reversed as investment takes place in the hinterland. On the other hand, depreciation limits resources, and investment in the hinterland is delayed while investment in the main city continues. This increases income in the main city, contributing to primacy. However, the difference between both locations is further widened as linkages increase the production function in the main city, while that in the hinterland remains unchanged. Thus, investment in the main city still relatively attractive, creating a cumulative, somewhat self-reinforcing effect. As the production functions diverged quickly in the initial time periods, as shown in figure 5, equilibrium population distribution favors the main city.

The impact of linkages is shown in the graph below, which displays the ratio of firm numbers for the corresponding locations in figure 6.

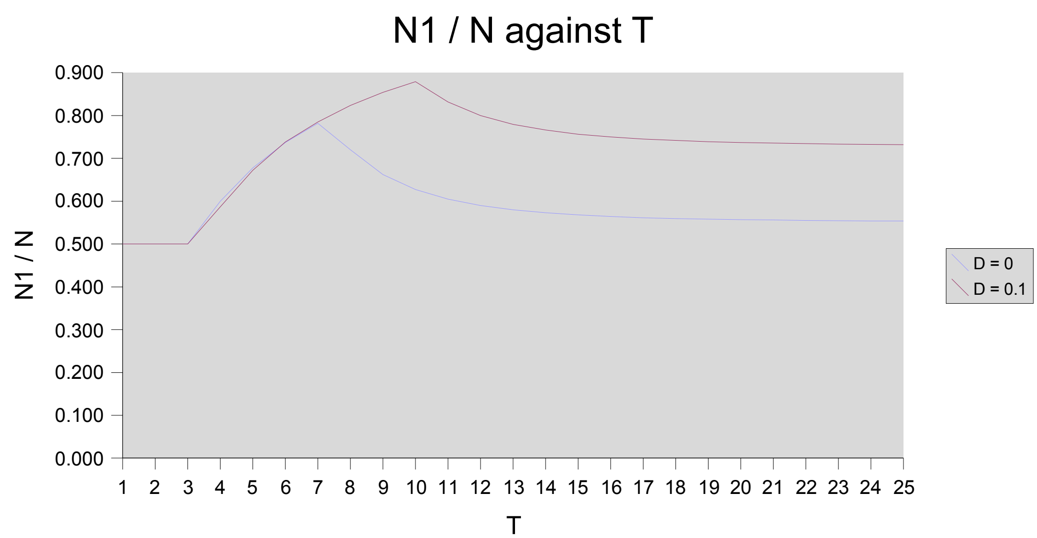

Figure 8: Proportion of firms $N_1 /(N_1 + N_2)$ against infrastructure time *t*

Using *N* as an estimate of the effects of linkages, it can be seen from the graph that with depreciation (D = 0.1), linkages are far stronger in location 1 than location 2, as N_1 is a far larger proportion of the total number of firms. As depreciation limits funds available, initial investment heavily favors the main city. Linkages cause this initial concentration in the main city to accumulate more productive capacity and shifts the fundamental long term equilibrium. Even if depreciation does not significantly reduce resources available in the later periods, the early effect it has causes persistent primacy.

As the primary impact of capital depreciation is to limit resources, the effect that rate of depreciation has on primacy would thus depend on funds available. This is illustrated in the graph below.

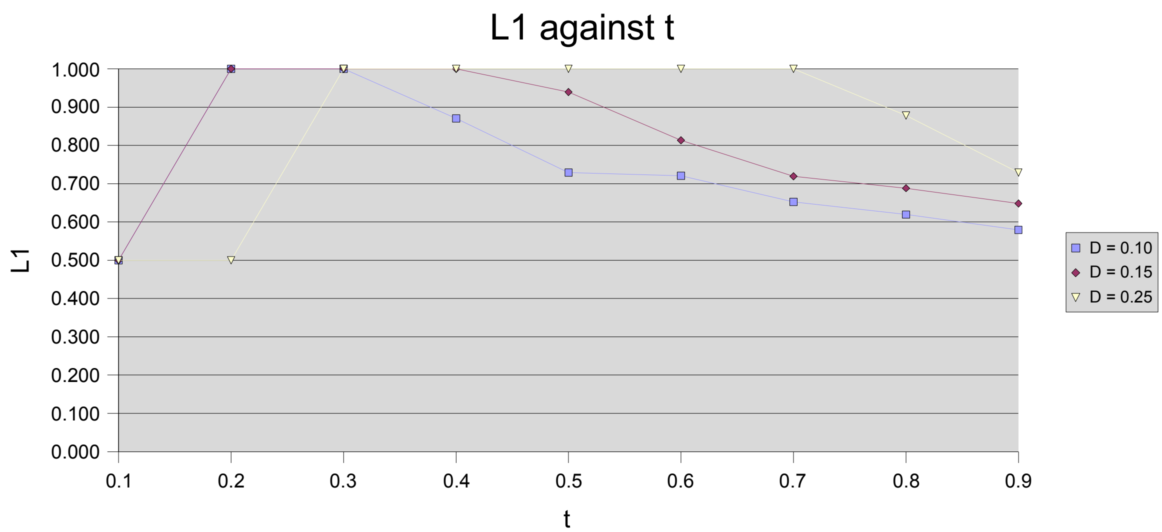

Figure 9: Equilibrium main city population L_1 against infrastructure spending τ, for $\delta = 0.1$, $\delta = 0.15$ and $\delta = 0.25$

As expected, higher depreciation rates (higher values of D in the graph) and less resources available (lower value of t in the graph) tend to cause more primacy as it encourages concentration of resources in the main city. Linkages reinforce this advantage, causing primacy.

From the graph above, extremely low levels of spending τ available relative to depreciation δ results in an even population distribution as infrastructure decays too quickly, and resources are too limited, to cover the fixed cost of investment, β. As spending increases to (still) relatively low levels, there is extreme primacy as depreciation limits funds and allows the main city to accumulate great advantages through linkages. As spending further increases, primacy declines as depreciation becomes a relatively less constraining factor.

Conclusion

This model investigates the relationship between infrastructure development and primacy, exploring the effects caused by linkages, flexibility in decision making, and depreciation. Although there is no empirical analysis in this paper, the model largely agrees with Henderson's findings (2002), that primacy first increases then decreases as income increases. Furthermore, any combination of the factors explored could be combined with characteristics of capital cities, such as easier accessibility, to explain capital city effects that have been found consistently in empirical studies. Although have not been many empirical studies that fully consider the relation between income, the state of infrastructure development and characteristics of capital cities, it is possible that economic factors suggested in this model account for some of the capital city effects found.

Based on this model alone, it seems that, with the most realistic set of assumptions, with capital depreciation, backward and forward linkages, and flexible decision-making, resource limitations in infrastructure investment can cause significant primacy, despite economically rational decisions. While this model offers quantitative analysis of an intuitively attractive idea, firm conclusions cannot be drawn without empirical testing.

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