Optimal Infrastructure after Trade Reform in India.

Priyam Verma*

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Abstract

Lower tariffs typically raise productivity, production, and trade, increasing the benefits from building infrastructure. Infrastructure spending by governments should therefore increase after countries open up to trade. I test this hypothesis empirically using a trade reform in India and find that a 1 percentage point reduction in tariffs increased states' infrastructure spending by 0.5% between 1991 and 2001. To understand the mechanisms behind my empirical findings, I develop and calibrate a multi-region model of international trade, private capital accumulation, and infrastructure spending, in which each government chooses such spending to maximize their state's welfare. I find if governments choose infrastructure following the reform optimally, infrastructure would have increased by 60% on average. The actual increase, based on my empirical findings, was about 29%. Looking at categories of infrastructure, I find that government's response in transport related infrastructure was 90% of what will be optimal within this model. Counterfactual exercises show that raising aggregate infrastructure towards its optimal following the trade reform will result in state GDP to increase by 7% on average.

Keywords: Infrastructure, Tariffs, Trade

JEL Classification: F11, F14, H41

*Aix-Marseille School of Economics. Email: priyam.VERMA@univ-amu.fr. I owe a great debt of gratitude to my advisor Kei-Mu Yi and my committee members Aimee Chin, German Cubas, and Bent Sørensen. I thank Steven Craig, Heena Kapoor, Samuel Kortum, Eva Van Leemput, Gergely Ujhelyi, Dietrich Vollrath, Sri Hari Naidu and Amar Nath. I benefited greatly from the seminar participants at Aix-Marseille School of Economics, UP Diliman, IIT Kanpur, University of Houston and conference participants at AMES and EEA-ESEM Congress. All errors are mine.

1 Introduction

Lower trade tariffs enable firms to source cheaper inputs from the rest of the world, which lowers the cost of production and raises productivity. Recent research has demonstrated this for India, Chile, Indonesia, and Hungary.[1] A higher level of productivity incentivizes firms to increase their output, requiring increased investments in private as well as infrastructure capital. A planner maximizing a country's welfare should therefore allocate more resources to infrastructure after opening up to trade.

In this paper, I study the effect of India's opening up to international trade in the early 1990's on its infrastructure spending policies. To test if the governments respond to tariff reductions by changing infrastructure spending, I use a differences-in-differences strategy in the background of large tariff reductions undertaken by India, starting in 1991. To quantify resulting gains from this response, I draw from regional trade models developed originally in Eaton and Kortum (2002). I extend their model to include for dynamic capital accumulation, as well as government taxation and infrastructure spending choices.

India started trade liberalization in 1991, leading to large tariff reductions amounting to around 50 percentage points. This reform increased the trade-to-GDP ratio from 18% to 30% and doubled aggregate productivity in the following decade. Topalova and Khandelwal (2011) find that industries that were more exposed to tariff reductions had larger productivity increases. States that housed industries with larger tariff reductions would have a larger incentive to build infrastructure. I show that incentives for building infrastructure increased after India's trade reform and resulted in governments raising their infrastructure by 25%.

India's tariff reductions provide an exogenous variation to determine its causal effects on infrastructure spending for primarily two reasons. First, the decision on tariff levels is orthogonal to states' infrastructure spending because of the federal structure of the government. The national government, which is the decision maker for tariff rates, does not decide the level of infrastructure in the states. Second, and more importantly, the tariff reductions were a result of a balance of payments crisis. Oil price spikes after the Gulf War caused India's import bills to balloon. To manage this shortfall, India took short-term loans from the IMF and the World Bank, which mandated tariff cuts. Hence, in a differences-in-differences framework, I use variation in tariff reductions across states as a treatment for identification.

[1] See Goldberg et al. (2010); Pavcnik (2002); Amiti and Konings (2007); Halpern, Koren and Szeidl (2005).

Comparing the years before and after the reform, I find that a 1 percentage point reduction in tariffs increased states' infrastructure spending by 0.53% between 1991 and 2001. The response started in 1993 and continued until 2001. The estimates for the later years are twice the size of the earlier years. The results are robust to pre-trends. To further test this hypothesis, I look at transport and non-transport infrastructure. Transport infrastructure is more complementary to tradable-sector firms, and hence its usage would increase by more after trade opening. I find that government spending on roads and bridges, compared to irrigation and power, increased by a factor of four.

To understand the incentives for infrastructure investment by governments, I build a regional trade model similar to Eaton and Kortum (2002), with private and infrastructure capital. Households consume and save every period, earn wages, and rent capital to firms. Firms in turn use private capital, labor, and material inputs for production as well as infrastructure capital, which is a pure public good and free for usage. Infrastructure is financed through an income tax. States maximize the local welfare by picking the tax rate and thereby decides the level of infrastructure in the economy every period. I solve the model in steady states.

I use this model to quantify the gains from a trade reform when the government's response is endogenous. The total gains are a result of the increase in productivity, private capital, and infrastructure capital. The capital accumulations result in regional spillovers due to domestic trade linkages, thereby raising aggregate gains. I calibrate the model to six major states in India and the rest of the world. I use estimates on domestic and international trade costs from Van Leemput (2016). I solve the model by choosing tax rate level in one state that maximizes local welfare, letting all states adjust their private capital but keeping the infrastructure capital in other states fixed. Then, I update the level of infrastructure capital in the first state from the previous step and solve for the optimal level of tax in the next state. I do this until the last state maximizes its local welfare and then iterate until convergence.

I find that the gains from a trade reform are much larger if governments adjust their infrastructures optimally. In my model, the optimal level of infrastructure increased by 60%, whereas based on my empirical estimates, governments raised it by 29%, following the trade reform. This finding implies that governments raised infrastructure to 50% of what would be optimal in this model. This is driven by transport related infrastructure spending. Based on the empirical estimates for roads and bridges, the governments response was a

55% increase in infrastructure spending following the reform. Hence government's response in transport-related infrastructure was 90% of what will be optimal in this model. Further counterfactual exercises show that state GDP increases by 7% more if the governments adjust their tax towards the optimal level following the reform.

In another counterfactual exercise, I want to see how the tax incentives would have changed had governments invested at the model-implied optimal levels even before the reform. Thus instead of using the initial tax rate imputed from the 1991 data, I solve for the optimal tax rate in the year 1991 and then again when tariffs are lowered. In this scenario, trade reform leads to state governments marginally raising the tax rate in four of the six states while marginally lowering it in the other two states. This finding implies that if governments are investing optimally, even a large tariff reduction would not alter their incentives for taxation to provide infrastructure.

To understand the extent of strategic interactions between states, I solve for the best response functions in terms of tax rates in a two-state case for Gujarat and West Bengal. The negative slope of these functions indicates that infrastructure is a strategic substitute. The magnitude of the slope is small however, indicating they are weak strategic substitute. The lack of strategic behavior between states allows me to solve the multi-region model with regional linkages via a sequential algorithm.

Related literature: My paper adds to a fast-developing new literature of regional trade models. I build on a tractable model of international trade, introduced in Eaton and Kortum (2002), and add multiple regions to allow for domestic trade as well. This framework allows for matching the regional as well as international trade flows in the economy. As a result, the counterfactual exercises done in this framework are based on a calibrated model which is well grounded in micro data. A closely related paper is that of Van Leemput (2016), which builds on a regional model of trade in the context of India but doesn't have the link to infrastructure.

My paper adds to the literature studying the link between infrastructure and trade. Motivated by a positive cross country correlation of trade openness and infrastructure spending, Bougheas, Demetriades and Morgenroth (1999) study and find a positive effect of infrastructure on trade for OECD countries in a gravity model framework. Francois and Manchin (2013) extend this analysis for developing countries and find the results to be robust. The underlying idea is that infrastructure reduces the cost of trading and thereby affects the domestic countries' comparative advantage. In both of these studies, infrastructure is the explanatory variable and trade is the dependent variable. In my paper, I show empirically and theoretically that incentives for trade can itself be a determinant of infrastructure spending.

Few studies have been done on the determinants of infrastructure spending. From the political economy side, Bostashvili and Ujhelyi (2019) and Khemani (2010) find that the electoral cycle is a good short-run determinant of infrastructure spending. My paper shows that trade incentives can be a long-run determinant of infrastructure spending. On the theoretical side, Chakravorty and Mazumdar (2008) develop a model of trade and endogenous infrastructure in a Cournot competition setup. Their framework, although parsimonious, cannot be used for the quantitative analysis.

The importance of infrastructure has been studied in the literature both empirically and theoretically by linking it to production and growth. Starting with the seminal works of Aschauer (1989) and Barro (1990), Kocherlakota and Yi (1996, 1997) find that there is a long-term impact of public infrastructure on the growth of advanced economies. Studies related to India show infrastructure to be important for production (Mitra, Varoudakis and Veganzones-Varoudakis, 2002; Sahoo and Dash, 2009) and growth (Lall, 2007; Nagaraj, Varoudakis and Véganzonès, 2000). Despite its importance, poor infrastructure in the developing economies could be caused by the lower returns on such investments (Briceño, Estache and Shafik, 2004; Estache and Fay, 2007; Ndulu et al., 2007). The results of my paper suggest that governments respond by allocating more resources to infrastructure when the potential for its utilization increases. Quantitative results indicate higher gains from building infrastructure in an open and regionally integrated economy. To the best of my knowledge, my paper is the first to look at the effect of a trade reform on infrastructure spending empirically and to quantify the resulting gains in a new model of trade with an endogenous infrastructure

This paper is organized as follows: Section 2 discusses the key empirical results that form the motivation for the model in the following section. Section 3 discusses the model in a dynamic setup. Section 4 discusses model results and counterfactual analysis. Section 5 concludes.

2 Empirical Results

In this section, I discuss the empirical results of the paper. Section 2.1 discusses the empirical strategy for estimating the causal effect of tariffs on infrastructure. Section 2.2 discusses the data and section 2.3 shows data plots for validating parallel trend assumption. Section 2.4 reports the yearly differences-in-differences coefficient for up to 10 years after the reform and 3 years before the reform (placebo test). It also reports the differences-in-differences estimates for transport versus non-transport infrastructure.

2.1 Strategy

The objective of this section is to estimate the effect of a change in tariffs on infrastructure spending. Since states have varying industrial compositions, they receive different dosages of tariff exposure. For instance, a state will be more exposed to manufacturing tariff reductions if it has a large share of workers in the manufacturing industry. I use the state-level variation in exposure to tariff reductions for identification in a differences-in-differences regression. In the baseline specification, I estimate

$$\log(\text{Infra}_{it}) = \alpha_i + \beta_1 \tau_{it} + \beta_2 \text{After}_t + \epsilon_{it} \tag{1}$$

where Infra_{it} is state i's infrastructure spending in period t, τ_{it} is state i's tariff in period t, and After_t is 1 if t $\geq$ 1992 and zero otherwise. In equation 1, α_i controls for state level differences in infrastructure spending and After_t controls for the increase in infrastructure over time. I take two years in the specification: one year before the start of reform (1991) and another year after 1991. The variable of interest in this specification is τ_{it} as β_1 gives the differences-in-differences estimate of the effect of a tariff reduction on infrastructure spending. The expected sign of β_1 is negative. This means that the states which had a larger reduction in tariffs, increased their spending on infrastructure more.

The underlying assumption in this specification is that the state's spending on infrastructure is not driven by pre-trends. To address this assumption, I take a two-step approach, as is common in the differences-in-differences literature. I plot the average level of infrastructure spending in the states with a high tariff decline compared to states with a low tariff decline. I expect the infrastructure spending in states with a high tariff decline to increase by more than in the states with a low tariff decline after the reform. The results from the differences-in-differences regression will be re-assuring if we do not find this pattern in the pre-reform period. This method however is that of a visual inspection. The second approach involves a formal statistical test. I take three years before the reform and run the differences-in-differences regression using the tariff declines as observed during the reform. I expect the estimated β_1 from these regressions to be ≥ 0. This would imply that states which received bigger tariff reduction were not spending more on infrastructure before the start of reform.

A concern with the choice of the dependent variable could be that infrastructure spending increase could be linked to pure income effects. The states which got bigger productivity gains would have bigger revenue collections. Hence the increase in infrastructure could be linked to higher spending capacity. To analyze this concern, I look at four types of infrastructure and categorize them as either transport or non-transport related. The motivation for this categorization is that transport-related infrastructure leads to higher trade, and hence the incentive to build it could be higher than others. I expect a larger magnitude of β_1 estimates for transport-related infrastructure than for non-transport infrastructure.

2.2 Variable Construction

I construct the measure of trade opening for states using an industrial composition of the states in 1989 such that

$$\text{Tariff}_{i,t} = \sum_{j}^{J} s_{j,i} \text{Tariff}_{j,t}, \tag{2}$$

where $s_{j,i}$ is the sector j's share in state i for the year 1989. This year is picked before the start of the trade reform so as not to confound the effect of trade reform on industrial transformation. The share is calculated using labor share of the industry in total urban working population such that

$$s_{j,i} = \frac{\text{Working Population}_{j,i}^{1989}}{\sum_j \text{Working Population}_{j,i}^{1989}} \tag{3}$$

Sectors that do not trade internationally get a weight of 0 . Thus, the trade exposure variable will be a weighted sum of tariff levels in the traded sectors. Kovak (2013) shows that including the non-traded sectors in the calculation of the shares would reduce the effective measure of trade opening and will give biased estimates. Giving non-zero weight to the non-traded sectors implies that the trade exposure to these sectors has remained at zero however, due to general equilibrium effects, both traded and non-traded sectors are affected from a trade reform. This trade exposure measure has been used to estimate the regional effects on India's trade reform on poverty, unemployment, and labor demand elasticity (Topalova, 2010; Hasan et al., 2012; Hasan, Mitra and Ramaswamy, 2007).

2.3 Data

For the measure of infrastructure spending, I use development expenditures in the state budget documents that correspond to spending on transport, energy, water, and allied services. These include only capital expenditures and hence attribute to new investments. In 1991, irrigation was the single most important category, such that its spending was 4 times that on roads and 16 times that on bridges. The spending on development expenditures subsequently increased by 3 times in the 10 year period. Within development expenditures, the spending on roads increased by a factor of 5, while spending on irrigation increased by a factor of 2. By the end of the reform period, irrigation spending was only 1.5 times that on roads (Table 1). For tariffs, I use data from Topalova (2010) which calculates a sector-wise measure of both tariffs and non-tariff barriers, adjusting for the input-output structure of the Indian economy.

Table 1: Summary Statistics

	1991	2001
State Tariffs	0.80 (0.28)	0.29 (0.07)
Development exp.	3,710	11,137
Roads	446	2,065
Bridges	103	273
Irrigation	1,605	3,484
Power	413	1,467

Notes: Spending is in million Rs normalized by 2011 prices. Tariffs are constructed using the industrial shares of the urban areas. Standard deviations are reported in parentheses.

Now I group the states into those with a high tariff reduction and those with a low tariff reduction. I plot the infrastructure spending for states in the top and the bottom quartiles in Figure 1. The blue line indicates the states with a higher relative tariff reduction and the red line indicate the ones with a lower relative tariff reduction. Before the start of the trade reform, the blue line is below the red line, indicating that the states that later get a larger tariff reduction were spending less on infrastructure relative to the states that later get a smaller tariff reduction. After the reform, the states that get a higher tariff reduction (indicated by the blue line) start to spend more on infrastructure relative to the states that get a smaller tariff reduction (indicated by the red line).

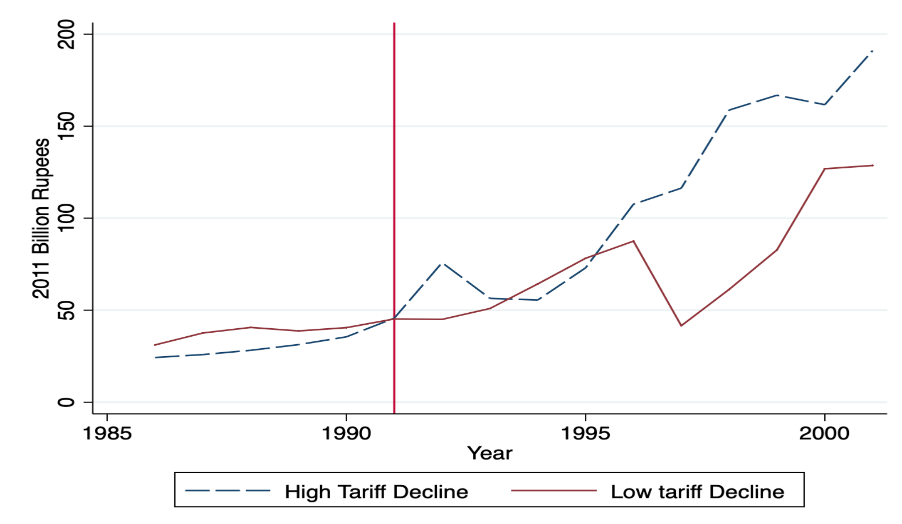


Figure 1: Infrastructure spending between 1985 and 2002 in groups of states with high and low tariff declines

2.4 Results

In this section, I present the results from the differences-in-differences regressions for infrastructure spending. I also present results from the sub-categories of infrastructure.

2.4.1 Main Results

I estimate equation (1) where the coefficient of interest is β_1. A negative sign indicates that the states that were more exposed to trade opening (i.e. states in which tariffs fell by more), increased the stock of infrastructure by more. First I take the dependent variable as infrastructure spending. Writing equation 1 in a differences-in-differences setup, I effectively estimate

Table 2: Differences-in-differences (DiD) estimates of β_1 using infrastructure spending as dependent variable.

Before Yr	After Yr	Pre-reform			Post-reform: Shorter Run			
1988		-0.003						
		(0.35)						
1989			0.19					
			(0.14)					
1990				0.17				
				(0.12)				
	1992				-0.11			
					(0.17)			
	1993					-0.71***		
						(0.09)		
	1994						-0.70***	
							(0.18)	
	1995							-0.69***
								(0.31)

Notes: The reference year in all specifications is 1991. Robust standard errors are in parentheses. N is 36. *** Significant at 1%. State and time fixed effects are included in the regression.

$$\Delta_t \log(\text{Infra}_{it}) = \beta_1 \Delta_t \tau_{it} + \gamma k + \Delta_t \epsilon_{it},$$

for different interceding years (k). I keep the tariff decline the same and see how state governments responded over the years. The estimated coefficients are reported in Tables 2 and 3. The first three columns of Table 2 report DiD estimates from taking before-year and after-year spending in the pre-reform period (1988-1991, 1989-1991, 1990-1991). The estimated coefficients are statistically indistinguishable from zero and hence indicate that pre-trends are not guiding the results. The last four columns of Table 2 show that on average a 10% reduction in tariffs, increased infrastructure spending by 7% during the period 1993-1995. Extending the time horizon further (Table 3), we can see that the effect persisted until 2001. For the years 1996-1998, the magnitude falls to 5.2% and then rises to 15% after 1999. The changing magnitude of β_1, which reflects the change in infrastructure spending, could be a result of economic growth fluctuations during this period. The downturn during 1996-98 could have affected the year-on-year spending capacity of the states. Pooling the years 1987-2001 together, the β_1 coefficient is 0.53, which is the average effect over this period.

Table 3: DiD and panel estimates of β_1 using infrastructure spending as dependent variable.

After Yr	Post-reform: Longer Run						Pooled regression (1987-2001)
1996	-0.53*** (0.23)						
1997		-0.51 (0.47)					
1998			-0.54 (0.39)				
1999				-1.70*** (0.38)			
2000					-1.28*** (0.26)		
2001						-1.46*** (0.40)	-0.53*** (0.19)

Notes: The reference year in all specifications is 1991. For the pooled regression estimations, I keep the tariff levels at the pre-reform level (1991) for all the years before 1991 and at the post-reform level (1998) for all the years after 1991. Robust standard errors are in parentheses. N is 36 for DiD estimations. For the panel estimations, N is 294. *** Significant at 1%, ** significant at 5% and * significant at 10%. State and time fixed effects are included in the regressions.

2.4.2 A closer look at infrastructure: Transport versus Non-transport

Transport infrastructure has been shown to affect trade significantly across a wide range of empirical work (Bougheas, Demetriades and Mamuneas, 2000; Limao and Venables, 2001; Fujimura and Edmonds, 2006). In this case, tariff reductions could have a bigger impact on transport-related infrastructure than on non-transport related infrastructure as the trade channel is much stronger for the former. I run the regression with respect to four infrastructure types: roads, bridges, power and irrigation. These four categories comprise of 65% of the infrastructure spending by states. I take stocks as the dependent variable and the before and after years as 1991 and 2001. The estimated β_1 will therefore give a cumulative effect of the trade reform. Table 4 reports the estimated differences-in-differences coefficients.

Table 4: Reports estimates using 1991 and 2001 as the before and after period.

	log(roads)	log(bridges)	log(power)	log(irrigation)
Tariff	-1.03^{***}	-1.89^{***}	-0.38	-0.31
	(0.21)	(0.85)	(1.75)	(0.19)

Notes: Robust standard errors are in parentheses. N is 36. *** Significant at 1%, ** significant at 5% and * significant at 10% . State and time fixed effect included in the regression.

A 10% reductions in tariffs increased the stock of roads and bridges by 14% in the 10-year period. The response of governments on power and irrigation was a quarter of the response on roads and bridges, thus supporting the hypothesis that states were responding to incentives from trade opening. Alternatively, aggregate infrastructure spending could have gone up because the cost of building infrastructure went down after trade opening. However, the heterogeneous response shows that governments were purposefully increasing spending on those infrastructure types for which the returns were higher.

In this section, we have seen that state governments respond to tariff reductions by raising infrastructure spending. To understand the incentives for building infrastructure after trade opening, I build a model of inter-national and intra-national trade with endogenous local infrastructure in the next section. This model will help to answer three questions. First, how large are the gains from trade opening after accounting for infrastructure response to tariffs? Second, relative to the model, how large is the infrastructure response based on the empirical estimates? Third, what would be the gains from trade opening if governments were already spending optimally? I solve for the model in steady state for longer run analysis.

3 Model

Consider n domestic regions and a rest of the world region, where each region has j sectors. The n+1 regions are trading with each other. Within each sector, a continuum of intermediate goods are produced, each indexed with a heterogeneous productivity parameter. Firms use private capital, labor, material inputs, and infrastructure for producing intermediate goods. The labor is assumed to be immobile between regions and private capital markets clear in each region. Infrastructure is provided by the government and financed through an income tax. Households in each region are infinitely lived, work each period inelastically, and earn wages. They also lend capital to firms each period and earn a rental rate. The after-tax wage and rental income are used by the households to consume and accumulate capital.

3.1 Firms

Firms face a static problem and hence I will suppress the t subscripts for now. The intermediate firm in each region produce a variety indexed by productivity level z. Productivity z comes from a Fréchet distribution such that $z \sim F(1, \theta^j)$ with scale parameter θ and location parameter 1. The parameter θ determines the variance in the firms' productivity draws where a higher value for θ implies less dispersion in productivity. Firms in each sector j take the level of infrastructure capital (G_n) as given and choose labor, private capital, and material inputs to produce intermediate goods using the following production function:

$$y_n^j(z) = z\left[T_n^j G_n^\gamma (k_n^j(z))^{\beta_n^k} (l_n^j(z))^{\beta_n^l}\right]^{\beta_n^j} \left[M_n^j(z)\right]^{1-\beta_n^j}, \tag{4}$$

where γ guides the output elasticity of infrastructure, β_n^j guides the value added share for sector j goods and $1 - \beta_n^j$ is the share of material inputs. In equation 4, β_l is the labor share and β_k is the capital share in the value added. This production structure assumed that the material inputs used to produce intermediate goods in a sector are sourced from the same sector. The parameter T_n^j is called the fundamental productivity parameter and enters the production function in the value-added part. It is a common parameters for all firms operating in sector j within a region n. Infrastructure stock, G_n enters the value-added part similar to the fundamental productivity parameter. This would imply that firms use infrastructure in the process of value addition. G_n is common to all sectors within a region while T_n^j is sector specific. Parameter γ guides the importance of infrastructure in the production process. Firms operate within perfectly competitive markets and hence profits are zero and the unit cost of production is

$$x_n^j = B_n^j \bigg((r_n)^{\beta_n^k} (w_n)^{\beta_n^l} \bigg)^{\beta_n^j} (p_n^j)^{1-\beta_n^j}, \tag{5}$$

where $B_n^j = \bigg(\beta_n^j (\beta_n^k)^{\beta_n^k} (\beta_n^l)^{\beta_n^l} \bigg)^{-\beta_n^j} (1 - \beta_n^j)^{-(1-\beta_n^j)}$ is a constant. Here, w_n and r_n are the nominal wages and rental prices, and p_n^j is the price of material inputs. The final goods in region n are produced using technology that is a CES aggregator over continuum of intermediate goods. Thus, the production of final goods is given by

$$Y_n^j = \bigg[\int_0^\infty y_n(z^j)^{1-1/\eta_n} \phi^j(z^j) dz^j \bigg]^{\eta_n/(\eta_n-1)}. \tag{6}$$

Here, $\phi^j(z^j)$ is the joint density of the vector of draws across regions for variety z such that

$$\phi^j(z^j) = (\Pi_{i=1}^N T_n^j) exp\{ - \sum_{i=1}^N T_n^j z_n^j \}, \tag{7}$$

based on the cumulative distribution function of the productivity draws z.

3.2 Market Prices and Trade shares

Based on the properties of a Fréchet distribution, as shown in Eaton and Kortum (2002), the price for the final good in the tradable sector can be written as

$$p_n^j = \bigg[\sum_{i=1}^N [\kappa_{ni}^j x_i^j]^{-\theta} (T_i^j G_i^\gamma)^{\beta_n^j \theta} \bigg]^{\frac{-1}{\theta^j}} \Gamma(\xi_n^j)^{1/1-\eta_n^j}, \tag{8}$$

where $\xi_n^j = 1 + (1-\eta_n^j)/\theta^j$. Here, κ_{ni}^j is the iceberg trade cost of transporting sector j goods from region i to region n. This price function can be seen as the inverse of the weighted sum of productivity parameter T and the level of infrastructure G across n+1 regions. Here, the weights depend on trade cost (κ_{ni}^j) and the unit cost of production (x_i^j) across regions. The cost of procuring the goods from region i for region n consumers is equal to the cost of producing goods in region i plus the cost of transporting goods from region i to n. The lower is the cost of procuring goods from region i for consumers in region n, higher will be the weight given to the T and G of region i in region n's price level. This is because more goods will be procured from the region with the low cost advantage and therefore the productivity of that region will have a bigger effect on local prices. Subsequently, the bilateral trade shares between region n and i will be

$$\pi_{ni}^j = \frac{[x_i^j \kappa_{ni}^j]^{-\theta^j} (T_i^j G_i^\gamma)^{\beta_n^j \theta}}{\sum_{m=1}^N [x_m^j \kappa_{nm}^j]^{-\theta} (T_m^j G_m^\gamma)^{\beta_m^j \theta}} \tag{9}$$

where π_{ni}^j indicates the share of region i goods that are consumed in region n within sector j. Therefore, the higher the productivity and the level of infrastructure of region i, the more goods will be sourced from that region. Replacing equation (8) in the denominator of equation (9), I get

$$\pi_{ni}^j = \Gamma(\xi_n^j)^{-\theta/1-\eta_n^j} \left[\frac{x_i^j \kappa_{ni}^j}{p_n^j}\right]^{-\theta^j} (T_i^j G_i^\gamma)^{\beta_n^j \theta}. \tag{10}$$

In case the elasticity of substitution η is 1, then the above expression can be written as[2]

$$\pi_{ni}^j = \left[\frac{x_i^j \kappa_{ni}^j}{p_n^j}\right]^{-\theta^j} (T_i^j G_i^\gamma)^{\beta_n^j \theta}. \tag{11}$$

In this setup, trade is balanced (i.e. the value of imports to a country will equal exports from the country). That condition implies

$$\sum_j L_i p_i^j q_i^j = \sum_j \sum_n \pi_{ni}^j L_n p_n^j q_n^j. \tag{12}$$

Also, for the goods market to clear, the final output in each sector must equal the demand for final goods from households and intermediate good firms which implies,

[2]When η=1 then ξ_n^j, which is equal to $1 + (1-\eta_n^j)/\theta^j$, becomes 1. Γ function evaluated at one is equal to one. Then raising Γ to ∞, leaves us with one.

$$L_n p_n^j q_n^j = \alpha_n^j (w_n L_n + r_n K_n) + (1 - \beta_n^j) L_n p_n^j q_n^j. \tag{13}$$

This can be written as

$$L_n p_n^j q_n^j = \frac{\alpha_n^j}{\beta_n^j} (w_n L_n + r_n K_n). \tag{14}$$

Substituting condition (14) in (12), we can rewrite trade balance equation as

$$\sum_j \frac{\alpha_i^j}{\beta_i^j} (w_i L_i + r_i K_i) = \sum_j \sum_n \pi_{ni}^j \frac{\alpha_n^j}{\beta_n^j} (w_n L_n + r_n K_n). \tag{15}$$

The static equilibrium in this framework is given by the following definition

Definition 1. *Given L_n, K_n, an equilibrium under trade costs κ will be a wage and rental rate vector $\boldsymbol{w}$, $\boldsymbol{r} \in \mathbb{R}_{++}^N$ and price matrix $\boldsymbol{p} \in \mathbb{R}_{++}^N \times \mathbb{R}_{++}^J$ that solve equilibrium conditions (5), (8), (9), and (15).*

3.3 Aggregation

3.3.1 Aggregate Productivity

Based on equation (5), we can write the unit cost of producing final goods in real terms as

$$\frac{x_n^j}{p_n^j} = B_n^j \left[\left(\frac{r_n}{p_n^j} \right)^{\beta_n^k} \left(\frac{w_n}{p_n^j} \right)^{\beta_n^l} \right]^{\beta_n^j}. \tag{16}$$

This represents the aggregate productivity of sector j firms in region n as it is a weighted average of returns on labor and capital inputs. Now recalling the trade share equation for the case when $i = n$ from equation 11,

$$\pi_{nn}^j = \left[\frac{x_i^j}{p_n^j} \right]^{-\theta^j} (T_i^j G_i^\gamma)^{\beta_n^j \theta}. \tag{17}$$

I can hence rewrite the sectoral aggregate productivity in terms of trade shares, fundamental productivity parameter and the stock of infrastructure,

$$\frac{x_n^j}{p_n^j} = \frac{(T_n^j G_n^\gamma)^{\beta_n^j}}{(\pi_{nn}^j)^{\frac{1}{\theta^j}}}. \tag{18}$$

Now, we can see that the aggregate productivity term is positively linked to the fundamental productivity parameter (T) and the stock of infrastructure (G) and negatively linked to the share of goods that are domestically produced (i.e the degree of specialization).

3.3.2 Aggregate Output

Since the input shares in output remain constant, aggregating them over all z's and substituting in equation (4), we get the aggregate sectoral real output as [See appendix 6.2 for derivation]

$$Y_n^j = \frac{x_n^j}{p_n^j} \left((k_n^j)^{\beta_n^k} (l_n^j)^{\beta_n^l} \right)^{\beta_n^j} (M_n^j)^{1-\beta_n^j} \tag{19}$$

Substituting in for $\frac{x_n^j}{p_n^j}$ we can write the aggregate output in sector j as

$$Y_n^j = \frac{T_n^{j\beta_n^j}}{(\pi_{nn}^j)^{\frac{1}{\theta^j}}} \left(G_n^{\gamma} (k_n^j)^{\beta_n^k} (l_n^j)^{\beta_n^l} \right)^{\beta_n^j} (M_n^j)^{1-\beta_n^j} \tag{20}$$

Thus the aggregate output is positively linked to the degree of specialization ($\frac{1}{\pi_{nn}}$), fundamental productivity (T_n), factor and material inputs used in the production of goods (k, l, and M). Also, higher will be the trade elasticity $1/\theta$, higher will be the aggregate output.

3.4 Dynamic Problem

Let each household live infinitely. Each period, households consume and save a part of their income. They earn wages on an inelastic labor supply and rental income on the capital stock, which they rent to the firms. The household's income is taxed at the rate τ. Governments balance their budgets each period. After setting up the optimization problem for a multi-sector model, I will solve a simple version of this dynamic problem in steady states for one sector in which the share of value added is 1.

3.4.1 Household's Problem

For an infinitely lived household in region n, the optimization problem is

$$\sum_{t=0}^{\infty} \beta^t \prod_j (c_{n,t}^j)^{\alpha^j} \tag{21}$$

Here β is the discount rate, $c_{n,t}^j$ is the consumption of sector j's final good in region n while α^j is the expenditure share of sector j goods in the total household expenditure on consumption goods. Households maximize (21) s.t the budget constraint

$$\sum_j c_{n,t}^j + (k_{n,t+1} - (1-\delta)k_{n,t}) = (1-\tau_n)(w_{n,t}l_{n,t} + r_{n,t}k_{n,t}). \tag{22}$$

Their income is proportionally taxed (τ_n) by the state governments for building infrastructure in the economy. Infrastructure however is assumed to affect household utility only through its effect on household income. Intuitively, the higher the level of infrastructure, the higher the returns from labor and capital employed, thereby increasing household's income. A higher tax rate will translate into higher disposable income in the future at the cost of sacrificing current consumption. The household's constrained maximization problem can then be written as

$$\mathcal{U} = \max_{\{c_{n,t}^j\}} \sum_t \left(\beta^t \prod_j (c_{n,t}^j)^{\alpha^j} - \lambda^t \left(\sum_j c_{n,t}^j + k_{n,t+1} - (1-\delta)k_{n,t} - (1-\tau_n)[\tilde{w}_{n,t}l_{n,t} + \tilde{r}_t k_{n,t}] \right) \right) \tag{23}$$

Let us now consider a case where there is only one sector. So now the utility function can be written as $U(c_{n,t})$ Then taking the first-order conditions, we get

$$\frac{\partial \mathcal{U}}{\partial k_{n,t+1}} = -\lambda^t + \beta \lambda^{t+1} \Big[(1-\delta) + (1-\tau_n)\tilde{r}_{n,t+1} \Big] = 0 \tag{24}$$

$$\frac{\partial \mathcal{U}}{\partial c_{n,t}} = U'(c_{n,t}) - \lambda^t. \tag{25}$$

Using (24) and (25), we can get the Euler equation

$$\beta \Big[(1-\delta) + (1-\tau)\tilde{r}_{n,t+1} \Big] = \frac{U'(c_{n,t})}{U'(c_{n,t+1})}. \tag{26}$$

In the steady state $c_{n,t} = c_{n,t+1}$ hence, we can rewrite (26) as

$$(1-\tau_n)\tilde{r}_{n,ss} = \frac{1}{\beta} - (1-\delta) \tag{27}$$

Here $\tilde{r}_{n,ss}$ is the real rental price in the steady state.

3.4.2 Factor Prices

Recalling the aggregate real output from Section 3.3.2,

$$Y_n^j = A\Bigg(G_n^{\gamma}(k_n^j)^{\beta_n^k}(l_n^j)^{\beta_n^l}\Bigg)^{\beta_n^j}(M_n^j)^{1-\beta_n^j} \tag{28}$$

Here, A= $\frac{T_n^{j\beta_n^j}}{(\pi_{nn}^j)^{\frac{1}{\theta^j}}}$ is aggregate productivity and G is the stock of infrastructure capital. Since I assume for now that the share of value added is 1 ($\beta_n^j = 1$) and that number of sectors are 1, the above expression can be written (in per capita terms) as

$$y_n = A_n G_n^{\gamma} k_n^{\beta_n^k} \tag{29}$$

Since markets are perfectly competitive in this set-up, rental payments are equal to β_k times the value of output by each firm z, and hence,

$$r_n k_n(z) = \beta_k p_n(z) y_n(z). \tag{30}$$

Integrating across all firms (indexed by z), we have

$$\int_z r_n k_n(z) dz = \int_z \beta_k p_n(z) y_n(z) dz \tag{31}$$

The left-hand side aggregates the capital usage across firms, which is equal to the regional capital stock k_n. The right-hand side aggregates the value of output across firms. The aggregation on the right-hand side comes from the fact that the elasticity of substitution is assumed to be 1. Final goods, which is a CES aggregator, then become a sum over intermediate goods as unit elasticity makes the aggregator a linear function:

$$r_n k_n = \beta_k p_n y_n. \tag{32}$$

Rearranging terms and substituting the expression for gross output from equation (29), we get

$$\frac{r_n}{P_n} = \beta_k \frac{A_n G_n^{\gamma} k_n^{\beta_n^k}}{k_n}, \tag{33}$$

which gives the expression for the real rental rate (for time t),

$$\tilde{r}_{n,t} = \beta_k A_{n,t} G_{n,t}^{\gamma} k_{n,t}^{\beta_k - 1}. \tag{34}$$

Similarly we get the expression for real wages,

$$\tilde{w}_{n,t} = (1 - \beta_k) A_{n,t} G_{n,t}^{\gamma} k_{n,t}^{\beta_k}. \tag{35}$$

3.4.3 Law of Motion

Infrastructure capital evolves as

$$G_{n,t+1} = G_{n,t}(1 - \delta_g) + \tau I_{n,t}. \tag{36}$$

In steady state,

$$G_{n,ss} = \frac{\tau}{\delta_g} I_{n,ss}. \tag{37}$$

3.4.4 Steady-State Capital (k)

The rental rate (from 34) will be

$$r_{n,ss} = \beta_k A_n G_{n,ss}^{\gamma} k_{n,ss}^{\beta_k - 1}. \tag{38}$$

Here, we can substitute $G_{n,ss}$ from (37) (for now let, $\delta_g = 1$) and get

$$r_{n,ss} = \beta_k A_n \tau^{\gamma} I_{n,ss}^{\gamma} k_{n,ss}^{\beta_k - 1}. \tag{39}$$

Substituting the Euler equation (27), we get

$$1 - \tau_{n,ss} = \frac{\mathcal{C}}{\beta_k A (\tau_{n,ss})^{\gamma} I_{n,ss}^{\gamma} k_{n,ss}^{\beta_k - 1}}, \tag{40}$$

where $\mathcal{C} = \frac{1}{\beta} - (1 - \delta)$. Rearranging terms, we get

$$k_{n,ss}^{1-\beta_k} = \mathcal{C}_1 A_n I_{n,ss}^{\gamma} \tau_{n,ss}^{\gamma} (1 - \tau_{n,ss}). \tag{41}$$

Here, $\mathcal{C}_1 = \frac{\beta_k}{\frac{1}{\beta} - (1-\delta)}$. Since the share of value added in output is 1, the income per capita is going to be the same as output per capita from equation (29), which gives

$$I_{n,ss} = A_n G_n^{\gamma} k_{n,ss}^{\beta_k}. \tag{42}$$

Now, substituting for the G_n as $\tau_n I_n$, the above expression becomes

$$I_{n,t} = A_n^{\frac{1}{1-\gamma}} k_{n,t}^{\frac{\beta_k}{1-\gamma}} \tau_{n,t}^{\frac{\gamma}{1-\gamma}} \tag{43}$$

Substituting this expression of income per capita in equation (41), we get

$$k_{n,ss} = \left(\mathcal{C}_1^{1-\gamma} A_n \tau_{n,ss}^{\gamma} (1 - \tau_{n,ss})^{(1-\gamma)} \right)^{\frac{1}{1-\beta_k-\gamma}}, \tag{44}$$

which is the steady-state level of private capital in the economy.

3.4.5 Government's Problem

Now the government picks the tax rate τ that maximizes the household's indirect utility function, which is

$$W_n = (1 - \tau_n) A_n^{\frac{1}{1-\gamma}} \tau_n^{\frac{\gamma}{1-\gamma}} \left(\mathcal{C}_1^{1-\gamma} A_n \tau_n^{\gamma} (1 - \tau_n)^{(1-\gamma)} \right)^{\frac{\beta_k}{(1-\beta_k-\gamma)(1-\gamma)}}, \tag{45}$$

which can be simplified as

$$W_n = (C_1^{\beta_k} A_n (1-\tau_n)^{1-\gamma} \tau_n^{\gamma})^{\frac{1}{1-\beta_k-\gamma}}. \tag{46}$$

Replacing the A term, this expression becomes

$$W_n = \left(C_1^{\beta_k} \frac{T_n}{(\pi_{nn})^{\frac{1}{\theta}}} (1-\tau_n)^{1-\gamma} \tau_n^{\gamma} \right)^{\frac{1}{1-\beta_k-\gamma}}. \tag{47}$$

This is a concave problem and will lead to a unique optimum at every level of tariff. I will now explore how the change in the optimum level of this function after a fall in tariff affects the optimal tax level in the economy.

3.5 Model Mechanisms

Equation (47) is the key statistic for calculating the optimal stock of infrastructure in a trading economy. In this section, I show that the optimal levels of infrastructure increase after tariff reductions. To see what drives the result in the model, I conduct three numerical exercises. The main takeaway from those exercises is that the infrastructure is complementary to trade opening as long as private capital is endogenous. The parameters I use are reported in Table 5. Figure 2 plots the welfare function for different tax rates. We can see that the optimal tax falls after trade opening as the orange line shifts toward the left. However, that would not mean that optimally the economies ought to spend less on infrastructure but rather that they spend a smaller share of GDP. Since GDP itself has increased, the net effect on infrastructure is that it ends up increasing. This can be seen more clearly in Table 6. When tariffs are lowered from 2.2 to 1.6, optimal spending on infrastructure increases by 0.4%. When they fall further, optimal infrastructure rises by 1.7%.

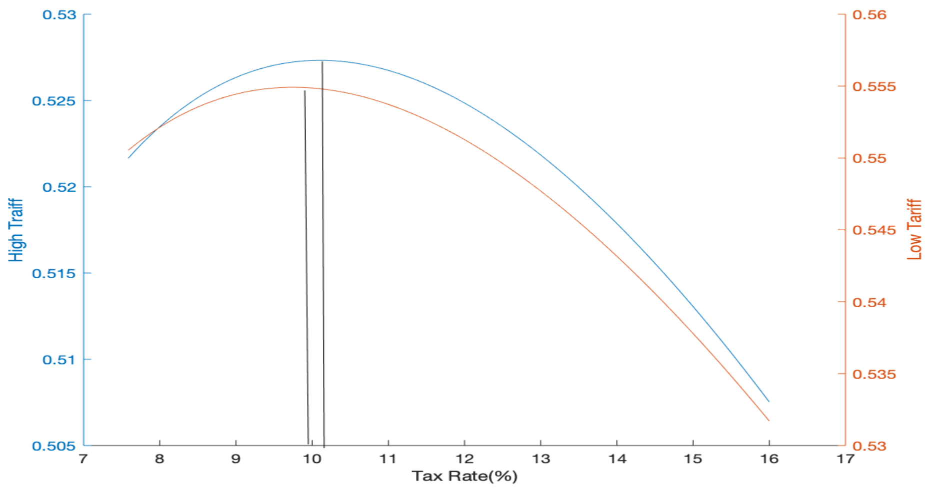
Table 5: Parameters Used for the Numerical Exercise

Parameter	Values	Source
L	0.8	Assumption
K (when K is fixed)	1.2	Assumption
G (in region 2)	0.03	Assumption
β_k (capital share)	0.29	CLN(2019)*
β_l (labor share)	0.65	CLN(2019)
γ (infrastructure share)	0.12	Cubas (2018)
β_j (value-added share)	1	Assumption
T (fundamental productivity)	2	Assumption
θ (productivity dispersion)	4	Literature
Impatience parameter	0.95	Literature
Private capital depreciation rate	0.05	Literature
Infrastructure capital depreciation rate	1	Assumption

*Chatterjee, Lebesmuehlbacher and Narayanan (2019)

When private capital is endogenous, we can see that trade opening raises the optimal level of infrastructure whereas when private capital is fixed, trade opening lowers the optimal level of infrastructure. When private capital is endogenous, lower tariffs raises the level of optimal infrastructure because infrastructure is complementary to private capital, and hence

Figure 2: Welfare Functions and Trade Opening.



Notes: High tariffs corresponds to a trade cost of 2.2 and low tariffs corresponds to a trade cost of 1.9

it is optimal to raise the stock of infrastructure as it crowds in private investments. This can be seen in the fourth column in Table 6: the optimal level of infrastructure increases after trade opening when private capital is endogenous.

Table 6: Trade Opening, Optimal Tax, and Change in Optimal Capital

	Endogenous K			Fixed K		
	τ	G	ΔG	τ	G	ΔG
Trade cost = 2.2	10.08%	0.0591		4.09%	0.0152	
Trade cost = 1.9	9.98%	0.0594	0.4%	3.89%	0.0146	-4.18%
Trade cost = 1.6	9.78%	0.0602	1.76%	3.69%	0.0141	-3.18%

It can be useful to disentangle the two mechanisms of the model when tariffs are lowered. One is the effect of higher aggregate productivity. Second is the effect of higher private capital, which can change the optimal level of infrastructure in the economy.

Lowering Tariffs: This opposite direction of optimal infrastructure after trade opening in the two cases can be rationalized by the nature of infrastructure when private capital is fixed. In this case, lower tariffs raise domestic productivity as a higher share of domestic goods are used for consumption. If infrastructure G does not crowd in private capital, infrastructure becomes a substitute for aggregate productivity in the economy implying that when a tariff reduction raises productivity, governments substitute out infrastructure for higher trade-induced productivity. We can see that the optimal tax as well as the optimal level of infrastructure both fall in the economy. Thus, in this framework, infrastructure is a substitute for regional productivity. When tariffs start to go down and the regional productivity increases, governments can find it optimal to lower the level of infrastructure in the economy.

Higher Private Capital: Lower tariffs, however, are accompanied by higher private capital accumulation. Cheaper inputs incentivize firms to scale their production by accumulating more private capital. Since infrastructure is an input in the production function, its optimal level increases as private capital rises. In Table 7, we can see that the optimal tax increases, as does the optimal level of infrastructure when private capital increases. In this case, I keep the tariffs fixed.

Table 7: Private Capital, Optimal Tax and Infrastructure.

Private Capital	τ	Infrastructure
$K = 1.2$	4.03%	0.0106
$K = 1.8$	4.12%	0.0122
$K = 2.4$	4.13%	0.0133
$K = 3.0$	4.16%	0.0143
$K = 3.6$	4.20%	0.0155

Thus, the net effect is higher infrastructure spending after a fall in tariffs as the complementary effect dominates the substitute effect in this framework.

4 Simulating India's Trade Opening

In this section, I simulate a multi-region, multi-country version of the above model, calibrated to six Indian states and the rest of the world. With the calibrated model, I simulate the effect of lower tariffs on trade, private capital, and infrastructure capital. I also conduct two counterfactual exercises to understand the mechanisms behind the main result. In Section 4.1, I discuss the calibration; in Section 4.2, I discuss the quantitative results from the model; and in Section 4.3, I discuss the rationale for the solution method adopted.

4.1 Calibration

The variables for which I need information on the seven regions (six states and the rest of the world) are: labor employed (L_n), initial level of infrastructure ($G_{n,1991}$), initial GDP ($Y_{n,1991}$), fundamental productivity parameter (T_n), and internal and external trade costs (κ_{ni}). I also need information on how much the tariffs fell during the trade reform for industries in each state, thereby affecting the trade cost between states and the rest of the world ($\Delta\kappa_{n,row}$). In addition I need information on Solow residuals (A_n), home trade shares (π_{nn}), and trade elasticity ($1/\theta$) to back out T_n.

I take information on labor employed and output from RBI's data repository, which aggregates total labor employed and output in the manufacturing sector from the Annual Survey of Industries. I calibrate the stock of infrastructure (G) from the EPWRF dataset, which has information on developmental expenditures by the state governments. I focus only on the economic services that relates to expenditures on roads, bridges, irrigation, power, and allied services. The dataset has information on flows, and I use a perpetual inventory method to calculate the stocks. I take the estimate of L_{row} from Van Leemput (2016), and for G_{row}, I calibrate it from the data, as shown in the next paragraph. The only variable that I now need to calibrate the T's is the home trade shares (π_{nn}). I use information on θ and γ as reported in Table 4.

To calibrate the fundamental productivity parameter, I use equation (18) where the real cost of production, which is the aggregate productivity in the region, is given as

$$A_n = \frac{(T_n G_n^{\gamma})}{(\pi_{nn})^{\frac{1}{\theta}}}. \tag{48}$$

Using information on Y_n, L_n, K_n, the labor and capital shares (β_l, β_k), I back out the Solow residual, A_n. I use the information on β_l and β_k as reported in Table 4. For A_{row}, I use FRED data on manufacturing productivity. Then using information on G, π_{nn}, γ, and θ, I can back out T_n. Since I keep the G fixed in the rest of the world, I calibrate a composite fundamental productivity parameter for the world, which is $\mathcal{T}_{row} = T_{row} G_{row}^{\gamma}$. To calibrate this, I will only need A_{row}, $\pi_{row,row}$, and θ.

I use data on trade flows to compute π_{nn}. DGCI&S provides data for interstate and international trade between 37 trade blocks within India.[3] This accounts for trade through railways, airways and inland waterways for 70 commodities. The most recent year for which

[3] http://www.dgciskol.gov.in

these data are available is 2013-14. Out of the 37 trade blocks, 7 are meant for international trade. Hence, it separates the goods going to these 7 blocks to distinguish between domestic and international trade. This database only has information on the quantities, however I use two databases for getting the price data and thereby compute the value of trade. The Department of Agriculture, Government of India, provides statewise wholesale prices and retail prices for agricultural commodities.[4] The Annual Survey of Industries has unit-level price data, which can then be aggregated to form a price index for 63 commodities in 6 states. Based on the trade flows, I compute the home trade shares (π_{nn}) for the 7 regions in my analysis and thereby compute the T's.

I need information on initial tax rates in 1991 to solve the model before the start of the trade reform. Since I have information on G and Y for the 6 states, I can compute the implied tax rates. In reality, the government's taxes help to pay for a host of things including infrastructure. However, in my model, I assume other government spending to be separable and paid for through a non-distortionary tax. Hence, I use the implied tax rate based on the G/Y ratio in 1991. I report the tax rate in Table 8.

Table 8: Tax Rate and International trade cost for the year 1991.

	Tax Rate (%)	International Trade cost (pp)
Andhra Pradesh	7.45	84
Delhi	5.64	98
Gujarat	7.33	93
Karnataka	7.59	91
Maharashtra	6.91	96
West Bengal	5.44	88

I also need information on internal as well as external trade costs. I use the calibrated trade costs from Van Leemput (2016) for trade costs between states and the rest of the world. Since she calibrates them from the trade flows in the post-reform period, the calibrated trade costs between the states and the rest of the world are lower than what they would be in 1991. To calibrate these international trade costs for the year 1991, I use information on changes in tariff and non-tariff barriers from Topalova (2010), to be multiplied by the post reform trade costs. Thus, I can back out what the pre-reform trade costs were for each state.

[4] https://eands.dacnet.nic.in

I report the calibrated trade cost for the year 1991 between the states and the rest of the world in Table 8.

4.2 Quantitative Results

I first lower the tariffs between 6 states and the rest of the world equal to the amount seen during the trade reform of 1991 and report the corresponding effects on the state-level variables in Table 9. Column 1 shows the amount by which tariffs fall. Lower tariffs result in a rise in domestic consumption of foreign goods as firms start to specialize in some of the varieties in the consumption basket while importing the rest. The home trade share(π_{nn}) therefore falls across the states as fewer domestically produced goods are consumed. Correspondingly, gains from specialization raise aggregate productivity, which results in firms accumulating more private capital. Hence, aggregate GDP starts to rise. The government decides on the optimal level of taxes that will maximize household welfare (given in Equation (47)).

I solve for each state's optimal tax in an iterative process. First for Andhra Pradesh, I solve for the optimal tax level and update its stock of infrastructure. Then for Delhi, I solves for the optimal tax level conditional on Andhra Pradesh having updated its infrastructure. Once I reach West Bengal's optimization problem, all the other states have updated their stocks of infrastructure once. I iterate this procedure until the optimal tax level in each state changes marginally compared to the one from the previous iteration. The fourth column in Table 9 shows that the tax rates predicted by the model after tariff reductions are considerably higher compared to their 1991 level. Delhi and Maharashtra have the largest increases in the tax rate, followed by Gujarat and West Bengal. The smallest tax rate increases are in Andhra Pradesh and Karnataka.

A higher tax rate raises G, which in-turn raises K because of the complementarity between private and infrastructure capital. A comparison of the increase in G after tariff reductions with the empirical estimates from the differences-in-differences estimates in Section 2 reveals that the governments raised their infrastructure by 40% of the predicted increase in the optimal level of infrastructure based on the model. The quantitative results from Table 8 suggest that the gains from tariff reductions, conditional on governments choosing the tax rate as predicted by the model, would be largest for Maharashtra, West Bengal and Gujarat as their manufacturing GDP would grow in the range of 9%-12%.

Table 9: Effects of Trade Reform

	Δ Tariff (pp)	Δ π_{nn} (pp)	Δ GDP (%)	Δ τ (pp)	Δ K (%)	Δ G (%)
Andhra Pradesh	-20.9	-2.3	3.96	1.80	18.5	36.2
Delhi	-19.5	-2.33	7.33	3.55	49.9	84.8
Gujarat	-30.0	-1.48	9.25	3.45	34.9	69.0
Karnataka	-17.1	-1.47	6.81	0.99	16.5	27.0
Maharashtra	-26.3	-1.28	12.87	3.68	46.5	82.0
West Bengal	-19.6	-0.27	11.71	2.25	42.4	67.1

Notes: This table reports numbers from the model when tariffs are lowered assuming states start with the tax for infrastructure spending in the year 1991 as calibrated from the data.

Table 10: Trade Reform with Taxes Fixed

	Δ Tariff (pp)	Δ π_{nn} (pp)	Δ GDP (%)	Δ K (%)	Δ G (%)
Andhra Pradesh	-20.9	-1.95	2.07	6.85	2.09
Delhi	-19.5	-3.81	2.79	15.1	2.80
Gujarat	-30.1	-2.37	2.05	6.82	2.08
Karnataka	-17.1	-0.45	1.53	1.64	1.53
Maharashtra	-26.3	-2.65	2.18	7.79	2.22
West Bengal	-19.6	-0.71	1.66	2.19	1.69

Notes: This table reports numbers from the model when tariffs are lowered, assuming states leave the tax rates unchanged.

To quantify the role of infrastructure in the above exercise, I conduct a counterfactual exercise in which I lower the tariffs by the same amount but keep the tax rates fixed. Table 10 reports the results from this exercise. We can see that K and G change by much less.[5] Since K is a function of the home trade share, an increase in trade that lowers the home trade share will then raise K as aggregate productivity in the region rises. However, compared to an average growth in K of 34% in Table 9, capital grew by only 7% when tax rates are held fixed. This implies that $1/5^{th}$ of the increase in K in Table 9 came from productivity gains whereas $4/5^{th}$ of its increase came from its complementarity with G. The increase in GDP on average would be 2% if governments keep the tax rate fixed, compared to 9% if governments raised the tax rate to its welfare maximizing level.

Table 11: Trade Reform with Optimal Taxes

	Δ Tariff (pp)	Δ π_{nn} (pp)	Δ GDP (%)	Δ τ (pp)	Δ K (%)	Δ G (%)
Andhra Pradesh	-20.9	0.70	1.77	0.00	5.70	1.76
Delhi	-19.5	-2.33	2.66	0.10	13.2	3.80
Gujarat	-30.0	-0.36	1.97	0.20	6.43	3.89
Karnataka	-17.1	0.95	1.13	-0.20	0.18	-1.18
Maharashtra	-26.3	-0.81	2.03	0.20	7.10	3.98
West Bengal	-19.6	-0.39	1.28	-0.10	1.03	-0.01

Notes: This table reports numbers from the model when tariffs are lowered, assuming states start with the optimal tax for infrastructure spending in the year 1991. Thus, the corresponding changes are not the actual stock of infrastructure as seen in the data in 1991 but with relative to a counterfactual stock of infrastructure as the starting point.

In the main exercise (Table 9), the initial tax rate was consistent with the actual infrastructure stock in that year. The above exercises show that most of the increase in GDP comes from increasing infrastructure and the tax rate to their optimal levels following the tariff declines. I conduct an additional exercise in which the initial tax rate and the stock of infrastructure are at their model-implied optimal values, and then tariffs are lowered. In this exercise, I solve for the optimal tax rate in each state twice, once before the start of the reform and once after the reform.

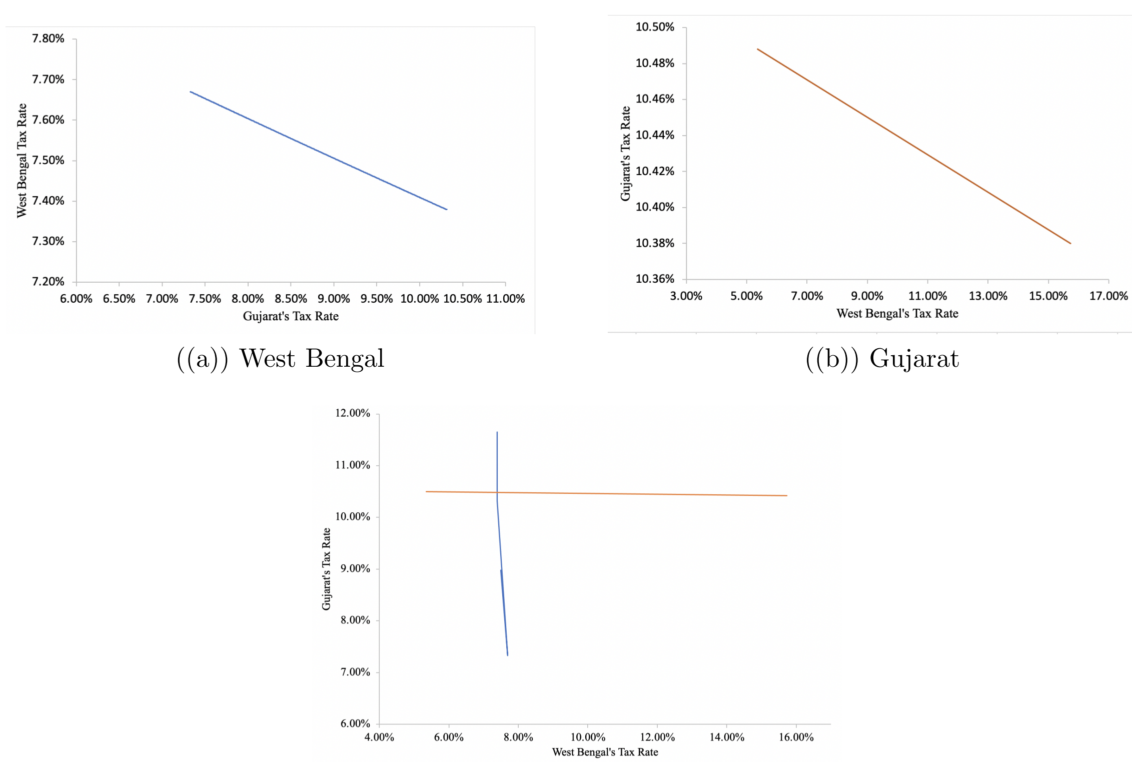
Table 11 reports the results from this exercise. We can see that the change in G is substantially smaller. This indicates that when the governments choose the optimal level of

[5] The measure G still changes, as in the model it is set equal to the tax rate times GDP. Hence, any increase in GDP will raise G by the same amount, even if the tax rate remains the same.

infrastructure, even a large trade reform would not affect the optimal tax rates for infrastructure spending. The optimal tax rises across four of the six states but it starts to decline in the other two. The states which find it optimal to lower infrastructure tax after trade opening are also the ones which get the smallest increase in private capital. Overall, the gains from trade opening in this exercise are around 2% GDP growth.

4.3 Strategic Interactions

In the exercises discussed above, I do not account for the strategic behavior of state governments. Some states may find it optimal to change their tax rates conditional on what the other states choose, and hence the solution method adopted in the previous section may be unfit. To understand the extent to which governments find it optimal to change their optimal tax rates in response to the tax rates chosen by other states, I solve for the best response functions for two states, West Bengal and Gujarat. Figure 3 (a) plots the best response for West Bengal, while Figure 3 (b) plots the best response for Gujarat.



((a)) West Bengal

((b)) Gujarat

((c)) Equilibrium

Figure 3: Best Response Functions in Two States.

The negative slope of the best response functions indicates that when the tax rates rise in one state, the other state finds it optimal to spend marginally less on its infrastructure. This implies that the state infrastructure levels are strategic substitutes, primarily because of the trade reallocation effect. As other states start to raise their stock of infrastructure and corresponding private capital, the home GDP falls in response to trade moving out. This raise the Infrastructure-to-GDP ratio (i.e. the tax rate starts to go up). This would mean that if the home region's tax rate was at the maximum of its welfare function earlier, then lowering of the GDP will move it to the right because of the concavity of the welfare function. Hence, the optimal response for the local governments is to lower the tax rate and thereby raise aggregate welfare back to its maximum level.

However, the slope of the best response function is negative, and the magnitude of the slope is close to 0 (i.e. the best response functions are almost horizontal). This can be seen more clearly in Figure 3 (c). We can see now that the best response curves looked negatively sloped earlier mostly because of the scale, but now they are horizontal and vertical lines, indicating that the interstate infrastructures are only weak strategic substitutes. This finding suggests that the iterative method adopted for solving the multi-region model in Section 4.2 is a reasonable approach.

5 Conclusion

I study empirically and theoretically the effect of India's opening up to international trade in the early 1990's on its infrastructure spending policies. Research has shown that infrastructure is important for production and trade. An increase in infrastructure spending (such as roads, power grid and water canals), makes related services, which are inputs for firms, cheaper. Building infrastructure also lowers trade costs thereby raise volume of trade. After tariffs come down, the return on infrastructure spending can increase due to its complementary with production and trade. To first test if the governments respond to tariffs by changing infrastructure spending pattern, I use a differences in differences strategy in the background of large tariff reductions undertaken by India starting in 1991. I find that a 1 percentage point reduction in tariff increased state's infrastructure by 0.5%.

This increase in infrastructure spending after lowering of tariffs could be for two reasons. First, reduction in cost of importing cheaper intermediate goods lead to efficiency gains in the economy[6]. Since more productive firms are now using infrastructure services, every unit increase of infrastructure lead to a bigger increase of output. Second, tariff reduction lowers international trade costs and therefore every unit of infrastructure built now leads to higher international trade. A benevolent government would rationally raise their infrastructure spending as its economy wide returns have gone up.

To further test the hypothesis, I see if there is a bigger response for transport related infrastructure. This is because building roads and highways reduce trade costs more than other infrastructure types. I find that government's response to transport related infrastructure was 4 times bigger than others. Overall this response of governments can be growth promoting and combined with productivity gains from tariff reductions, the aggregate gains can be much larger.

To quantify these gains, I turn to recent structural models of trade. Tractability of these class of models makes them useful for quantifying aggregate gains in a general equilibrium setup. They show mechanisms through which an economy's aggregate productivity and rate of private capital accumulation increases following tariff reductions. Since these models do not have an inbuilt government spending decision, I build a multi-country, multi-state dynamic model of trade with government provided infrastructure using insights from Eaton and Kortum (2002).

In my setup, government in each state taxes household for financing infrastructure while maximizing household's welfare. This model captures the incentive structure for infrastructure in a trading economy by evaluating the costs of taxation versus the benefits through higher production and trade. I show that the optimal tax for infrastructure spending across Indian states rose after tariffs fell i.e. governments found it optimal to increase spending on infrastructure after the trade reform.

Adding government's response, I can generate higher gains from trade opening than the existing models predict. Two features which I leave out in the modeling choice is the sectoral heterogeniety and the variable firm markups. However recent literature has downplayed their importance in quantitative analysis (Giri, Yi and Yilmazkuday, 2020; Arkolakis et al., 2019). I use a calibrated model to quantify much are the optimal increases in government spending on infrastructure after tariff reductions. I find that government's response was 40% of the model implied optimal increase. I also find much of the increase in optimal level

[6]Topalova and Khandelwal (2011) estimates that every percent reduction in Indian tariffs increased domestic manufacturing firm's productivity by 0.05%.

of infrastructure is due to sub-optimal level of infrastructure before the start of the trade reform.

6 Appendix

6.1 Household's Optimization

The optimization problem for the representative household is,

$$\mathcal{L} = \max_{C_1, C_2} \sum_{t=1}^{2} \beta^{t-1} log(C_t) - \lambda \bigg(C_1 + \frac{C_2 - w_2}{(1 + r_2)} - (1 - \tau) w_1 \bigg) \tag{49}$$

The first order conditions w.r.t C_1 and C_2 are

$$\frac{1}{C_1} = -\lambda$$

and

$$\beta \frac{1}{C_2} = -\lambda \frac{1}{(1 + r_2)}$$

respectively. Together they give the euler equation for the household,

$$\frac{C_2}{C_1} = \beta(1 + r_2). \tag{50}$$

Based on this equilibrium condition, the consumption in period 1 and 2 will be

$$C_1^* = \frac{1}{1 + \beta} \bigg((1 - \tau) w_1 + \frac{w_2}{1 + r_2} \bigg) \tag{51}$$

and

$$C_2^* = \frac{\beta}{1 + \beta} \bigg((1 - \tau) w_1 (1 + r_2) + w_2 \bigg) \tag{52}$$

respectively.

6.2 Aggregate Production Function

Let us recall that the input shares in the intermediate good production remain fixed as

$$\frac{k_n^j(z) R_n}{p_n^j(z) y_n^j(z)} = \beta_n^j \beta_n^k \tag{53}$$

$$\frac{l_n^j(z)W_n}{p_n^j(z)y_n^j(z)} = \beta_n^j\beta_n^l \tag{54}$$

$$\frac{m_n^j(z)P_n^j}{p_n^j(z)y_n^j(z)} = 1 - \beta_n^j \tag{55}$$

where the left hand side is the factor cost as a share of gross revenue while the right hand side is that factor's share in the production function. Since this holds for all z, I can take an aggregation over z and re-write the equations as

$$\int_z k_n^j(z)R_n dz = \int_z \beta_n^j\beta_n^k y_n^j(z)p_n^j(z)dz \tag{56}$$

$$\int_z l_n^j(z)W_n dz = \int_z \beta_n^j\beta_n^l y_n^j(z)p_n^j(z)dz \tag{57}$$

$$\int_z m_n^j(z)P_n^j dz = \int_z (1-\beta_n^j)y_n^j(z)p_n^j(z)dz \tag{58}$$

Since the sum of inputs employed across firms within a sector is going to be equal to the gross inputs used within that sector therefore we can write $\int_z k_n^j(z)dz = K_n^j$, $\int_z l_n^j(z)dz = L_n^j$ and $\int_z m_n^j(z)dz = M_n^j$ while the sum of intermediate good output across forms within a sector will be equal to the total gross output within that sector such that $\int_z p_n^j(z)y_n^j(z)dz = P_n^jY_n^j$

Hence equations 56,57 and 58 can we written as

$$\frac{R_n}{P_n^j} = \frac{\beta_n^j\beta_n^k Y_n^j}{K_n^j} \tag{59}$$

$$\frac{W_n}{P_n^j} = \frac{\beta_n^j\beta_n^l Y_n^j}{L_n^j} \tag{60}$$

$$\frac{P_n^j}{P_n^j} = \frac{(1-\beta_n^j)Y_n^j}{M_n^j} \tag{61}$$

Now recalling the expression for the unit cost of production,

$$x_n^j = B_n^j\bigg((R_n)^{\beta_n^k}(W_n)^{\beta_n^l}\bigg)^{\beta_n^j}\bigg(P_n^j\bigg)^{1-\beta_n^j} \tag{62}$$

where $B_n^j = \bigg(\beta_n^j(\beta_n^k)^{\beta_n^k}(\beta_n^l)^{\beta_n^l}\bigg)^{-\beta_n^j}(1-\beta_n^j)^{-(1-\beta_n^j)}$. Dividing both sides by the price of the intermediate goods (P_n^j),

$$\frac{x_n^j}{P_n^j} = B_n^j\left(\left(\frac{R_n}{P_n^j}\right)^{\beta_n^k}\left(\frac{W_n}{P_n^j}\right)^{\beta_n^l}\right)^{\beta_n^j}\left(\frac{P_n^j}{P_n^j}\right)^{1-\beta_n^j} \tag{63}$$

Now we can substitute in the expression 59, 60 and 61 in 63,

$$\frac{x_n^j}{P_n^j} = B_n^j\left(\left(\frac{\beta_n^j\beta_n^k Y_n^j}{K_n^j}\right)^{\beta_n^k}\left(\frac{\beta_n^j\beta_n^l Y_n^j}{L_n^j}\right)^{\beta_n^l}\right)^{\beta_n^j}\left(\frac{(1-\beta_n^j)Y_n^j}{M_n^j}\right)^{1-\beta_n^j} \tag{64}$$

Now taking K, L and M to the other side and taking out Y, we get

$$\frac{x_n^j}{P_n^j}((K_n^j)^{\beta_n^k}(L_n^j)^{\beta_n^l})^{\beta_n^j}(M_n^j)^{1-\beta_n^j} = B_n^j\mathcal{B}_n^j(Y_n^j)^{[(\beta_n^k+\beta_n^l)\beta_n^j+(1-\beta_n^j)]} \tag{65}$$

where

$$\mathcal{B} = ((\beta_n^k)^{\beta_n^k}(\beta_n^l)^{\beta_n^l})^{\beta_n^j}(\beta_n^j)^{\beta_n^j}(1-\beta_n^j)^{1-\beta_n^j} \tag{66}$$

Since B_n^j is the inverse of $\mathcal{B}_n^j$, both terms get cancelled. Then, by assumption we know that capital and labor coefficients sum to 1 and therefore the coefficient on Y will be

$$(\beta_n^k+\beta_n^l)\beta_n^j + (1-\beta_n^j) = (1)\beta_n^j + (1-\beta_n^j) = 1 \tag{67}$$

Hence equation 65 can be written as

$$Y_n^j = \frac{x_n^j}{P_n^j}((K_n^j)^{\beta_n^k}(L_n^j)^{\beta_n^l})^{\beta_n^j}(M_n^j)^{1-\beta_n^j} \tag{68}$$

6.3 Static problem

In this setup, government acts as a socially benevolent planner and wants to maximize the utility of the household by picking the optimal tax rate every period. Hence the problem of the government is to pick tax rate (τ_n) which maximizes,

$$\mathcal{W} = \max_{\tau_n} \frac{(1-\tau_n)I_n}{\prod_j (p_n^j)^{\alpha^j}}.\mathcal{C} \tag{69}$$

where $\mathcal{C}$ is a constant and hence can be dropped without affecting the optimal tax rate. For ease of substitution, I will re-write the welfare function as

$$\mathcal{W} = \max_{\tau_n} \left[(1-\tau_n) \prod_j \left(\frac{I_n}{p_n^j} \right)^{\alpha^j} \right] \tag{70}$$

I assume the governments balance their budgets and hence the stock of infrastructure capital in the economy is equal to the tax collected,

$$G_n = \tau_n \frac{I_n}{P_n} \tag{71}$$

Recall, that the term in the parenthesis, I_n/p_n^j is nominal income of the household, which is sum of labor and rental income, normalized by sector j prices. Substituting in the closed form representation of factor prices (24), I can re-write this expression as

$$\frac{I_n}{p_n^j} = \left(\frac{T_n^j G_n^{\gamma \beta_n^j}}{\pi_{nn}^j} \right)^{\frac{1}{\theta^j \beta_n^j}} \left[\Gamma_l l_n^j + \Gamma_k k_n^j \right] \tag{72}$$

Since the factor of production is fixed, l and k are exogenous and are not affected by the tax rate τ_n. The two variables which will be affected by the tax rate in the above expression are G_n and π_{nn}^j. G_n is directly affected by τ_n as all the tax collection goes towards building infrastructure capital, as shown in equation 71. π_{nn}, which is the home share of goods in domestic consumption basket, is affected by the tax rate as τ_n affects G_n, which in turn affects region n's comparative advantage by lowering the cost of production for its firms. Due to which home goods become more attractive and π_{nn} goes up, all else equal.

Now taking derivative of the welfare function with respect to τ_n,

$$\frac{\partial \mathcal{W}\backslash}{\partial \tau_n} = - \prod_j \left(\frac{I_n}{p_n^j} \right)^{\alpha^j} + (1-\tau_n) \sum_j \alpha^j \left(\frac{p_n^j}{I_n} \right) \prod_j \left(\frac{I_n}{p_n^j} \right)^{\alpha^j} \frac{\partial \left(I_n/p_n^j \right)}{\partial \tau_n} = 0 \tag{73}$$

Using equation 91, the above f.o.c can be written as

$$(1-\tau_n) \sum_j \frac{\alpha^j}{\theta^j} \left[\frac{\gamma}{G_n} I_n - \frac{1}{\pi_{nn}^j} \frac{\partial \pi_{nn}^j}{\partial \tau_n} \right] = 1 \tag{74}$$

Using expression for sectoral elasticity of infrastructure from equation **??**, I can re-write the above expression as

$$(1-\tau_n)\sum_j \alpha^j \tilde{\gamma}^j \left[\frac{I_n}{G_n} - \frac{1}{\pi^j_{nn}}\frac{\partial \pi^j_{nn}}{\partial \tau_n}\right] = 1 \tag{75}$$

Here, the term in summation can be interpreted as the aggregate infrastructure elasticity,

$$\gamma^A = \sum_j \alpha^j \tilde{\gamma}^j$$

which is a weighted sum of sectoral infrastructure elasticity where the weights are the expenditure shares of each sector.

6.3.1 Autarky Case

Suppose now we are in a situation where there is no trade such that all the goods consumed domestically are also produced domestically. This will imply that $\pi_{nn} = 1$ and any changes in infrastructure will leave π_{nn} unchanged as it is a share and 1 is the upper limit. In this case, equation 75 can be written as

$$\tau_n = 1 - \frac{1}{\gamma^A}\left[\frac{G_n}{I_n}\right] \tag{76}$$

Then for any given region,

$$\tau = \begin{cases} 0 & \text{if} \quad {}^{G}/_{I} = \gamma^A \\ > 0 & \text{if} \quad {}^{G}/_{I} < \gamma^A \end{cases}$$

This implies that the optimal stock of infrastructure to income ratio is equal to the aggregate infrastructure elasticity (γ^A) in the autarky case.

6.3.2 Trading Case

Let us consider it for one sector such that J=1 and the utility function is of the log utility form and correspondingly the f.o.c. can be written as

$$\frac{\partial \mathcal{W}_\backslash}{\partial \tau_n} = -\frac{I_n}{p_n} + (1-\tau_n)\frac{\partial \left({}^{I_n}/_{p_n} \right)}{\partial \tau_n} = 0 \tag{77}$$

Re-writing this condition and replacing the terms with equilibrium prices gives:

$$\frac{1}{1-\tau_n} = \frac{1}{\theta\beta_n}\left[\frac{\gamma\beta_n}{\tau_n}\left[\frac{1}{1-\tau_n}\right] - \frac{1}{\pi_{nn}}\frac{\partial\pi_{nn}}{\partial\tau_n}\right] \tag{78}$$

In equation 78, if we do not have the term with the trade shares, optimal tax will be equal to γ/θ. However when in a trading economy, we will have an additional effect of raising infrastructure on domestic income which comes through trade. This is the term which I call the trade effect:

$$\text{Trade Effect} = \frac{1}{\pi_{nn}}\frac{\partial\pi_{nn}}{\partial\tau_n} \tag{79}$$

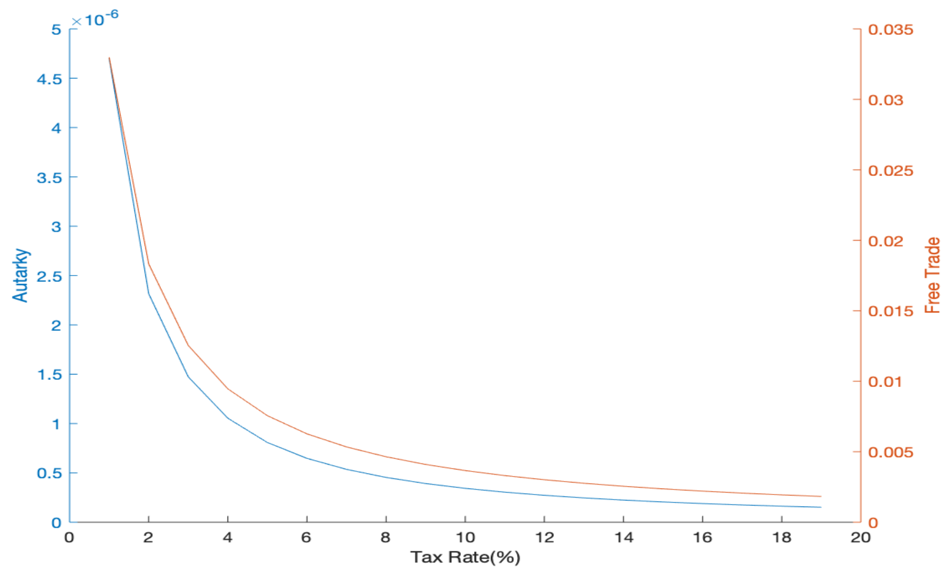


Figure 4: Trade effect across different tax rates under free trade and autarky.

Under autarky, trade effect is close to 0 (blue axis in figure 1). Hence plugging that in equation 78, we get

$$\frac{1}{1-\tau_n} = \frac{1}{\theta\beta_n}\left[\frac{\gamma\beta_n}{\tau_n}\left[\frac{1}{1-\tau_n}\right] - 0\right] \tag{80}$$

$$\frac{1}{1-\tau_n} = \frac{1}{\theta}\left[\frac{\gamma}{\tau_n}\left[\frac{1}{1-\tau_n}\right]\right] \qquad \rightarrow \qquad \tau_n = \frac{\gamma}{\theta} \tag{81}$$

Under free trade, trade effect is positive (orange axis in figure 1) hence the optimal tax will be less than γ/θ as

$$\tau_n = \frac{\gamma}{\theta} - \underbrace{\frac{\beta_n}{\theta}\tau_n(1-\tau_n)\frac{1}{\pi_{nn}}\frac{\partial \pi_{nn}}{\partial \tau_n}}_{\text{term 1}} \tag{82}$$

We can see from equation 17 that the optimal tax will be lower than $\frac{\gamma}{\theta}$ as term 1 will be positive.

6.4 One sector government's problem

The f.o.c. for the government maximization problem is

$$\frac{\partial \mathcal{W}\backslash}{\partial \tau_n} = -\prod_j \left(\frac{I_n}{p_n^j}\right)^{\alpha^j} + (1-\tau_n)\sum_j \alpha^j \left(\frac{p_n^j}{I_n}\right)\prod_j \left(\frac{I_n}{p_n^j}\right)^{\alpha^j} \frac{\partial \left({}^{I_n}\!/_{p_n^j} \right)}{\partial \tau_n} = 0 \tag{83}$$

Let us consider it for one sector such that J=1 and the utility function is of the log utility form. Then the welfare function can be written as

$$\mathcal{W} = \max_{\tau_n} \log\left(\frac{(1-\tau_n)I_n}{p_n}\right) \tag{84}$$

and correspondingly the f.o.c. can be written as

$$\frac{\partial \mathcal{W}\backslash}{\partial \tau_n} = -\frac{I_n}{p_n} + (1-\tau_n)\frac{\partial \left({}^{I_n}\!/_{p_n} \right)}{\partial \tau_n} = 0 \tag{85}$$

Re-writing this gives:

$$1 - \tau_n = \frac{{}^{I_n}\!/_{p_n}}{\partial \left({}^{I_n}\!/_{p_n} \right) \big/ \partial \tau_n} \tag{86}$$

Hence the optimal tax is

$$\tau_n = 1 - \frac{{}^{I_n}\!/_{p_n}}{\partial ({}^{I_n}\!/_{p_n}) \big/ \partial \tau_n} \tag{87}$$

Recalling that the income is the some of labor and capital income, normalized by prices and hence can be written as

$$\frac{I_n}{p_n^j} = \frac{w_n}{p_n} l_n + \frac{r_n}{p_n} k_n \tag{88}$$

with the corresponding factor prices being

$$\frac{w_n}{p_n} = \left[\frac{x_n}{p_n}\right]^{\frac{1}{\beta_n}} \frac{\beta_n^k}{\beta_n^l} \qquad \text{and} \qquad \frac{r_n}{p_n} = \left[\frac{x_n}{p_n}\right]^{\frac{1}{\beta_n}} \frac{\beta_n^l}{\beta_n^k} \tag{89}$$

where

$$\frac{x_n}{p_n} = \left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)^{\frac{1}{\theta}} (A_n B_n)^{-1} \tag{90}$$

Hence substituting 7 in 6 and using 8, we can get the expression of real income in terms of capital stocks (private and public), labor and trade shares:

$$\frac{I_n}{p_n} = \left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)^{\frac{1}{\theta\beta_n}} \left[\Gamma_l l_n + \Gamma_k k_n\right] \tag{91}$$

where $\Gamma_l = \frac{\beta_n^k}{\beta_n^l}(A_n B_n)^{-\frac{1}{\beta_n}}$ and $\Gamma_k = \frac{\beta_n^l}{\beta_n^k}(A_n B_n)^{-\frac{1}{\beta_n}}$. Now taking derivative of real income w.r.t tax rate τ_n, we get

$$\partial(I_n/p_n)/\partial\tau_n = \frac{1}{\theta\beta_n}\left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)^{-1} \frac{I_n}{p_n}\left[\left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)\left(\frac{\gamma\beta_n}{G_n}\right) - \left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}^2}\right)\frac{\partial\pi_{nn}}{\partial\tau_n}\right] \tag{92}$$

Cancelling common terms on the RHS we get

$$\partial(I_n/p_n)/\partial\tau_n = \frac{1}{\theta\beta_n}\frac{I_n}{p_n}\left[\frac{\gamma\beta_n}{G_n}\frac{I_n}{p_n} - \frac{1}{\pi_{nn}}\frac{\partial\pi_{nn}}{\partial\tau_n}\right] \tag{93}$$

Recalling the expression for π_{nn},

$$\pi_{nn} = \left(\frac{x_n}{p_n}\right)^{-\theta} (A_n B_n)^{-\theta} T_n G_n^{\gamma\beta_n} \tag{94}$$

and then expanding the partial derivative in the RHS,

$$\frac{\partial\pi_{nn}}{\partial\tau_n} = \pi_{nn}\left[\frac{\gamma\beta_n}{G_n}\frac{I_n}{p_n} - \frac{\theta}{x_n/p_n}\frac{\partial x_n/p_n}{\partial\tau_n}\right] \tag{95}$$

Then again expanding the partial derivative in the RHS,

$$\frac{\partial x_n/p_n}{\partial \tau_n} = \left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)^{-1} \frac{1}{\theta}\frac{x_n}{p_n}\left[\left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}}\right)\left(\frac{\gamma\beta_n}{G_n}\right)\frac{I_n}{p_n} - \left(\frac{T_n G_n^{\gamma\beta_n}}{\pi_{nn}^2}\right)\frac{\partial \pi_{nn}}{\partial \tau_n}\right] \tag{96}$$

solving further

$$\frac{\partial x_n/p_n}{\partial \tau_n} = \frac{1}{\theta}\frac{x_n}{p_n}\left[\left(\frac{\gamma\beta_n}{G_n}\right)\frac{I_n}{p_n} - \left(\frac{1}{\pi_{nn}}\right)\frac{\partial \pi_{nn}}{\partial \tau_n}\right] \tag{97}$$

Putting 15 in 13

$$\frac{\partial \pi_{nn}}{\partial \tau_n} = \pi_{nn}\left[\frac{\gamma\beta_n}{G_n}\frac{I_n}{p_n} - \frac{\theta}{x_n/p_n}\frac{1}{\theta}\frac{x_n}{p_n}\left[\left(\frac{\gamma\beta_n}{G_n}\right)\frac{I_n}{p_n} - \left(\frac{1}{\pi_{nn}}\right)\frac{\partial \pi_{nn}}{\partial \tau_n}\right]\right] \tag{98}$$

Cancelling terms, I get

$$\frac{\partial \pi_{nn}}{\partial \tau_n} = \pi_{nn}\left[\frac{\gamma\beta_n}{G_n}\frac{I_n}{p_n} - \left(\frac{\gamma\beta_n}{G_n}\frac{I_n}{p_n}\right) + \left(\frac{1}{\pi_{nn}}\right)\frac{\partial \pi_{nn}}{\partial \tau_n}\right] \tag{99}$$

Again cancelling terms,

$$\frac{\partial \pi_{nn}}{\partial \tau_n} = \pi_{nn}\left[\left(\frac{1}{\pi_{nn}}\right)\frac{\partial \pi_{nn}}{\partial \tau_n}\right] = \frac{\partial \pi_{nn}}{\partial \tau_n} \tag{100}$$

This implies that $\frac{\partial \pi_{nn}}{\partial \tau_n}$ has no unique solution as it is not identified in the model. In which case $\frac{\partial \pi_{nn}}{\partial \tau_n} = 0$ is an admissible solution in the model and substituting it in the optimal tax equation (5) along with (11) we get,

$$\tau_n = 1 - \frac{G_n/\frac{I_n}{p_n}}{\gamma/\theta} \tag{101}$$

This equation shows that as long as the G as a share of real income I/P remains equal to the aggregate infrastructure elasticity γ/θ, the optimal tax remains unchanged.

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