A Bridge to Equality: How Investing in Infrastructure Affects the Distribution of Wealth

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Abstract

Public infrastructure is one of the foundations for the economic growth of a country. While there is a strong consensus regarding infrastructure's effect on growth, the results regarding the effect of infrastructure on the distribution of wealth are mixed. In this paper we examine the quantitative significance of investing in infrastructure on the degree of inequality present within a country. We calibrate our baseline model to replicate key features of a developing economy and then simulate the counter-factual wealth distribution that would arise if investment in infrastructure was increased. We find that when infrastructure influences the economy through both the utility and production functions, increasing infrastructure investment significantly increases growth and reduces wealth inequality, leading to a sharp increase in the level of wealth held by the poorest agents. However, when the utility-enhancing aspects of infrastructure are ignored, growth effects become smaller and the distributional effects are almost non-existent.

Keywords: Infrastructure, Inequality, Incomplete Markets, Stationary Distribution.

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1 Introduction

Going back to Adam Smith (1776), economists have asserted that the stock of public infrastructure constitutes the foundations for a country's productive activities and economic growth. For example, firms need reliable water and electricity provision and roads in good condition to be able to produce goods and services efficiently and deliver them to the market place. While understanding the growth effects of infrastructure is extremely important, most governments are also interested in reducing, or at least not increasing, the level of inequality present in their country. Therefore, it is important that we consider the distributional affects of investing in infrastructure along with the average growth affects. It is not clear how wealth inequality may be affected by additional investment in infrastructure. On the one hand, more infrastructure may benefit the poor since it reduces transportation costs to the workplace. Similarly, an increase in infrastructure may cause labor productivity to rise, leading to an increase in the wage paid to poorer individuals. On the other hand, more affluent individuals will likely also benefit since they typically own physical capital, which will also experience productivity increases as a result of increased infrastructure. Our paper quantitatively evaluates the distributional effects of public infrastructure policies and highlights which channels (utility and/or production) are important for transmitting these effects using a heterogeneous agents model.

There is a large literature on how public infrastructure affects economic growth going back to Aschauer's (1989) seminal paper that found large effects of public infrastructure on U.S. total factor productivity. Subsequent empirical studies covering many countries have generally supported Aschauer's finding, reporting that public infrastructure investment positively affects economic growth (see literature survey papers by Bom and Lighthart (2008) and Romp and De Haan (2007)). Barro (1990) and Glomm and Ravikumar (1994a, 1997) started a theoretical literature that developed general equilibrium models of economic growth that included public infrastructure as one of the engines of growth. Subsequent papers in this tradition, like Rioja (1999, 2003), use a "quantitative theory" approach where a general equilibrium model is used to analyze the quantitative effects of various policy changes in infrastructure investment. A key simplifying assumption of the above mentioned models is that a country consists of a single representative household. This assumption, while innocuous when one is concerned with aggregate growth patterns, implies that these models are unable to address how wealth distributions vary as policies change.

While there is strong consensus that investing in infrastructure leads to economic growth, the empirical literature as described, for example, in the recent survey paper by Calderon and Serven (2014), has found mixed results on the effects of infrastructure on inequality. For example, the cross-country empirical studies by Calderon and Serven (2004) and Calderon and Chong (2004) find some evidence that infrastructure can help reduce inequality. At a more micro level, Khandker, Bakht, and Koolwal (2009), find that the poorest households benefitted the most from road improvement projects in Bangladesh. Conversely, Artadi and Sala-i-Martin (2004) find that infrastructure spending may have contributed to income inequality in Africa due to the siphoning of funds designated for infrastructure and the construction of large, inefficient infrastructure projects. Similarly, Khandker and Koolwal (2010) find that richer households benefitted more than poorer households from more access to paved roads and irrigation programs in Bangladesh. Given these mixed results, there is a clear need for a theoretical framework that could shed light on the channels through which infrastructure affects wealth accumulation.

Theoretically, a related paper to ours is Glomm and Ravikumar (1994b) which studies the growth and inequality effects of a pure public good (describde as Public Sector R&D) which affects production. They find that, in the long-run, public sector R&D affects the growth rate of GDP per capita, but does not affect income inequality, which is introduced by agents having different initial endowments. Ferreira (1995) develops a model with three types of agents: subsistence workers, middle-class entrepreneurs and upper-class entrepreneurs. Ferreira (1995) shows theoretically that increasing infrastructure can reduce inequality in a country, but his results are sensitive to exogenous credit constraints that prevent subsistence workers and middle class entrepreneurs from accumulating increasing stocks of private capital. Klenert et al. (2014) develop a model with two types of agents, middle-income and high income agents, who are made to differ in terms of their rate of time preference, savings behavior, and labor supply choice. They find that in the long-run, inequality can be reduced by increasing infrastructure. However, Klenert et al. (2014) do not have low-income agents in their model, yet real-world policymakers are typically very concerned about how low-income individuals are affected by policies. Chatterjee and Turnovsky (2012) develop and simulate a model populated by many agents who differ in terms of their initial wealth levels. Contrary to Ferreira (1995) and to Klenert et al. (2014), they find that, in the long-run, an increase in infrastructure investment leads to an increase in the dispersion of income and wealth distributions and an increase in inequality. The somewhat contradicting results in the papers described above suggest that a clear answer to the question, "How does investing in infrastructure affect wealth inequality?" requires more investigation, in particular of the channels through which infrastructure may affect the distribution of wealth.

In our paper, we go further than Ferreira (1995), Klenert et al. (2014) and Chatterjee and Turnovsky (2012) by both calibrating our model to data and providing detailed quantitative evaluations of the distributional effects of various infrastructure policy changes. In order to achieve this, we modify the model presented in Aiyagari (1994) to include an endogenous labor supply decision and to allow infrastructure to impact the agents's utility function and the economy-wide production function.[1] One advantage of our incomplete markets model approach compared to the previous literature is that heterogeneity arises not as an ex-ante

[1]For a review of the equilibrium concept and other technical details see Hugget (1993). The interested reader is referred to Heathcote et al. (2009) and Guvenen (2011) for an excellent review of incomplete markets models.

initial condition to the problem (as in Chatterjee and Turnovsky, 2012) or as exogenously imposed differences between agents (as in Ferreira, 1995; and Klenert et al., 2014), but rather endogenously as individuals optimally respond to the economic environment. A second advantage of our approach is that we can use wage and income data to calibrate our model to a particular country, in our case Mexico, where a lack of infrastructure is a major issue. A third advantage of our approach is that it allows us to consider both aggregated and disaggregated distributional effects. Not only can we examine how aggregate measures of inequality, such as the Gini coefficient, change with the various policies, but we can also examine how the share of wealth held by each individual quintile or decile is affected.

In our model infrastructure affects individual choices through two main channels. The first channel operates through the production function. Specifically, the level of infrastructure present in the economy, as well as the tax instruments used to finance its construction, impacts the wage rate and the rental rate on capital. Therefore, investing in infrastructure alters the marginal product of labor and capital which, in turn, influence individuals' labor supply and capital accumulation decisions. The second channel operates through the agents' utility function. Specifically, the stock of infrastructure interacts with individual hours devoted to leisure, giving rise to a measure of effective leisure. By using effective leisure, we are able to capture the utility-enhancing aspects of infrastructure that have been document in the literature (See Chatterjee and Ghosh (2011)). Ultimately, we find that an expansion of infrastructure leads to a large reduction of wealth inequality regardless of the financing method used. However, if the increased investment is financed by a tax on interest income, then output growth will be lower than if other financing methods (consumption tax, labor income tax or international donations) had been used. In order to determine which channel, production or utility, drive our distributional results, we resolve our model (both baseline and policy changes) with the utility-enhancing aspects of infrastructure removed. In this case, we find that increasing infrastructure investment leads to a very small increase in wealth inequality, indicating that the utility channel is the channel through which distributional effects operate.

The paper proceeds as follows: Section 2 describes the model. Section 3 describes the calibration and computational procedure. Section 4 discusses the results and Section 5 concludes.

2 Model

In order to study the distributional effects of investing in infrastructure, we build upon the model developed in Aiyagari (1994). Specifically, we extend the Aiyagari model by adding an endogenous labor supply decision and by allowing infrastructure to impact the agents' utility function and the economy-wide production function. The following subsections provide a detailed description of our model setup.

2.1 Households

The economy is populated by a large number of agents who possess identical preferences over consumption, c, and effective leisure, $L = lK_G$, where l denotes individual hours devoted to leisure and K_G denotes the aggregate stock of infrastructure in the economy. Their period utility function is given by:

$$u(c, L) = \frac{1}{\gamma}\left[c^{-\xi} + \eta L^{-\xi}\right]^{-\frac{\gamma}{\xi}} \tag{1}$$

where γ and ξ determine the intertemporal and intratemporal elasticity of substitution respectively, while γ is the relative weight on effective leisure in the utility function. We follow Chatterjee and Ghosh (2011) and Chatterjee and Turnovsky (2012) by allowing infrastructure to affect individual utility through an interaction with private leisure. Justification for this modeling strategy can be found in Agenor and Canuto (2013) who find evidence that infrastructure makes non-market activities like home production and child rearing more efficient. In our model, all non-market activities are implicitly lumped into leisure. Hence, modeling infrastructure augmenting leisure is consistent with Agenor and Canuto (2013). This modeling strategy can also be justified intuitively. For example, infrastructure like electricity networks provide agents with electricity supply that allows them to enjoy their leisure more at night. Similarly, roads provide access for agents to enjoy leisure outside the immediate vicinity of their homes. We also consider a version of the model where agents simply derive utility from consumption and leisure. This allows us to identify which channel, production or utility, is driving our distributional results.

While the agents's preferences are identical, they differ in terms of their labor position. Some agents are unemployed and receive unemployment benefits, b, from the government, while other agents are employed and receive labor income from the firm.[2] Labor income, defined by $wn\theta$, consists of the following three components; the aggregate wage rate, w, the agent's labor supply, n, and the agent's labor productivity, θ. Therefore, while all employed agents take the same aggregate wage as given, they face different efficiency wages depending on their specific realization of θ when choosing their labor supply.

Each agent's labor position is the result of the idiosyncratic shock, θ, that occurs at the start of each period. We use a five state Markov process for θ, where the first state corresponds to unemployment ($\theta = 0$). The remaining four values of θ, along with their transition probabilities, are estimated from the Mexican data following the method outlined in Heer and Maussner (2009) (See calibration section for more details). While agents lack the ability to perfectly insure against fluctuations in θ, they have the ability to save by accumulating assets, a, that pay a market determined return, r. Standard precautionary savings motives apply, and agents will accumulate assets while their productivity is high

[2]While the country to which we subsequently calibrate the model, Mexico, does not have unemployment insurance at the national level, unemployment benefits equal to the monthly minimum wage are paid in Mexico City.

in order to partially insure against the risk of becoming less productive or unemployed in the future. Over time, these differences in productivity translate into large differences in individual asset holdings, giving rise to an endogenous wealth distribution.

An agent's individual state consists of their asset holdings, a, and their labor productivity, θ. Given their current state, each agent chooses consumption, c, labor, n, leisure, l, and their next period asset level, a', to maximize the present discounted value of their expected utility. We can setup the household's problem as the following dynamic program:

$$V(a,\theta) = \max_{c,n,l,a'} \left[u(c,L) + \beta \sum_{\theta'} \pi(\theta'|\theta) V(a',\theta') \right]$$

s.t.

$$(1+\tau_c)c + a' \leq \left\{ \begin{array}{ll} (1+(1-\tau_a)r)a + (1-\tau_n)wn\theta & \text{if employed} \\ (1+(1-\tau_a)r)a + b & \text{if unemployed} \end{array} \right\} \tag{2}$$

$$n + l \leq 1 \tag{3}$$

$$k' \geq 0 \tag{4}$$

Equation (2) is the household's budget constraint. It simply states that a household's spending on consumption and investment cannot exceed their current resources. The terms τ_c, τ_a and τ_n found in this equation denote the marginal tax rates on consumption, interest income and labor income respectively. These taxes are collected by the government in order to finance the unemployment benefit, b, provide infrastructure, K_G, and engage in government consumption, G. Equation (3) is a standard time constraint. It states that all time is either spent working or taking leisure. In the event that an agent is unemployed ($\theta = 0$), $l = 1$, $n = 0$ and equation (3) becomes redundant. Equation (4) is a no-borrowing constraint, which prevents any household from carrying a negative asset balance.

Solving the household's problem yields the following Euler equations:

$$u_c = \beta \sum_{\theta'} \pi(\theta'|\theta) u_{c'} (1 + (1 - \tau_a) r') + (1 + \tau_c) \lambda_3 \tag{5}$$

$$u_l = u_c \left[\frac{(1 - \tau_n) w \theta}{1 + \tau_c} \right] \tag{6}$$

Equation (5) governs the household's choice between consuming more today and investing more in assets. The shadow price on the no-borrowing constraint, λ_3, appears in this equation because the constraint may occasionally bind. Equation (6) governs the household's choice between working more hours and taking leisure. This equation can be used to derive the following optimal labor supply condition that is a function of an agent's current labor productivity and his current and future individual asset holdings:

$$n(\theta, a) = \frac{1 + \tau_c + \left[\frac{\eta(1+\tau_c)}{K_G^{\xi}(1-\tau_n) w \theta} \right]^{\frac{1}{1+\xi}} [a'(a, \theta) - (1 + (1 - \tau_a) r) a]}{1 + \tau_c + \left[\frac{\eta(1+\tau_c)}{K_G^{\xi}(1-\tau_n) w \theta} \right]^{\frac{1}{1+\xi}} (1 - \tau_n) w \theta} \tag{7}$$

Therefore, given an agent's state (a, θ) and their optimal investment decision rule, $a'(a, \theta)$, equation (7) yields the agent's optimal labor supply decision rule.

As mentioned earlier, there are two channels through which infrastructure influences individual choices. Both of the these channels can be seen in equation (7). The first channel is transmitted indirectly through factor prices, w and r, and marginal taxes, τ_c, τ_n and τ_a. As we will see in the results section, increasing the level of infrastructure increases both factor prices. Also, under standard balanced budget assumptions, if the government increases infrastructure investment they must offset these costs through increased taxation. So, at least one of the marginal tax rates will rise. How these indirect effects influence labor supply is hard to determine ex ante. An increase in the wage rate gives rise to both income and substitution effects that push the labor supply decision in opposite directions. Furthermore, an increase in tax rates reduce the marginal benefit of working, leading to a reduction in labor supply. The second channel is transmitted directly through the presence of K_G in the optimal labor supply decision rule. Specifically, increasing infrastructure increases effective leisure, L, leading to a reduction in the marginal utility of leisure. Therefore, the direct effect of increasing infrastructure is an increase in hours worked and a reduction in leisure hours.

2.2 Firm's Problem

On the production side of the economy, there is a single representative firm that takes as inputs aggregate capital, K, aggregate labor, N, and infrastructure, K_G. While infrastructure is provided by the government at an aggregate level, aggregate capital and labor must be computed from the individual households' solutions:

$$K = \sum_{\theta} \int_0^{\bar{a}} a f(a,\theta) da \tag{8}$$

$$N = \sum_{\theta} \int_0^{\bar{a}} \theta n(a,\theta) f(a,\theta) da \tag{9}$$

where $f(a,\theta)$ denotes the invariant density of individual states. Therefore, K is simply the average of individual asset holdings while N is the average of the individual productivity-weighted labor supplies.

The firm combines K_G, K and N to produce aggregate output using the following technology:

$$Y = K_G^{\phi} K^{\alpha} N^{1-\alpha} \tag{10}$$

The firm chooses aggregate capital and labor in order to solve the following period specific profit maximization problem:

$$\max_{K,N} K_G^{\phi} K^{\alpha} N^{1-\alpha} - wN - (r+\delta)K$$

which yields:

$$r = \alpha K_G^{\phi} \left(\frac{K}{N}\right)^{\alpha-1} - \delta \tag{11}$$

$$w = (1-\alpha) K_G^{\phi} \left(\frac{K}{N}\right)^{\alpha} \tag{12}$$

The outcome of the firm's problem is that the gross return on capital, $r+\delta$, and the wage rate, w, are both equal to their respective factors' marginal products.

2.3 Government

The government provides unemployment benefits, b, produces infrastructure, K_G, and consumes, G. In terms of unemployment benefits, the government pays out a fixed amount, b, to each unemployed individual. Therefore, the total payment made by the government for unemployment benefits, B, is given by:

$$B = \int_0^{\bar{a}} b f(a, \theta = 0) da \tag{13}$$

Like all other forms of capital, infrastructure is subject to depreciation. We assume that infrastructure depreciates at a constant rate, δ_G, each period. The government's job is to invest in infrastructure at a rate that keeps up with depreciation so that the stock of infrastructure is constant in steady state. Therefore, the government's total spending on infrastructure in given by $\delta_G K_G$. Furthermore, we assume that the government's total spending on infrastructure is a share, x, of the economy's GDP.

$$\delta_G K_G = xY = x K_G^{\phi} K^{\alpha} N^{1-\alpha} \tag{14}$$

We can then use equation (14) to solve for the level of infrastructure in the economy as:

$$K_G = \left[\frac{xK^{\alpha}N^{1-\alpha}}{\delta_G}\right]^{\frac{1}{1-\phi}} \tag{15}$$

Putting everything together, we see that total government spending, TS, is given by:

$$TS = B + \delta_G K_G + G \tag{16}$$

As discussed in the household's problem, the government levies marginal taxes on consumption, labor income and interest income. These taxes are denoted by τ_c, τ_n and τ_a respectively. The government collects these taxes from all individuals, except the labor income tax which is not collected from the unemployed. Therefore, the government's total revenue, TR, is given by:

$$TR = \tau_c C + \tau_n wN + \tau_a rK \tag{17}$$

Finally, we require that the government balance it's budget every period, so the government's budget constraint is given by:

$$TS = TR \tag{18}$$

Later, we will consider the case where the government receives international donations, D, to finance additional infrastructure investment. However, for the time being we have assumed that $D = 0$.

2.4 Equilibrium

A stationary equilibrium for this economy is a value function, $v(a, \theta)$, individual decision rules, $a'(a, \theta)$, $n(a, \theta)$, $l(a, \theta)$ and $c(a, \theta)$, a time-invariant density of individual states, $f(a, \theta)$, time invariant factor prices, w and r, time-invariant government taxes and transfers, τ_a, τ_n,

τ_c, and b, and a vector of aggregates, K, N, C, K_G, B, G, TS, D and TR such that:

1. Given the factor prices, government taxes and transfers, and the level of infrastructure in the economy, the value function solves the household's problem and the individual decision rules are the optimal decision rules.

2. The vector of aggregates are obtained as follows:

$$K = \sum_\theta \int_0^{\bar{a}} af(a,\theta)da$$
$$N = \sum_\theta \int_0^{\bar{a}} \theta n(a,\theta)f(a,\theta)da$$
$$C = \sum_\theta \int_0^{\bar{a}} c(a,\theta)f(a,\theta)da$$
$$K_G = \left[\frac{xK^\alpha N^{1-\alpha}}{\delta_G}\right]^{\frac{1}{1-\phi}}$$
$$B = \int_0^{\bar{a}} bf(a,\theta=0)da$$
$$TS = B + \delta_G K_G + G$$
$$TR = \tau_c C + \tau_n wN + \tau_a rK$$

3. Factor prices, w and r, satisfy the firm's FOCs (equations (11) and (12))

4. Goods market clears: $C + \delta K + \delta_G K_G + G = K_G^\phi K^\alpha N^{1-\alpha} + D$

5. Government balances its budget: $TS = TR$

6. Distribution of individual states is stationary: $F(a', \theta') = \sum_\theta \pi(\theta'|\theta)F(a'^{-1}(a',\theta),\theta)$

3 Calibration and Solution

In this section, we will describe the methods used to calibrate our model to data. We will also describe the basic numerical methods used to approximate the solution to our model.

3.1 Preference and Production Parameters

The model is calibrated to an annual frequency. Standard values are used for the discount rate, β, set to 0.96, the rate of depreciation on private capital, δ, set to 0.06, and the rate of depreciation on infrastructure, δ_G, set to 0.04. Public infrastructure is mostly structures which depreciate slower than equipment which is a major component of private capital (along with private capital structures). The production function is assumed to display constant returns to scale in aggregate capital, K, and labor, N. The income shares are set to their standard values of 0.36 for capital and 0.64 for labor, which are consistent with Gollin's (2002) estimates for developing countries. The share of infrastructure in production, ϕ, is set to 0.15, which is an average estimate for developing countries according to Bom and Ligthart (2008). The utility function parameters, η, γ and ξ are set to match the intertemporal and intratemporal elasticity of substitution and the level of hours worked at steady state. Specifically, we set $\gamma = -1.5$ and $\xi = 1.5$ so that both the intertemporal elasticity of substitution, $\frac{1}{1-\gamma}$, and the intratemporal elasticity of substitution, $\frac{1}{1+\xi}$, equals 0.4.[3] With γ and ξ pinned down, η is set to match the steady state level of hours worked in the economy. For a complete review of the preference and production parameters, see Table 1.

3.2 Income Shock Process

The Mexican National Institute of Statistics and Geography (INEGI) collects household surveys that include data on employment status, income, and worker flows. The National Survey

[3]See Guvenen (2006) for empirical estimates of the intertemporal elasticity of substitution. For the intratemporal elasticity of substitution, we adopt the value, 0.4, reported in Stern (1976).

of Occupation and Employment (ENOE) surveys over 100,000 households in 48 metropolitan and rural areas in Mexico every quarter. Since ENOE started in 2005, we focus on the period 2005 to 2010.[4] Individuals are surveyed for 5 consecutive quarters, so we assemble a longitudinal panel to determine transition probabilities among income quintiles. The average productivities,

$$[\theta_2, \theta_3, \theta_4, \theta_5] \tag{19}$$

are estimated from the data for the average income of each quartile. We normalize the average productivity across all four quartiles to 1 following Heer and Trede (2003). These are presented in Table 2 along with the transition probability matrix. The first row and first column of this matrix tell us about the transition from unemployment to working and vice versa. Following Heer and Trede (2003), we assume that agents' skills erode while in the unemployment state, so that agents may only transition from unemployment to the lowest productivity employment state. The exact values in the first row and column of the transition matrix are set to match the average rate and duration of unemployment observed in the data. During the period that we study, the average unemployment rate in Mexico was 3.99 percent, while the average duration of unemployment was approximately 10 months (OECD Stats, 2014).[5] The lower 4x4 of the transition matrix is obtained as the average transition probability between two consecutive years in our sample period. The results have been renormalized to ensure that each row sums to 1.

[4]The household survey prior to ENOE's creation was ENEU which had somewhat different coverage and methodology.

[5]Given that our model is calibrated to an annual frequency, it is impossible for us to exactly match the duration of unemployment found in the data. However, we set the probability of remaining unemployed to a low value, which allows to come close to the empirical estimate.

3.3 Solution Method and Methodology

With the model calibrated to the Mexican data, we proceed by approximating a solution to the model economy. According to Calderon and Serven (2010), public infrastructure investment in Mexico averaged about 2% of GDP during the last 3 decades. Hence, for our baseline solution we set x, the ratio of infrastructure spending to GDP, equal to 0.02, so that the government spends approximately 2% of GDP on infrastructure. Following from the fact that Mexico does not have a comprehensive unemployment insurance program, we set the unemployment benefit, b, to a very small value equal to 1% of the average labor income earned by the least productive worker.[6] According to the World Tax Indicators (2014), the average tax rate on income in Mexico is 10%, which applies to any type of income: labor income, interest income, etc. Therefore, we set the marginal tax rates as follows: $\tau_a = 0.1$, $\tau_n = 0.1$. The indirect tax rate (value added, sales tax) in Mexico is 15%, therefore $\tau_c = 0.15$. With all tax rates set, government consumption, G, is backed out using the government's budget constraint:

$$G = \tau_a r K + \tau_n w N + \tau_c C - \delta K_G - B \tag{20}$$

To solve the model we employ standard methods for computing the stationary distribution of an incomplete markets model with idiosyncratic shocks. Specifically, we start with guesses of aggregate capital, K, and labor, N. We use these values to compute r, w, and K_G, using equations (11), (12) and (15). We discretize private assets, restricting assets to 100 unevenly spaced grid points on the interval (0,15).[7] Given these asset values, we use equation (7) to solve for all possible optimal labor supply decisions. With these values in hand, we use value function iteration with linear interpolation to solve for the agents' decisions rules. Next, these decision rules are used to solve for the invariant density, $f(a, \theta)$. Since we are

[6] This level of unemployment benefit is needed to ensure that all agents, even those with no assets, can afford a positive level of consumption in all periods.

[7] While we use 15 as the upper limit of our asset grid in our baseline case, we increase this to 35 when conducting policy experiments.

interested in how this wealth density changes across specification, we approximate it on a much finer grid than we used to compute the decision rules (2000 grid points). Once we have the invariant density, we update our values of K and N and repeat the process until K and N no longer change.[8]

4 Results

In this section we will provide an overview of our model's results. We will compare the outcomes of our baseline calibration to four alternatives where infrastructure investment, as a share of GDP, is increased. We focus on analyzing the long-run or steady state effects of these infrastructure policy changes, which we think is an appropriate time framework since infrastructure has effects that accumulate over a number of years. The four alternatives differ in how the additional infrastructure is financed. For the first three alternatives, we adjust the marginal tax rates (τ_a, τ_n and τ_c) individually in order to determine if one financing strategy dominates the others in terms of average growth or distributional effects. For the fourth alternative, we allow the additional infrastructure to be financed by international donations, D. As this method does not require an increase in tax rates, we can assess whether increased taxation or the additional infrastructure itself caused the distributional effects. We also repeat the preceeding exercise on a version of our model where the utility-enhancing aspects of infrastructure have been removed. By comparing both sets of solutions we are able to identify through which channel, production or utility, the distributional effects operate.

Before proceeding further into the results, we should indicate how well our baseline model replicates Mexico's wealth distribution. Table 3 presents the share of wealth held by each quintile and decile for Mexico along with the values recovered from the two different versions

[8] See Heer and Maussner (2009) for a textbook treatment of these methods.

of our model, one where the utility channel is operational and one where the utility channel has been shutdown. Inspection of Table 3 indicates that our baseline model does a reasonable job at replicating the degree of wealth concentration observed in the data. However, it is clear that our baseline model underestimates the share of wealth held by the poorest agents and underestimates the share of wealth held by the richest agents.

The fact that our model incorrectly estimates the share of wealth held in the tails of the asset distribution is a common shortcoming of incomplete markets models that are calibrated using income data. Alternatively, one could calibrate the labor productivity shock so that the baseline model's wealth distribution matches the data as close as possible (See Castaneda et al (1998)). However, as we will see in the next few sections, the degree of redistribution that occurs following an increase in infrastructure investment is driven primarily by the labor supply decision. Therefore, given that our focus is on quantifying the degree of redistribution, it is more important for us to accurately match labor productivities and transition probabilities than the wealth distribution at a point in time. Similarly, we could match the wealth distribution more closely by introducing heterogeneity in discount rates (See Krusell and Smith (1998)), but as the individual labor supply decision is independent of the discount rate this addition would not substantially alter our results.

4.1 Average (Growth) Results

As mentioned earlier, the government spends 2% of GDP on infrastructure in our baseline calibration. In a detailed study of Latin America countries, Fay and Morison (2007) propose that these countries require about 5% of GDP to be spent on infrastructure investment. Similar public investment levels were successfully undertaken in Indonesia, Malaysia, South Korea in the 1970s and 80s building up those countries' infrastructure stock. We examine what happens in our model when the government increases its spending on infrastructure to 5% of GDP. The first four columns of Table 4 present the results of this experiment, where the first column corresponds to our baseline case ($x = 0.02$) and the next four columns corresponds to the specific method used to finance the extra spending. Inspection of these columns reveal many similarities between the various financing schemes. For example, in all cases aggregate capital, K, aggregate output, Y, and aggregate consumption, C increase. These aggregate results are consistent with the literature findings described in the introduction. Since we focus on long-run or steady state effects, one can think of these effects occurring over a period of say 30 years. Hence, the large increases in output and other variables have reasonable sizes if they are divided over a 30 year period. Furthermore, the aggregate wage rate, w, and the rental rate on capital, r, increase in all specifications as well. Another common theme across specifications is that aggregate labor, N, increases significantly. This follows from the fact that the strong increase in K_G drives down the marginal utility of leisure leading to an increase in labor supply following the policy change. As unemployment is exogenous to our model, the entire labor response occurs through fluctuations in hours worked. Therefore, one can view the large increase in hours worked following the policy experiment as capturing the increase in both the intensive and extensive margins that may follow an expansion of infrastructure.

Further inspection of Table 4 indicates that while the direction of the results are consistent across specifications, the magnitudes differ. For example, if the tax on interest income is used to finance the additional infrastructure, then aggregate capital will increases from 2.66 to 5.38. However, if the labor income tax, consumption tax, or donations are used, then K will increase to 5.81, 6.04, 5.91 respectively. This result is intuitive, as increasing the tax on interest income discourages saving while the other financing methods avoid such distortions. Perhaps more importantly, these differences are also present for aggregate output. If the interest income tax is used, then aggregate output grows from 0.57 to 1.28 while the other financing methods (τ_n, τ_c and D) increase this value to 1.32, 1.35, 1.31 respectively. If one evaluated the performance of these financing methods solely on the basis of increasing aggregate output, then the consumption tax would be preferred.

4.2 Distributional Results

The results presented in the previous section support the widely-held belief that infrastructure investment stimulates growth. Furthermore, if we were to focus solely on the average results we would conclude that financing the expansion of infrastructure by a tax on interest income is the worst strategy as it leads to the smallest increase in aggregate capital and output. Similarly, we would conclude that financing through a consumption tax is preferable as it leads to the largest growth in these variables. However, we are not yet able to conclude which financing strategy is the best as we have only considered part of the story. We are also interested in how the distribution of wealth is affected by the policy change, and the previously documented results are silent on this front.

The first two panels of Figure 1 present plots of the wealth density of the baseline calibration above the densities recovered after the policy change. These plots indicate that, regardless of the financing method used, increasing infrastructure spending reduces inequality. This can be seen by the widening of the densities and their tendency to shift right following the policy change. The third panel of Figure 1 presents the wealth distributions for the model both before and after the policy change. The results again paint a consistent picture. Increasing infrastructure investment reduces inequality regardless of the financing method used.

Now that we have the qualitative result that investing in infrastructure reduces wealth inequality regardless of the financing scheme, we can consider the quantitative implications. The first five columns of Table 5 present the distributional results of this policy experiment. The first thing to notice is that the results under column ΔD are very similar to the other policy change columns. This indicates that the distributional effects we are observing are driven by the increase in infrastructure, not distortions from tax rate changes.[9] Further inspection of the first four columns indicates that if the additional infrastructure investment is financed by the interest income tax, then the wealth Gini falls from 0.387 to 0.375. However, if the labor income tax or the consumption tax is used, the wealth Gini falls to 0.370 or 0.371 respectively. We can also determine the magnitude of the distributional effects by looking at the share of wealth held by various segments of the economy. Inspection of these results confirms the finding that increasing infrastructure investment reduces inequality and the level of redistribution is consistent across financing methods. Specifically, increasing infrastructure investment, as a fraction of GDP, from 2% to 5% increases the share of wealth held by the bottom quintile from 3.95% to 4.49% on average. Also, the share of wealth held by the top quintile falls from 41.43% to 40.75% on average. This leads to a reduction in wealth concentration (top quintile over bottom quintile) of 13.4 percent on average. Similarly, we see that the share of wealth held by the bottom decile rises from 1.28 to 1.43 on average, while the share of wealth held by the top decile falls from 23.82 to 23.53 on average. These changes result in a reduction in wealth concentration (top decile over bottom decile) of 11% on average. In sum, additional infrastructure increases the share of wealth for poorer segments and reduces the share of wealth of the wealthier segments. Taken in combination with the average growth results presented in the previous section, we see that expanding infrastructure from 2% to 5% of output increases the level wealth held by the bottom quintile by 147% in the long run. The intuition of these results is discussed in section 4.4.

[9] We also solved a version of the model where taxes are never used. Instead, international donations are used to finance all government spending, unemployment insurance and infrastructure both before and after the policy change. The results from this model (available upon request) are consistent with what is presented here.

4.3 Remove Utility Channel

The previous results indicate that the degree of wealth inequality can be reduced by increasing investment in infrastructure. Furthermore, we find that there are only small differences in the distributional effects depending on which financing method is used. These results where found while allowing infrastructure to influence the model through two distinct channels, production and utility. In order to determine which channel is driving our distributional results, we repeat our previous exercise with the utility channel shutdown. Specifically, we remove the utility-enhancing feature of infrastructure by using the following utility function:

$$u(c,l) = \frac{1}{\gamma}\left[c^{-\xi} + \eta l^{-\xi}\right]^{-\frac{\xi}{\gamma}}$$

Under this utility function, the agents' optimal labor supply decision rule becomes:

$$n(\theta,a) = \frac{1+\tau_c + \left[\frac{\eta(1+\tau_c)}{(1-\tau_n)w\theta}\right]^{\frac{1}{1+\xi}}\left[a'(a,\theta) - (1+(1-\tau_a)r)a\right]}{1+\tau_c + \left[\frac{\eta(1+\tau_c)}{(1-\tau_n)w\theta}\right]^{\frac{1}{1+\xi}}(1-\tau_n)w\theta} \tag{21}$$

Notice that K_G no longer enters the agents' optimal labor supply decision rule directly as it did in equation (7). Therefore, changes in infrastructure will only influence labor supply indirectly through changes in factor prices, w and r, and changes in tax rates, τ_a, τ_n and τ_c.

In order to ensure comparability between model specifications, we maintain the same calibration throughout. The only parameter value that must change when the utility channel is removed is η, which was originally set so $N \approx 0.33$ when 2% of output was dedicated to infrastructure investment. In order to keep N constant between the two baseline cases, η must be increased from 0.75 to 4.77.

We find that removing the utility channel significantly alters both the growth and distributional results presented earlier. As for the growth results, inspection of Table 4 indicates that while increasing infrastructure investment from 2% to 5% of GDP still increases capital, output and consumption, the increases are much smaller than they were when both channels were operational. For example, when both channels were operational, steady state output grew on average by 128.8% with the policy change. When the utility channel is shut down, average output growth fell to approximately 18%. This result suggests that earlier work on the average growth effects of investing in infrastructure may have underestimate the full effect, as they ignored the utility-enhancing aspects of infrastructure.

As for the distributional results, Figure 2 presents the asset densities and distributions that are recovered when the utility channel has been shutdown. Inspection of these plots clearly indicates that distributional effects are now much smaller than they were when both channels were operational. This can be seen by the very slight movements in densities and distributions following the policy change once the utility channel has been shutdown. Our quantitative results support this finding. Inspection of the last five columns of Table 5 indicate that when the additional investment is financed by either the interest income tax, consumption tax or international donations, the wealth Gini actually increases slightly from 0.386 to 0.393, 0.388 and 0.388 respectively, indicating a very slight increase in wealth inequality. However, if the labor income tax was used, then the wealth Gini would fall slightly to 0.385. Similarly, we find that increasing infrastructure investment no longer leads to large changes in the share of wealth held by the various quintiles or deciles. The small distributional effects observed when the utility-enhancing channel is shut down is consistent with the theoretical findings of Glomm and Ravikumar (1994b) and indicates that the utility channel is the channel through which distributional effects operate.

4.4 Discussion of Results

In this section we discuss and compare the intuition of both with- and without-utility-channel results. The differences in distributional effects observed between the two cases considered follows from differences in the responsiveness of labor supply to changes in infrastructure. When the utility-enhancing aspects of infrastructure are considered, agents' utility is a function of effective leisure. In this case, an increase in infrastructure will cause the agents' utility to rise and their marginal utility of leisure to fall. This reduction in the marginal utility of leisure causes agents to supply more labor regardless of wealth levels, but the trade-offs are such that lower and middle wealth agents increase their labor supply more than the rich. This increase in labor income for poor and middle-wealth agents allows them to both consume more and save more, where the latter works to reduce wealth inequality. The large distributional effects stem from the large responses in labor supply to changes in infrastructure that occur in this case. These large changes can be seen in the change in N that are reported in the first four columns of Table 4.

When the utility-enhancing aspects of infrastructure are ignored, infrastructure no longer impacts the agents' utility directly. Instead, it only operates indirectly through changes in factor prices, r and w, and tax rates, τ_a, τ_n and τ_c. As can be seen in Table 4, increasing infrastructure leads to a strong increase in the wage rate, w. A higher wage rate could cause an agent's labor supply to change in either direction depending on if the income or substitution effect dominates. What we find is that the income effect dominates for low-wealth agents, while the substitution effect dominates for high-wealth agents. This result is intuitive as low-wealth agents were already supplying a great deal of labor prior to the policy change. So, when the utility channel is shut down, increasing infrastructure will cause poor agents to reduce their labor supply and rich agents to increase their labor supply. Ultimately, this differential effect may lead to an increase in wealth inequality. However, individual labor supplies only change slightly in this case, so the overall distributional effects are negligible.

5 Conclusions

In this paper we investigate the distributional effect of investing in infrastructure. Our results confirm the widely-held belief that investing in infrastructure increases economic growth. Our results also suggest that a government can reduce the level of inequality present in their country by investing in infrastructure. This result can be seen by the increase in the right tail of all density functions after the policy change. Furthermore, the poorest quintile is particularly positively affected due to the combination of the growth in the economy plus the increased share of wealth accruing to them. While all financing methods increase growth and reduce inequality, they do not perform equally well at both tasks. Our results suggest that a tax on interest income should be avoided as it generates smaller growth relative to the other tax changes while yielding similar distributional effects.

The results above were found when infrastructure is allowed to directly influence the aggregate production function and the agents' individual utility functions. Therefore, infrastructure was assumed to influence individual choices through two separate channels, production and utility. While both of these channels have been discussed in the literature, no previous paper has attempted to uncover which channel drives the distribution affects. We proceed by shutting down the utility channel by removing the utility-enhancing aspects of infrastructure from the model. Once the utility channel is shutdown, we find that increasing infrastructure investment leads to a very small changes in wealth inequality. Therefore, the utility channel is the channel through which our distributional affects operate.

Several related and interesting questions are left for future research. For example, are there distributional trade-offs that governments face between investing in infrastructure and investing in education (human capital formation)? It would also be interesting to expand the current model to allow for aggregate shocks, government debt and the potential for a binding government borrowing constraint. These features would allow one to consider other issues such as the cyclicality of inequality and the effect of a government's debt balance on their infrastructure investment decision over the business cycle.

Table 1: Model Parameters

$\beta = 0.96$	$\eta = 0.75$	$\gamma = -1.50$	$\xi = 1.50$
$\alpha = 0.36$	$\phi = 0.15$	$\delta = 0.06$	$\delta_G = 0.04$

Table 2: Productivity Shock Process

$\theta_1 = 0.000$	$\theta_2 = 0.331$	$\theta_3 = 0.588$	$\theta_4 = 0.878$	$\theta_5 = 2.203$	
	θ_1	θ_2	θ_3	θ_4	θ_5
θ_1:	0.200	0.800	0.000	0.000	0.000
θ_2:	0.032	0.551	0.247	0.115	0.055
θ_3:	0.032	0.240	0.397	0.244	0.087
θ_4:	0.032	0.113	0.235	0.402	0.218
θ_5:	0.032	0.056	0.085	0.207	0.620

Table 3: Model vs. Data

	Data[a]	Model with Utility Channel	Model without Utility Channel
Quintile 1	7.76	3.95	3.94
Quintile 2	10.78	10.36	10.50
Quintile 3	14.18	17.71	17.70
Quintile 4	20.85	26.54	26.48
Quintile 5	44.70	41.43	41.37
Decile 1	3.31	1.28	1.27
Decile 2	4.45	2.67	2.68
Decile 3	4.74	4.33	4.38
Decile 4	6.04	6.03	6.12
Decile 5	7.00	7.88	7.74
Decile 6	7.18	9.83	9.97
Decile 7	9.20	11.95	11.82
Decile 8	11.57	14.59	14.67
Decile 9	14.57	17.62	17.53
Decile 10	29.91	23.82	23.84

a Wealth distribution data for Mexico at the quintile and decile level was obtained from De la Torre y Moreno (2004). Their wealth measure is constructed from the INEGI household survey data in Mexico. The data are defined as net total wealth, so it includes financial wealth and real estate wealth.

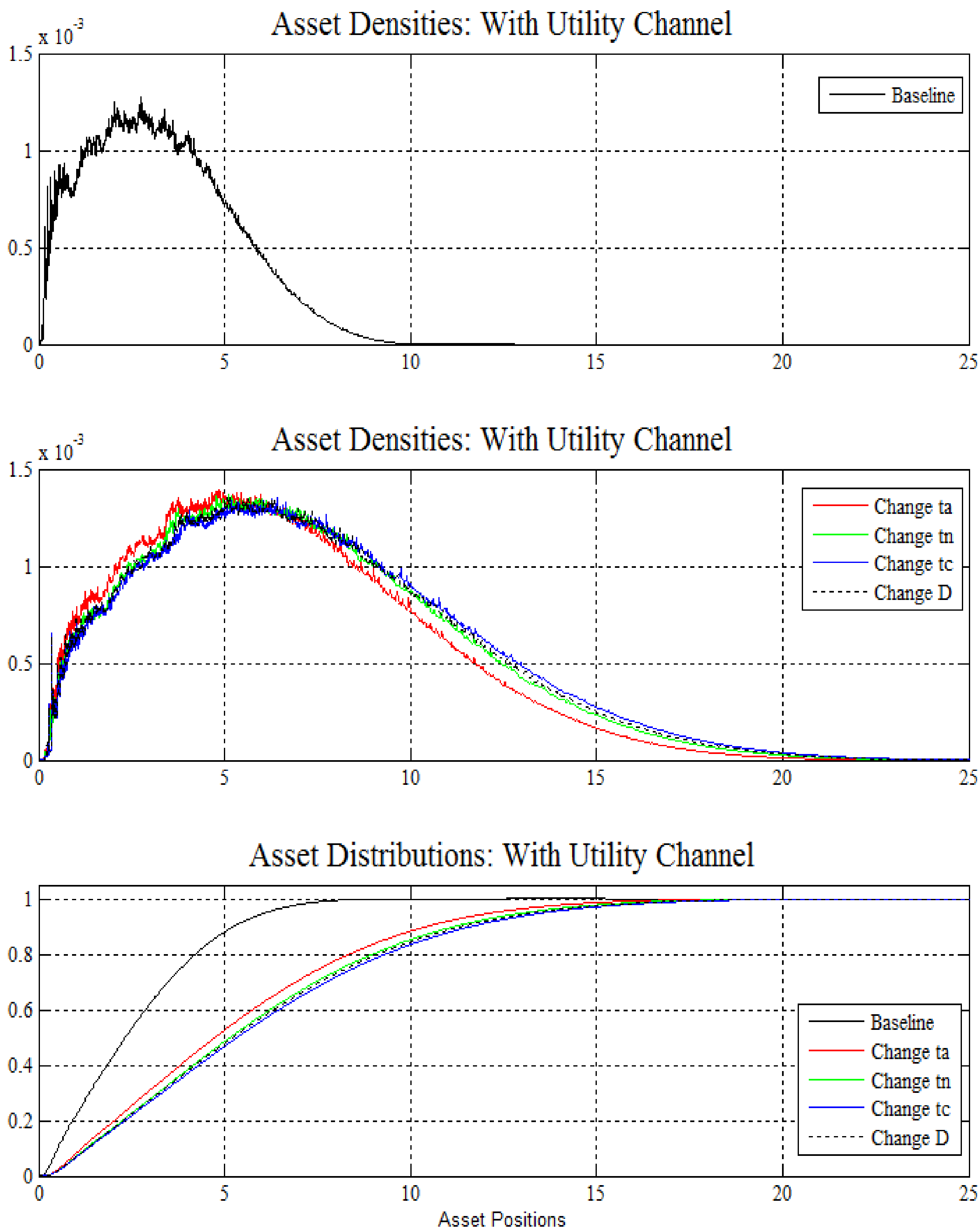
Table 4: Average Results

	With Utility Channel					Without Utility Channel				
	Baseline	$\Delta\tau_a$	$\Delta\tau_n$	$\Delta\tau_c$	ΔD	Baseline	$\Delta\tau_a$	$\Delta\tau_n$	$\Delta\tau_c$	ΔD
x	0.020	0.050	0.050	0.050	0.050	0.020	0.050	0.050	0.050	0.050
K	2.660	5.383	5.813	6.035	5.905	2.670	2.918	3.119	3.231	3.158
N	0.325	0.508	0.509	0.512	0.503	0.326	0.304	0.300	0.301	0.295
K_G	0.287	1.593	1.648	1.681	1.643	0.288	0.834	0.851	0.865	0.843
Y	0.574	1.275	1.318	1.345	1.314	0.576	0.667	0.681	0.692	0.675
C	0.324	0.714	0.724	0.732	0.752	0.326	0.367	0.366	0.368	0.380
w	1.132	1.605	1.658	1.682	1.674	1.133	1.407	1.451	1.472	1.465
r	0.018	0.025	0.022	0.020	0.020	0.018	0.022	0.019	0.017	0.017
τ_a	0.100	0.364	0.100	0.100	0.100	0.100	0.414	0.100	0.100	0.100
τ_c	0.150	0.150	0.150	0.209	0.150	0.150	0.150	0.150	0.216	0.150
τ_n	0.100	0.100	0.148	0.100	0.100	0.100	0.100	0.153	0.100	0.100

Table 5: Distributional Results

	With Utility Channel					Without Utility Channel				
	Baseline	$\Delta\tau_a$	$\Delta\tau_n$	$\Delta\tau_c$	ΔD	Baseline	$\Delta\tau_a$	$\Delta\tau_n$	$\Delta\tau_c$	ΔD
Wealth Gini	0.380	0.368	0.363	0.364	0.364	0.386	0.393	0.385	0.388	0.388
Quintile 1	3.95	4.44	4.52	4.50	4.50	3.94	3.79	3.89	3.84	3.81
Quintile 2	10.36	10.93	11.14	11.09	11.05	10.50	10.16	10.47	10.34	10.25
Quintile 3	17.71	17.72	17.77	17.80	17.86	17.70	17.65	17.91	17.72	17.85
Quintile 4	26.54	25.88	26.01	25.93	25.88	26.48	26.48	26.66	26.54	26.72
Quintile 5	41.43	41.03	40.57	40.68	40.72	41.37	41.91	41.06	41.56	41.37
$\frac{\text{Quintile 5}}{\text{Quintile 1}}$	10.48	9.24	8.98	9.04	9.06	10.50	11.06	10.56	10.81	10.85
Decile 1	1.28	1.43	1.42	1.43	1.42	1.27	1.23	1.25	1.26	1.25
Decile 2	2.67	3.01	3.10	3.07	3.07	2.68	2.56	2.64	2.59	2.57
Decile 3	4.33	4.61	4.70	4.70	4.69	4.38	4.23	4.40	4.32	4.33
Decile 4	6.03	6.31	6.44	6.39	6.35	6.12	5.93	6.07	6.02	5.92
Decile 5	7.88	8.01	7.98	8.08	8.04	7.74	7.70	7.92	7.97	7.99
Decile 6	9.83	9.71	9.78	9.71	9.82	9.97	9.96	9.99	9.75	9.86
Decile 7	11.95	11.81	11.87	11.79	11.75	11.82	12.10	11.87	12.23	12.12
Decile 8	14.59	14.07	14.13	14.15	14.13	14.67	14.38	14.79	14.31	14.60
Decile 9	17.62	17.37	17.12	17.23	17.17	17.53	18.02	17.48	17.89	17.78
Decile 10	23.82	23.66	23.45	23.45	23.56	23.84	23.90	23.59	23.66	23.59
$\frac{\text{Decile 10}}{\text{Decile 1}}$	18.57	16.59	16.54	16.45	16.54	18.82	19.42	18.89	18.82	18.94

Figure 1


Asset Densities: With Utility Channel
x 10^-3
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0.5
0
0
5
10
15
20
25
Baseline
Asset Densities: With Utility Channel
x 10^-3
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1
0.5
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15
20
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Change ta
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Asset Distributions: With Utility Channel
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0.8
0.6
0.4
0.2
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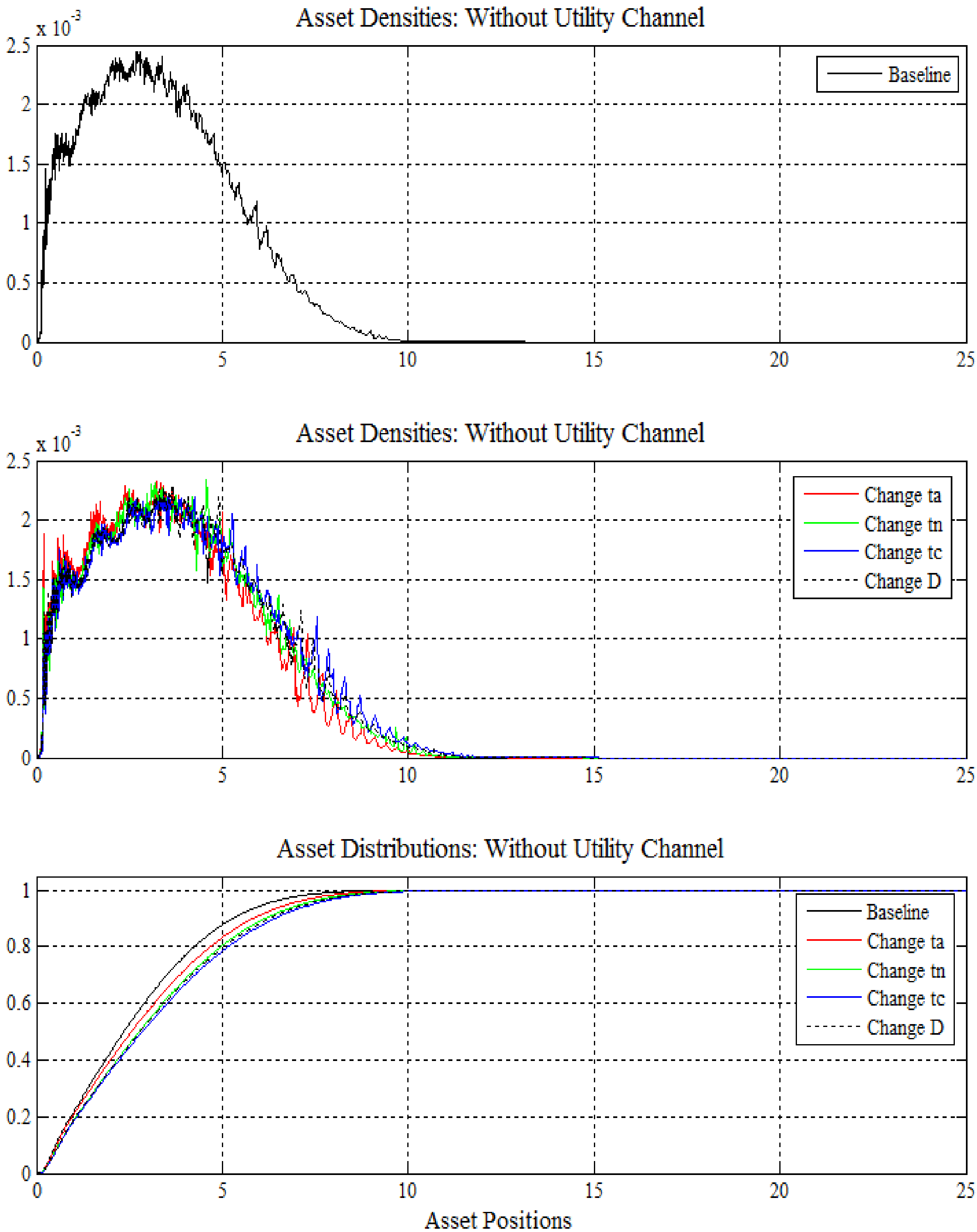
15
20
25
Baseline
Change ta
Change tn
Change tc
Change D
Asset Positions

Figure 2


Asset Densities: Without Utility Channel
x 10^-3
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Baseline
Asset Densities: Without Utility Channel
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Asset Distributions: Without Utility Channel
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Baseline
Change ta
Change tn
Change tc
Change D
Asset Positions

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