The Welfare Effects of Infrastructure Investment in a Heterogenous Agents Economy*

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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, less is known about the effect of infrastructure on welfare and the distribution of wealth. In this paper, we examine the quantitative effect of investing in infrastructure on welfare, at both the aggregate and individual levels, and on the degree of inequality present within a country. We calibrate our baseline model to replicate key features of a developing economy, and then we compute the transition path to the new stationary equilibrium that would arise if investment in infrastructure was increased. We find sizable aggregate and individual welfare effects of raising investment in infrastructure. Poorer households benefit more if asset taxes are used to finance the additional infrastructure, while richer households can benefit more if consumption or labor income taxes are used. We also find that wealth inequality, as measured by the Gini coefficient, rises in the periods immediately following the policy change, but tends to fall over time as the economy approaches its new stationary equilibrium.

Keywords: Infrastructure, Welfare, Inequality, Incomplete Markets, Stationary Distribution, Transitional Dynamics.

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1 Introduction

Going back to Adam Smith (1776), economists have asserted that the stock of public infrastructure constitutes one of 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 important, understanding its effects on the welfare of the population and on inequality would also be of primary concern to policy makers. A priori, it is not clear how welfare and inequality will be affected by additional investment in infrastructure as the direction and magnitude of the effects will likely depend on the channels through which infrastructure impacts individual choices. In this paper, we quantitatively evaluate the welfare effects, both at the aggregate and individual levels, of investing in public infrastructure within a calibrated heterogenous agents model. We apply our model to Mexico, a developing country in which infrastructure is a major issue. While Mexico's income per capita is in the top third of the Latin America and Caribbean region, its infrastructure investment as a percent of GDP has been one of the lowest in the recent decade in this region and the quality of its infrastructure is well below the regional average (Cavallo and Serebrisky, 2016; Cerra et al., 2016).

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 paper by Bom and Lighthart (2008)). 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, however, is that a country consists of a single representative household.[1] This assumption, while innocuous when one is concerned with aggregate growth patterns, implies that these models are unable to address how wealth distributions or individual welfare vary as policies change. While there is a growing literature

[1] A notable exception is Glomm and Ravikumar (2001) who utilize an overlapping generations (OLG) model to demonstrate the importance of public investment, in the form of school funding, in raising human capital and aggregate productivity.

on the distributional effects of infrastructure investment, our paper is, to the best of our knowledge, the first to consider the welfare effects at the individual level based on an agent's wealth prior to the policy change[2]

The empirical literature on infrastructure and inequality as described in the recent survey paper by Calderon and Serven (2014) has found mixed results. 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, 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 and the welfare of different agents.

The theoretical literature on the effects of public infrastructure investment on inequality also comes to differing conclusions. For example, Glomm and Ravikumar (1994b) introduce Public Sector R&D into the economy's aggregate production function and find that in the long-run, this type of public investment affects the growth rate of GDP per capita but does not affect inequality. Ferreira (1995) shows that increasing infrastructure can reduce inequality in a country, but this result depends on exogenous credit constraints that prevent poor agents from accumulating increasing stocks of private capital. 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), they find that an increase in infrastructure investment leads to an increase in wealth inequality in both the short and long run. The variety of results in both the empirical and theoretical literatures indicate that a common consensus regarding the influence of infrastructure investment on welfare and inequality has yet to be reached. Our paper's findings, to be described below, suggest that variations in the mode of financing infrastructure investment, as well as the time horizon considered (long-run vs short-run) may explain some of the differences found in the previous literature.

In our paper we adapt the standard incomplete markets model presented in Aiyagari

[2]In this regard, our paper is related to a recent strand of literature that explores the welfare impacts of various infrastructure policies across agents or governmental areas. For example, Arcalean, et al. (2010) determine the optimal degree of fiscal decentralization and infrastructure spending within a small open economy where infrastructure productivity is allowed to vary across localities. An example of recent work that focuses on the individual effects of infrastructure investment can be found in Cubas (2016), where the author develops a model to determine the impact of infrastructure availability on female labor force participation.

(1994) to a public infrastructure/public finance context. In order to achieve this, we modify the existing model to allow infrastructure to enter as an input in the production process, and we allow for an endogenous labor supply decision. One advantage of our incomplete markets approach compared to the previous literature is that heterogeneity arises not as an ex-ante initial condition to the problem (as in Glomm and Ravikumar, 1994b; and Chatterjee and Turnovsky, 2012) or as exogenously imposed differences between agents (as in Ferreira, 1995), but rather endogenously as individuals optimally respond to idiosyncratic productivity shocks. The importance of such ex-post heterogeneity was demonstrated by Getachew and Turnovsky (2015), who conclude that ex-post heterogeneity dominates ex-ante heterogeneity in determining the long-run impacts of infrastructure investment on the distribution of wealth.[3] A second advantage of our approach is that we can easily calibrate our model using readily-available survey data on income and wages. A third advantage of our approach is that it allows us to consider both aggregated and disaggregated welfare measures. Not only can we examine how various policy changes affect the welfare of agents on average, we can also look at specific agents with different initial conditions and determine how the policy effects their welfare. The model developed in this paper is similar to that presented in our previous work in Gibson and Rioja (2017).[4] However, Gibson and Rioja (2017) does not study the welfare effects of infrastructure investment, which is the main focus of our current paper. Furthermore, we now account for short-run transitional dynamics when determining the the impact of our infrastructure policies, a point not captured by Gibson and Rioja (2017). As discussed below, these short-run dynamics are very import given the nature of our policy experiments (e.g., infrastructure accumulates gradually over time).

We find that an increase in infrastructure investment leads to a significant increase in aggregate welfare. When comparing steady states before and after additional investment in infrastructure, the welfare effect is on the order of 8% of consumption with some variations depending on which tax is used to finance the additional infrastructure investment.[5] While

[3]While both our paper and Getachew and Turnovsky (2015) investigate the distributional effects of investing in infrastructure using a model with idiosyncratic shocks, our methodologies differ. We extend Aiyagari (1994), where idiosyncratic shocks follow a first-order Markov process, while Getachew and Turnovsky (2015) assume that private capital and the idiosyncratic shock are represented by lognormal distributions. One key implication of our methodology is that it allows us to consider how the welfare of agents of different wealth levels (poor/rich) is affected by policy changes. Getachew and Turnovsky (2015), on the other hand, only focus on the aggregate measure of dispersion of the capital distribution.

[4]Gibson and Rioja (2017) compares the effect of allocating resources to maintaining the existing infrastructure stock versus allocating resources to building new infrastructure in terms of both growth and inequality effects.

[5]All welfare calculations are computed in consumption equivalent units.

these steady state results suggest a large welfare impact accompanying the policy change, they ignore the short run effects that occur along the transition path, which may be very important given the nature of our policy experiment. Specifically, the stock of infrastructure and associated welfare gains do not accrue instantly when infrastructure investment is increased. Instead, they will gradually rise as the economy transitions to its new stationary equilibrium. As agents discount future periods, the welfare effects occurring during later periods of the transition will be discounted more heavily. Nevertheless, we find that after taking into account the transitional dynamics, the aggregate welfare effects are still approximately 2% of steady state consumption.

While aggregate welfare is important, we are also interested in how the policy change effects the welfare of agents with different initial conditions. Once transitional dynamics are accounted for, we find that most agents benefit from the policy change. Poorer agents may benefit more if asset taxes are used for financing more infrastructure, while rich agents may benefit more if consumption or labor income taxes are used. In terms of impact on inequality, our results indicate a differential effect depending on the time-horizon considered, with the Gini coefficient rising following the policy change but converging to its new long run level from above. Whether the policy change leads to a long run increase or decrease in wealth inequality is found to depend on which tax is used to finance the additional infrastructure. Using the interest income tax to finance additional infrastructure leads to higher inequality in the long run, while using the consumption or labor income tax ultimately reduces inequality.

The paper proceeds as follows: Section 2 provides a detailed description of our model. Section 3 describes the calibration and computational procedure that we use to approximate a solution to this model, while Section 4 discusses the results. Section 5 concludes.

2 Model

We extend the model of Aiyagari (1994) by adding an endogenous labor supply decision and by allowing infrastructure enter the economy-wide production function. The following subsections provide a detailed description of our model.

2.1 The Firm

Output in the economy is produced by a representative firm that takes as inputs the aggregate capital stock, K, aggregate labor supply, N, the economy-wide stock of infrastructure, K_G, and a technological factor, A, which is constant. The firm combines these inputs to produce output using the following technology:

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

Similar production functions have been used by Glomm and Ravikumar (1994) and Rioja (1999, 2003). The firm chooses aggregate capital and labor in order to solve the following profit maximization problem:

$$\max_{K,N} AK_G^{\phi} K^{\alpha} N^{1-\alpha} - wN - (r+\delta)K \tag{2}$$

where w is the market clearing wage rate, r is the market clearing rental rate on capital, and δ is the fixed exogenous depreciation rate of private capital, K. Solving the firm's problem yields the standard result that the gross return on capital, $r+\delta$, and the wage rate, w, are both equal to their respective factors' marginal products.

2.2 Government

The government provides infrastructure, K_G; transfers, TR; and consumes, G. Infrastructure, like all other forms of capital, is subject to depreciation. We assume that infrastructure depreciates at a constant rate, δ_G, each period. Government investment in infrastructure is denoted I_G, so the public infrastructure accumulation equation is given by,

$$K'_G = I_G + (1-\delta_G)K_G \tag{3}$$

Furthermore, we assume that infrastructure investment, transfers, and government consumption are fixed shares of the economy's GDP.

$$I_G = xY;\ TR = trY;\ G = gY \tag{4}$$

Therefore, the government's total spending is given by:

$$\text{Total Spending} = I_G + TR + G \tag{5}$$

The government raises revenue by levying taxes on consumption, labor income, and interest income. These taxes are denoted by τ_c, τ_n and τ_a respectively. Therefore, the government's total revenue is given by:

$$\text{Total Revenue} = \tau_c C + \tau_n wN + \tau_a rK \tag{6}$$

We require that the government balance its budget every period, so

$$\text{Total Revenue } = \text{Total Spending} \tag{7}$$

While Mexico has a large informal sector, we choose to abstract from this realism in order to maintain a parsimonious model structure. However, as explained below, we consider the impact of adjustments in infrastructure funded by the consumption tax and labor income tax, and interest income taxes independently. While the results derived under the labor tax may be impacted by our choice to abstract away from informality, the results observed under the consumption tax and interest income tax should be robust to this assumption.

2.3 Households

The economy is populated by a unit measure of agents who possess identical preferences over consumption, c, and leisure, l. Their period utility function is a standard CRRA function given by:

$$u(c, l) = \frac{1}{1-\sigma} c^{1-\sigma} + \eta \frac{1}{1-\sigma} l^{1-\sigma} \tag{8}$$

where σ denotes the Arrow-Pratt measure of relative risk aversion, and η determines the relative weight on leisure in the utility function.

While agents's preferences are identical, they differ in terms of their labor income. Some agents are unemployed, while others are employed and receive labor income from the firm.[6] Labor income, defined as wnz, consists of the following three components; the aggregate wage rate, w, the agent's labor supply, n, and the agent's labor productivity, z. Therefore, while all agents take the same aggregate wage as given, they face different efficiency wages depending on their specific realization of z.

Each agent's labor position is the result of the idiosyncratic labor productivity shock, z, that occurs at the start of each period. We use a five state Markov process for z, where the first state corresponds to unemployment ($z = 0$). While agents lack the ability to perfectly insure against fluctuations in z, they have the ability to save by accumulating assets, a, that pay a market determined return, r. Standard precautionary savings motives apply, and

[6] All agents receive lump-sum transfers from the government.

agents will accumulate assets while their productivity is high 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, z. 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:

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

s.t.

$$(1+\tau_c)c + a' \leq (1+(1-\tau_a)r)a + (1-\tau_n)wnz + TR \tag{9}$$

$$n + l \leq 1 \tag{10}$$

$$a' \geq 0 \tag{11}$$

Equation (9) is the household's budget constraint. It simply states that a household's spending on consumption and investment cannot exceed their current resources. The variables 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 lump sum transfers, TR, provide infrastructure, K_G, and engage in government consumption, G. Equation (10) 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 ($z = 0$), $l = 1$, $n = 0$ and equation (10) becomes redundant. Equation (11) 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:

$$u_c = \beta \sum_{z'} \pi(z'|z) u_{c'}(1+(1-\tau_a)r') + (1+\tau_c)\lambda_3 \tag{12}$$

$$u_l = u_c \left[\frac{(1-\tau_n)wz}{1+\tau_c} \right] \tag{13}$$

Equation (12) 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 (13) governs the household's choice between working more hours and taking leisure. This equation can be used to derive the agents' optimal labor supply condition as a function of their current labor productivity, current asset holdings, and their optimal investment decision rule:

$$n(a,z) = \frac{1+\tau_c+\left[\frac{\eta(1+\tau_c)}{(1-\tau_n)wz}\right]^{\frac{1}{\sigma}}[a'(a,z)-(1+(1-\tau_a)r)a-TR]}{1+\tau_c+\left[\frac{\eta(1+\tau_c)}{(1-\tau_n)wz}\right]^{\frac{1}{\sigma}}(1-\tau_n)wz} \tag{14}$$

While infrastructure does not enter the households' problem directly, changes in its level will impact the individual agents' decisions. Specifically, changes in the stock of infrastructure will affect individual agents 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 tends to increase 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. Importantly for the distributional effects, the response in labor supply also depends on the wealth and productivity of the agent as equation (14) shows. Hence, poorer, less productive agents may change their labor supply in different proportion than richer agents which could affect savings and have distributional implications.

2.4 Equilibrium

We consider two equilibrium concepts in this paper. The following two subsections provide a definition for these concepts.

2.4.1 Stationary Equilibrium

A stationary equilibrium for this economy is a value function, $v(a,z)$, individual decision rules, $a'(a,z)$, $n(a,z)$, $l(a,z)$ and $c(a,z)$, a time-invariant distribution of individual states, $F(a,z)$, time invariant factor prices, w and r, time-invariant government policies, τ_a, τ_n, τ_c, x, G, and TR, and a vector of aggregates, K, N, C, K_G, Y 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 by aggregating over individual decisions
3. Factor prices, w and r, satisfy the firm's FOCs
4. Goods market clears: $C + \delta K + \delta_G K_G + G = Y$
5. Government balances its budget
6. Distribution of individual states is stationary: $F(a', z') = \sum_z \pi(z'|z)F(a'^{-1}(a', z), z)$

2.4.2 Transitional Equilibrium

A transitional equilibrium is defined as the equilibrium of the economy at each point in time as it transitions from one steady state to another. For this economy, the transitional equilibrium consists of sequences of time varying decision rules, $\{a'_t(a, z),\ n_t(a, z),\ l_t(a, z),$ and $c_t(a, z)\}_{t=1}^{T}$, the time varying distribution of individual states, $\{F_t(a, z)\}_{t=1}^{T}$, the time varying factor prices and government policies, $\{w_t,\ r_t,\ \tau_{a,t},\ \tau_{n,t},\ \tau_{c,t},\ x_t,\ G_t,$ and $TR_t\}_{t=1}^{T}$, and time-varying aggregates $\{K_t,\ N_t,\ C_t,\ K_{G,t},\ Y_t\}_{t=0}^{T}$, such that:

1. The economy at time $t = 1$ is consistent with our initial stationary equilibrium
2. The economy at time $t = T$ is consistent with our terminal stationary equilibrium equilibrium
3. Given the sequence x_t, factor prices, and taxes, the decision rules solve the household's problem for each time period.
4. The sequence of factor prices satisfy the firm's FOCs for each time period
5. The goods market clears:

$$C_t + K_{t+1} - (1-\delta)K_t + K_{G,t+1} - (1-\delta_G)K_{G,t} + G_t = Y_t,\ \forall t$$

6. Government balances its budget each period
7. The distribution of individual states evolves as:

$$F_{t+1}(a, z) = \sum_z \pi(z'|z)F_t(a^{-1}(a_{t+1}, z), z)$$

3 Calibration and Solution

Our model is calibrated to an annual frequency and set to match several basic properties of the Mexican economy. In this section we will provide details regarding our calibration procedure as well as the numerical methods that were employed to approximate a solution to our model. We chose the country of Mexico since it is ranked in the top third of Latin American and Caribbean (LAC) countries in income per capita, yet its infrastructure quantity is only about at the average of this group of countries (Calderon and Serven, 2010) and its quality is one standard deviation below the median of LAC countries (Cerra et al., 2016). Investment in infrastructure as a share of GDP has declined in the past decade and has been one of the lowest in the LAC region, therefore infrastructure is a very important issue in Mexico (Cavallo and Serebrisky, 2016). Furthermore, the type of heterogenous agents model that we use requires information on household surveys with longitudinal data on income, wealth, and employment. Mexico's Statistical Institute (INEGI) provides an accessible household survey that tracks all the data that we need to calibrate our model.

3.1 Parameters

The discount factor, β, is set to target the annual rental rate on capital for Mexico, which is approximately 4% (Esteban-Pretel and Kitao, 2013). Following Inklaar and Timmer (2014) and Krusell and Smith (2015), we set the depreciation rates for private and public capital to 0.085, which falls near the middle of the estimated range in these papers of $(0.04, 0.10)$.[7] Following convention, capital's share of output, α, is set to 0.36 (see Gollin, 2002). The elasticity of output with respect to infrastructure has been estimated in a number of studies. Bom and Ligthart (2008) survey this literature; we use the average value in developing counties which is $\phi = 0.15$.[8] We set σ and η to target a reasonable value for the Arrow-Pratt measure of relative risk aversion and the aggregate labor in the economy. Lastly, we set the constant technological factor, A, equal to 1. See Table 1 for a complete list of all parameter values and empirical targets.

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. According to the World Tax Indicators

[7]We assume that private and public capital depreciate at the same rate for simplicity. Our model's results are not sensitive to small differences in these rates.

[8]Our primary results are robust to modest variation in the value of ϕ

(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 $\tau_c = 0.15$. Lastly, government transfers as a share of GDP are set to approximately 7% following Inegi (2012). With all tax rates set, government consumption, G, is backed out using the government's budget constraint:

$$G = \tau_a r K + \tau_n w N + \tau_c C - I_G - TR \tag{15}$$

which yields a government consumption to GDP ratio, g, of approximately 8%. With our model's parameters calibrated to the Mexican data, we proceed by specifying our shock process and approximating a solution to the model economy.

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 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.[9] Individuals are surveyed for 5 consecutive quarters, so we assemble a longitudinal panel to determine transition probabilities among income quintiles. The average productivities,

$$[z_2, z_3, z_4, z_5] \tag{16}$$

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

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

(OECD Stats, 2014).[10] 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.

3.3 Solution Methodology

To solve the model we employ standard methods for computing the stationary distribution of an incomplete markets model with idiosyncratic shocks. Specifically, we start by guessing values for aggregate capital, K, and labor, N, and we use these values to compute r, w, and K_G. We discretize private assets, restricting assets to 100 unevenly spaced grid points on the interval (0,25). Given these asset values, we use equation (14) to solve for all possible optimal labor supply decisions. With these values in hand, we use value function iteration with golden section search and parabolic interpolation to solve for the agents' decisions rules. Next, these decision rules are used to solve for the invariant density, $f(a, z)$. Since we are 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 (500 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.

The process described above is used to solve for the stationary equilibrium under both the baseline policy and the alternative policy where infrastructure investment as a share of GDP is increased. Once these stationary equilibria are found, we use the method outlined in Domeij and Heathcote (2004) and Heer and Mausneer (2009) to compute the transition path between the two stationary equilibria.

3.4 Welfare Measure

Assume that the economy is initially in a stationary equilibrium. At time 1, the government permanently increases infrastructure investment. This one-time policy change starts the economy along its transition path to a new stationary equilibrium that will be reached after T periods. We are interested in the welfare effects of such a policy.

Following the literature (see Aiyagari and McGrattan (1994), Floden (2001), and Domeij

[10] 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.

and Heathcote (2004)) we adopt the following utilitarian social welfare function:

$$\Omega^I = \int_a \int_\epsilon v^I(a,\epsilon) f^I(a,\epsilon) da d\epsilon \tag{17}$$

where the superscript "I" indicates that we are considering the welfare, value function, and invariant density from the initial stationary equilibrium. By integrating over a and ϵ, we are computing the ex-ante expected welfare of the average agent in the economy. The welfare function presented in (17) applies equal weight to each agent according to their prevalence in the economy and can be interpreted as providing a measure of aggregate or economy-wide welfare.

We consider two alternative methods for computing the long-run welfare impact of the policy change. The first method ignores the transition path and simply compares the utilitarian social welfare functions found in the initial and terminal stationary states. Specifically, we compute the percentage of consumption, cv, the agent must give up in the terminal stationary state in order to be indifferent between remaining in the terminal state or returning to the original stationary equilibrium:

$$\Omega^I = \Omega^T(cv) \tag{18}$$

The second method takes account of the transition path by computing the welfare effect as:

$$\int_a \int_\epsilon \sum_{t=0}^{T} \beta^t U(c^I(a,\epsilon), l^I(a,\epsilon)) f^I(a,\epsilon) da d\epsilon = \int_a \int_\epsilon \sum_{t=0}^{T} \beta^t U((1-cv)c_t(a,\epsilon), l_t(a,\epsilon)) f_{t-1}(a,\epsilon) da d\epsilon \tag{19}$$

where $c^I(a,\epsilon)$ and $l^I(a,\epsilon)$ denote the time invariant decision rules from the initial stationary equilibrium, while $c_t(a,\epsilon)$ and $l_t(a,\epsilon)$ denote the time-varying decision rules recovered along the transition path.

While the analysis above focuses on aggregate welfare, we are also interested in how increasing infrastructure investment impacts the welfare of agents with different initial conditions. The calculations of individual welfare are analogous to those presented above, except we must simulate the time paths for individual agents (See Section 4.2 for details).

4 Results

Before we present the results of our infrastructure policy changes, we must discuss how well our baseline model replicates Mexico's wealth distribution. Table 3 presents the share of wealth held by each quintile for both the Mexican economy and our baseline model. Inspection of Table 3 indicates that our model does a reasonable job at replicating the degree of wealth concentration observed in the data. The model roughly matches the wealth shares in quintiles 2 through 5, but it underestimates the share of wealth held by the poorest agents in quintile 1. Alternatively, one could calibrate the labor productivity shocks so that the baseline model's wealth distribution matches the data as close as possible (See Castaneda et al. (1998)). However, as our primary interest lies in the welfare effects associated with increased infrastructure investment, it is more important for us to accurately match labor productivites, transition probabilities, and associated labor supply decisions than the wealth distribution at a point in time.

Next, to study the welfare implications of a unit increase in infrastructure investment we compute the transition path between our baseline model where infrastructure investment is 2% of GDP to a new stationary equilibrium where infrastructure investment is 3% of GDP. After recovering these unit effects, we consider an alternative policy where infrastructure investment is increased to 5% of GDP. While the latter represents a large policy experiment, the magnitude of the change is not unprecedented. In a detailed study of Latin American countries, Fay and Morrison (2007) estimate that countries such as Mexico require about 5% of GDP to be spent on infrastructure investment. Similar public investment levels were successfully undertaken in Indonesia, Malaysia, and South Korea in the 1970s and 80s building up those countries' infrastructure stock. For both policy experiments, 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 welfare, distributional effects, or growth.

4.1 Aggregate Welfare Effects

We begin by determining the long run effect of increasing infrastructure investment from 2% of GDP to 3% of GDP on aggregate welfare in the economy using the utilitarian social welfare function introduced in (17). The first column of Table 4 presents the steady state welfare effects in consumption equivalent units. These results are computed assuming the economy instantly adjusts to a new stationary equilibrium on impact of the policy change. Inspection of this column indicates that increasing infrastructure investment significantly increases aggregate welfare, regardless of how the additional infrastructure is financed. Specifically, if the interest income tax is used to finance the increased infrastructure then 7.51% of consumption must be taken away from agents in the terminal stationary equilibrium in order to equate welfare with the initial stationary state. The welfare effects are roughly of the same magnitude despite which tax is used to finance the infrastructure (7.89% for τ_n, and 8.06% for τ_c).

While the results presented above indicate that increasing infrastructure investment can lead to a substantial boost in aggregate welfare, the results were derived assuming that the economy instantly transitioned to the new stationary equilibrium following the one-time permanent increase in infrastructure investment. However, for completeness, one should take into account the transition path the economy takes as it converges to the new stationary equilibrium when computing welfare measures as the short-run and long-run welfare effects may differ. The fourth column of Table 4 presents these results. The welfare gains are now close to 2% of consumption. That is, the welfare gains that account for changes during the transition from one stationary equilibrium to another are smaller than those computed for an instantaneous adjustment between steady states. The reason for smaller welfare effects when accounting for transitional dynamics is as follows: the stock of infrastructure and its associated welfare benefits do not increase instantaneously over the transition path. Instead, they are accrued year by year as the economy transitions to its new stationary equilibrium. Since agents discount future periods, the welfare effects due to increases in the stock of infrastructure occurring during later periods of the transition will be heavily discounted. Interestingly, even after controlling for these effects we still find a sizable impact on aggregate welfare at approximately 2% of steady state consumption.

To establish how the welfare enhancing effects of increasing infrastructure investment scale as the policy is increased, we also consider the effects of increasing infrastructure investment by 3% of GDP. Results of this exercise are also presented in the second panel of Table 4. The results from this policy experiment are consistent with the 1% increase considered earlier. However, it should be noted that the welfare effects did not increase linearly. Specifically, while this policy experiment is three times larger than our earlier experiment (i.e., it increases infrastructure investment by 3% rather than 1% of GDP), the welfare effects are only about twice as large. These results show that the welfare gains that a country like Mexico could accrue by raising infrastructure investment to levels similar to that found in South Korea and Malaysia during the 1970s are sizable.

4.2 Individual Welfare Effects

Now that we have discussed how increasing infrastructure investment affects welfare at the aggregate level, we investigate how the policy change affects agents' welfare at the individual level. To measure this differential effect we consider three different wealth levels, "poor", "average", and "rich". "Poor" agents are defined as agents with wealth (capital) holdings equal to 1% of the average level ($0.01K$). "Average" agents have wealth holdings given by the average level, K, and "rich" agents are defined as agents with wealth holdings equal to $10K$. In terms of the data, the average per capita wealth in Mexico during the period we study was about $20,000 according to Credit Suisse (2013). Then, the "poor" would be defined as those that have wealth of $200 and the "rich" would have wealth of $200,000.

We will also consider agents starting with each of the five potential realizations of productivity. Therefore we will consider agents ranging from the low-productivity poor (those who start with $a = 0.01K$ and $z = z_1$), to the high-productivity rich (those who start with $a = 10K$ and $z = z_5$). To compute individual welfare effects we must simulate time paths for the agents described above assuming three different economy-wide environments. First, we simulate the agents' time paths assuming the economy remains in the initial stationary equilibrium. Second, we simulate the agents' time paths assuming the economy instantly jumps to the new stationary equilibrium at the onset of the policy change, and third, we simulate the agents' time paths assuming the economy gradually evolves to the new stationary equilibrium over T periods. By comparing across these three variations we can compute the welfare effects both ignoring and including transitional dynamics (see Table 5)[11]. Inspection of Table 5 indicates that if we focus on only steady state effects, poor agents benefit the most while rich agents benefit the least. Poor agents experience a welfare gain of about 8% of consumption.

Focusing only on steady state changes can be misleading as Table 5 shows. When transitional dynamics are included in the welfare calculation, poor agents benefit more only in the case when the additional infrastructure is financed by increasing the asset tax. In this case, the additional infrastructure is being funded primarily by the incomes of rich agents who earn a disproportionately large share of their income through investment. Conversely, when the labor income or the consumption tax are used for financing the additional infrastructure, rich individuals benefit more than the poor. One reason for these differential effects is that the rental rate on capital spikes during the early periods of the transition (See Figure 1).

[11] The simulations described above are all repeated 100 times and averaged so as to reduce the impact of random number draws.

Therefore, if the welfare effects are computed ignoring the transitional dynamics, the spike in the interest rate will be ignored, which will significantly reduce the welfare effect for rich agents who benefit the most from sudden increases in the interest rate. We also see that the welfare effect increases with the agents' initial productivity level, indicating that agents who start in a high productivity state tend to benefit more from the policy change than agents who start from a low productivity state. This occurs as the policy significantly increases wages and agents with higher labor productivity tend to supply more labor. Thus, these agents see a larger increase in income as a result of the policy relative to their less productive counterparts. This effect tends to fade as wealth increase because labor supply declines with wealth. The results from increasing infrastructure investment by 3% of GDP are consistent with the results above and are presented in Table 6.

4.3 Wealth Inequality and other Aggregate Variables

To gain further insights into what is driving the welfare effects described above we must look more closely at the transitional dynamics of the model's key aggregate variables. The first panel of Figure 1 shows how increasing infrastructure investment by 1% of GDP impacts the stock of infrastructure in the economy. Inspection of this panel indicates that the stock of infrastructure responds gradually to the policy change, eventually reaching a new stationary level that is significantly larger than the initial level. Part of this strong increase in infrastructure is driven by the increase in output that accompanies the policy. Aggregate output increases by approximately 7.4% on average in the long run, with a large portion of the gains accumulated in the first several periods. The new level of output reached in the long run is shown to be sensitive to the financing method used, with the consumption tax yielding the largest output increase and the interest income tax yielding the smallest increase. The policy change is also shown to significantly increase the wage rate and aggregate consumption, with the consumption (interest income) tax yielding the largest (smallest) long run increases.

While the transition paths for infrastructure, output, wages, and consumption all increased monotonically to their new steady state levels, other aggregates have more interesting dynamics. For example, private capital initially falls slightly following the policy and then gradual increases, converging to its new steady state level from below. This occurs because the large increase in infrastructure accompanying the policy change increases individual's incomes, allowing them to increase consumption and save less. The infrastructure increase leads to an initial sharp increase in the rental rate which over time converges to the new steady state level from above. Interestingly, the long run values for the interest rate differ considerably between policies. Specifically, when the interest income tax is used to finance the additional investment, the rental rate increases from 3.5% to approximately 4.75%, while the long run changes are much smaller under the other tax policies. This is due to the large increase in τ_a that is needed to finance the additional infrastructure. Finally, aggregate labor increases in the short run and decreases in the long run, converging to its new long run level from above.

While the changes in consumption and leisure considered so far have an impact on welfare, another important factor determining welfare is the degree of inequality present in the economy. The second panel of Figure 1 presents the transition path for the wealth Gini coefficient. There are long-run differences in the Gini depending on how the additional infrastructure investment is financed. Specifically, if the interest income tax is used, there is an increase in the Gini (approximately from 0.4375 to 0.439), while the other tax policies lead to less noticeable long run changes. We also see that for all tax policies, the Gini coefficient rises following the policy and converges to its new steady state level from above. This is driven by the large spike in the rental rate of capital which boosts the income of wealthy agents disproportionately more than poorer agents in the beginning periods of the transition. Overtime, poorer agents are able to increase savings and the Gini falls. The exception to this is when the interest income tax is increased to finance the additional infrastructure investment, as this reduces the marginal benefit of savings, discouraging poor agents from increasing their wealth holdings. For completeness, Figure 2 presents the transitional paths for the case where infrastructure investment is increased by 3% of GDP. The results from this experiment are consistent with the 1% results discussed above.

In summary, we find that increasing infrastructure investment from 2% of GDP to 3% of GDP has a strong impact on aggregate welfare, yielding a consumption equivalence measure on the order of 2% when the transitional dynamics are considered. The policy also leads to a strong long run increase in aggregate output, capital, infrastructure, consumption, leisure, and wages. We find evidence of differential distributional effects along the transition paths with inequality rising initially and then converging to its new steady state level from above. At the individual level, we see that most agents benefit welfare-wise from the policy change, but which agents benefit most depends on how the additional infrastructure is funded. Poor agents benefit more when the asset tax is used since wealthier agents have more assets which are taxed at a higher rate to finance infrastructure. Conversely, rich agents benefit more when the consumption or labor income tax are used as the use of these taxes shift the funding burden to lower wealth agents. Also, individual welfare effects tend to be positively related to an agent's initial productivity level, but this effect fades as wealth rises.

5 Conclusions

Public infrastructure serves as one of the underpinnings for economic growth in a country. Many papers have investigated its growth effects and fewer papers have investigated the distributional effects. We proceed further by evaluating the aggregate and individual welfare consequences of additional infrastructure investment in an economy of heterogenous agents. When transitional dynamics are considered, increasing infrastructure investment by 1% of GDP is found to increase aggregate welfare by approximately 2% of consumption. At the individual level, we find that while most agents experience welfare gains from the policy change, poor agents benefit the most when the asset tax is used to finance additional infrastructure. Conversely, rich agents benefit the most when the labor income tax or consumption tax is used to finance more infrastructure. These results stem from the fact that increasing infrastructure investment is found to increase the economy-wide interest rate significantly in the short run, which disproportionately benefits rich agents who hold a substantial portion of the economy's wealth.

While uncovering the welfare consequences of increasing infrastructure investment is our primary objective, we are also interested in our model's distributional results. We find that increasing infrastructure investment impacts inequality differently depending on the time-horizon considered. Specifically, we find that the Gini coefficient on wealth increases for several periods following the policy change before converging to its new long-run level from above. This initial increase in inequality stems from the large short-run increase in the interest rate that accompanies the policy change. The higher interest rate increases the incentive to save but it also disproportionately increases the income of richer agents in the first few periods. Our finding that increased infrastructure investment may increase inequality in the short run while reducing it in the long run has the potential to explain some of the inconsistent results found in the empirical literature related to this topic, though further empirical work is required to conclusively make this case.

Several interesting questions are left for future research. For example, 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

Parameter	Value	Target
β	0.9215	Capital Rental Rate = 4%
σ	2.5	Std. Arrow-Pratt CRRA
α	0.36	Capital's Income Share
ϕ	0.15	Elasticity of Y w.r.t. Infrastructure
δ	0.085	Annual Depreciation Rate
δ_G	0.085	Annual Depreciation rate
η	7.5	Aggregate Labor = 0.33
τ_a, τ_n, τ_c	0.10, 0.10, 0.15	World Tax Indicators

Table 2: Productivity Shock Process

$z_1 = 0.000$	$z_2 = 0.331$	$z_3 = 0.588$	$z_4 = 0.878$	$z_5 = 2.203$

	z_1	z_2	z_3	z_4	z_5
z_1:	0.200	0.800	0.000	0.000	0.000
z_2:	0.032	0.551	0.247	0.115	0.055
z_3:	0.032	0.240	0.397	0.244	0.087
z_4:	0.032	0.113	0.235	0.402	0.218
z_5:	0.032	0.056	0.085	0.207	0.620

Table 3: Model vs. Data

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Data[a]	7.76	10.78	14.18	20.85	44.70
Model	2.70	8.30	17.46	26.91	44.62

a Wealth distribution data for Mexico at the quintile and decile level was obtained from De la Torre and 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: Aggregate Welfare Changes

	Increase Infrast. Inv. 1% of GDP		Increase Infrast. Inv. 3% of GDP	
	Steady State[a]	Transition[b]	Steady State[a]	Transition[b]
$\Delta\tau_a$	7.51	2.44	14.7	5.2
$\Delta\tau_n$	7.89	2.27	15.7	4.7
$\Delta\tau_c$	8.06	2.13	16.2	4.3

a Welfare computed assuming the economy instantly moves to the new stationary equilibrium

b Welfare computed taking into account the transition path to the new stationary equilibrium

Table 5: Individual Welfare Effects (1% Increase)

	Ignoring Transition			Including Transition		
	Poor	Average	Rich	Poor	Average	Rich
			Adjusting τ_a Case			
z_1	6.51	5.79	-0.21	1.08	2.21	1.02
z_2	8.37	5.89	-0.21	2.11	2.26	1.02
z_3	8.49	6.05	-0.21	2.28	2.30	1.02
z_4	8.54	6.20	-0.21	2.40	2.33	1.02
z_5	8.61	6.52	-0.21	2.56	2.39	1.02
			Adjusting τ_n Case			
z_1	6.58	5.77	1.89	0.76	2.31	3.67
z_2	8.02	5.95	1.89	1.52	2.36	3.67
z_3	8.14	6.11	1.89	1.69	2.39	3.67
z_4	8.21	6.26	1.89	1.83	2.43	3.67
z_5	8.31	6.60	1.89	2.05	2.50	3.67
			Adjusting τ_c Case			
z_1	6.19	5.51	-0.21	0.69	2.03	2.26
z_2	8.37	5.72	-0.21	1.60	2.10	2.26
z_3	8.53	5.90	-0.21	1.79	2.15	2.26
z_4	8.61	6.09	-0.21	1.94	2.20	2.26
z_5	8.73	6.49	-0.21	2.18	2.31	2.26

Table 6: **Individual Welfare Effects (3% Increase)**

	Ignoring Transition			Including Transition		
	Poor	Average	Rich	Poor	Average	Rich
			Adjusting τ_a Case			
z_1	13.5	11.6	-1.3	2.3	4.5	0.8
z_2	16.6	12.0	-1.3	4.5	4.6	0.8
z_3	17.0	12.3	-1.3	4.9	4.7	0.8
z_4	17.1	12.5	-1.3	5.1	4.7	0.8
z_5	17.1	13.2	-1.3	5.5	4.8	0.8
			Adjusting τ_n Case			
z_1	13.7	11.7	4.8	1.3	4.9	8.7
z_2	15.9	12.1	4.8	2.7	4.9	8.7
z_3	16.0	12.4	4.8	3.1	5.0	8.7
z_4	16.1	12.7	4.8	3.4	5.1	8.7
z_5	16.3	13.3	4.8	3.9	5.2	8.7
			Adjusting τ_c Case			
z_1	12.6	11.1	-1.3	1.1	4.0	4.6
z_2	16.8	11.5	-1.3	3.0	4.2	4.6
z_3	17.1	11.9	-1.3	3.4	4.3	4.6
z_4	17.2	12.3	-1.3	3.8	4.4	4.6
z_5	17.4	13.1	-1.3	4.3	4.6	4.6

Figure 1: Transition Path, 1 Percent Change

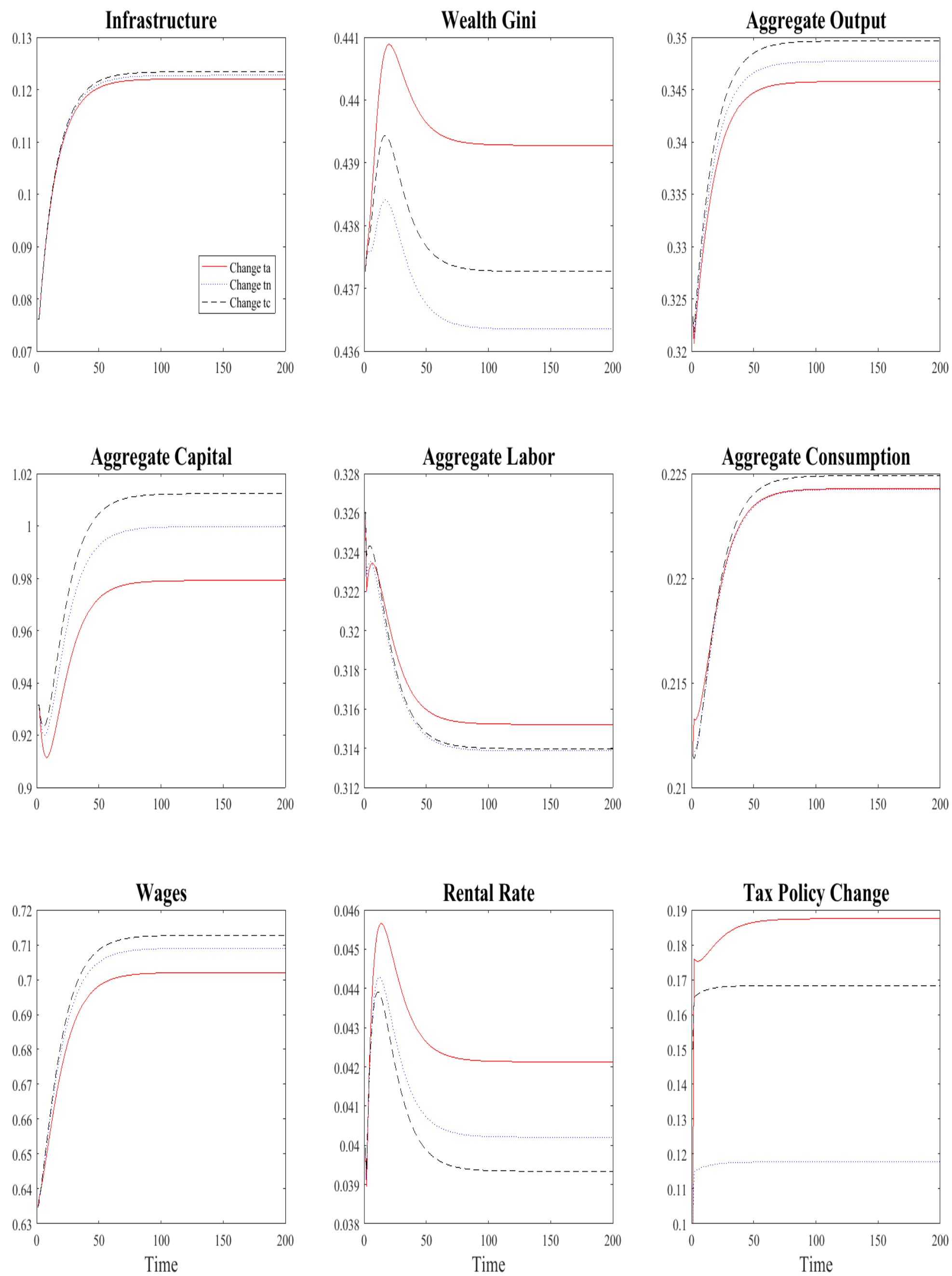
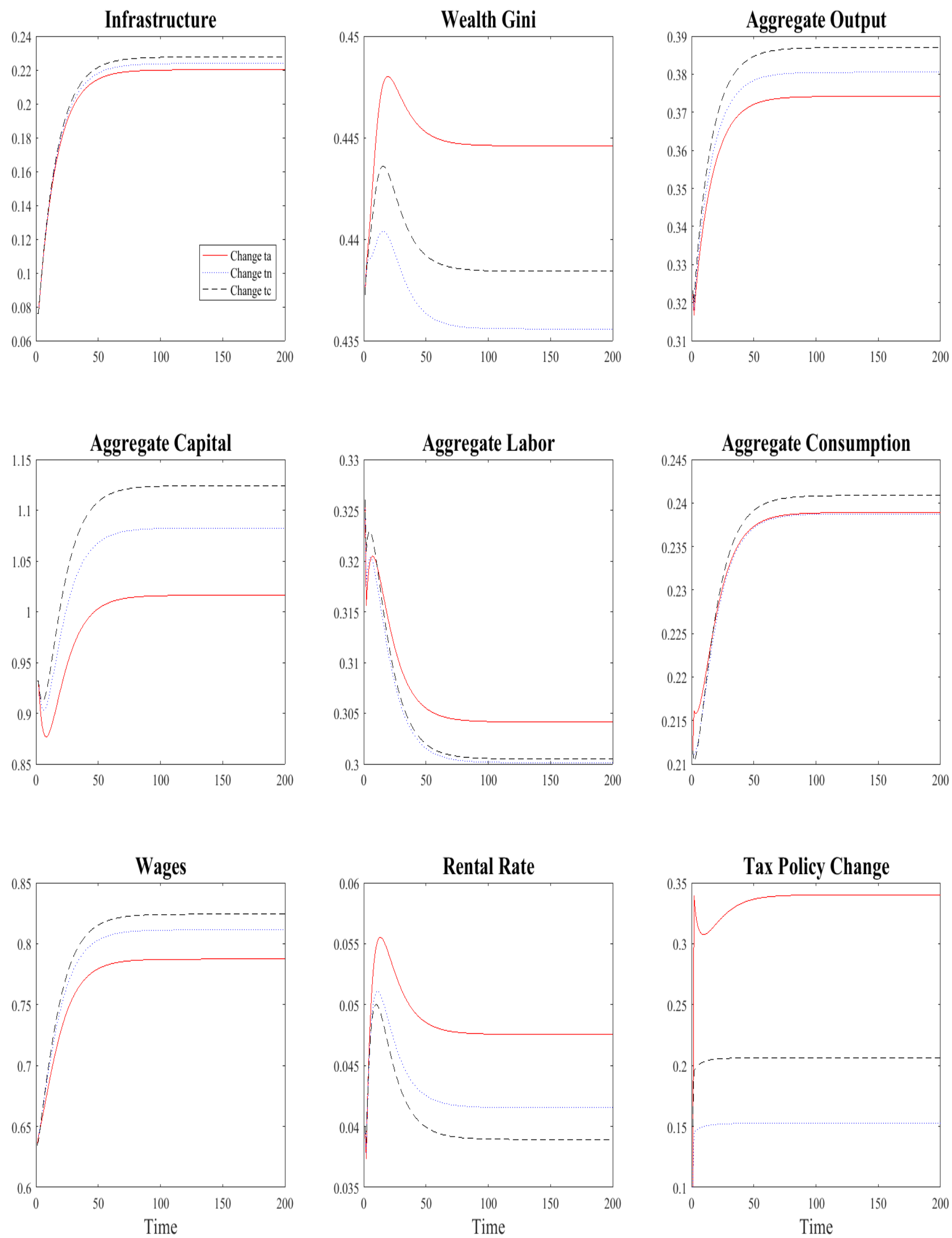


Figure 2: Transition Path, 3 Percent Change



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