



Infrastructure and inequality[☆]

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ABSTRACT

We develop a model in which public capital is both **an engine of growth and a determinant of the distributions of wealth, income, and welfare**. Government investment **increases wealth inequality over time, regardless of its financing**. The time path of income inequality is, however, **highly sensitive to financing policies**, and is often characterized by **sharp intertemporal tradeoffs, with income inequality declining in the short run but increasing in the long run**. Public investment generates a positive correlation between growth and income inequality along the transition path, but their short-run and long-run relationship depends critically on **(i) how externalities impinge on allocation decisions, (ii) financing policies, and (iii) the time period of consideration**. Finally, these policies also **generate sharp trade-offs between average welfare and its distribution**, with government investment improving average welfare, but also increasing its dispersion. Our results are obtained numerically but extensive sensitivity analysis confirms their robustness across key parameter values.

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1. Introduction

The expressway network (in China) has...helped to promote a sharp increase in private car ownership...roads are sometimes built expressly for the purpose of converting countryside into revenue-generating urban land...For Beijing's airport expansion, 15 villages were flattened and their more than 10,000 residents resettled...but...former farmers... (were) barred from unemployment benefits and other welfare privileges.

The Economist (February 14, 2008).

Government provision of public goods such as infrastructure represents an important mechanism through which wealth can be redistributed across society. Many emerging-market countries such as India, China, and Brazil have embarked on ambitious expansions of public investment in roads, ports, communication and transportation networks, power generation and water services, mainly as a means to sustain their high growth rates of the last two decades. Among

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developed countries, a significant fraction of the increase in government stimulus spending in the aftermath of the Financial Crisis of 2007–08 was targeted towards infrastructure. At the same time, income inequality has also risen steadily across the world, both in emerging markets and most OECD countries. An important question that arises in this context is the effect of pro-growth policies on the dynamics of inequality. Indeed, as Anand and Segal (2008) point out, reducing inequality may be an important social objective for a government. The issue then is the extent to which investment in public infrastructure, with its accompanying growth and productivity benefits, is compatible with this objective.

Beginning with Arrow and Kurz (1970) and later Barro (1990), the relationship between public investment and growth has been widely studied, with general agreement that government spending on infrastructure can yield significant productivity and growth benefits.² At the same time, by affecting factor productivity and therefore relative factor returns, public investment may also play a critical role in the evolution of wealth and income distributions as the economy grows over time. However, *a priori*, it is unclear what the nature of such a relationship will be.

In contrast to the public investment–growth relationship, empirical evidence on the relationship between infrastructure investment and inequality is sparse, inconclusive, and largely anecdotal. For instance, Ferranti et al. (2004), Fan and Zhang (2004), Lopez (2004), and Calderon and Servén (2004) find that public investment has promoted growth and contributed towards the alleviation of inequality. Wolff and Zacharias (2007) document an inverse short-run relationship between government expenditure and inequality for the United States, though they do not distinguish between public consumption and investment. In contrast, Brakman et al. (2002) find that government spending on infrastructure has increased regional disparities within Europe, and Artadi and Sala-i-Martin (2003) point to excessive public investment as a contributing factor to rising income inequality in Africa. Banerjee and Somanathan (2007) report that in India, access to critical infrastructure services and public goods is in general positively correlated with social status, while a World Bank (2006) report also finds that the quality and performance of state-provided infrastructure services tend to be the worst in India's poorest states. Further, Khandker and Koolwal (2007) find that access to paved roads has had a limited distributional impact in rural Bangladesh. The diversity of these empirical findings underscores the need for a well-specified analytical framework within which the link between infrastructure spending, economic growth and inequality can be systematically studied.

This paper seeks to synthesize these two extensive, but independent, strands of literature into a unified framework. On the one hand, the theoretical literature on growth and inequality has not dealt with issues related to public investment and its financing.³ On the other hand, the literature on public investment and growth has generally ignored distributional issues.⁴ Studying the public investment–inequality relationship in the context of a dynamic growth model therefore represents an important synthesis of previous work. In doing so, we address the following issues:

- (i). The mechanism through which government spending on infrastructure and accompanying taxation policies affects the distributions of wealth, income, and welfare over time.
- (ii). The dynamics of the growth–inequality relationship along the transitional path.
- (iii). Trade-offs between average welfare and its dispersion resulting from fiscal shocks.

The model we employ has several key elements. First, the underlying source of heterogeneity arises through agents' differential initial endowments of private capital.⁵ Combined with an endogenous labor–leisure choice, this yields an endogenous distribution of income. Second, we introduce a growing stock of a government-provided good (public capital) that is non-rival and non-excludable. This interacts with the aggregate stock of private capital to generate composite externalities for both labor productivity in production and the labor–leisure allocation in utility. The government has a range of fiscal instruments available to finance its investment, namely distortionary taxes on capital income, labor income, and consumption, and a non-distortionary lump-sum tax (equivalent to government debt). The accumulation of public capital and the spillovers it generates serves both as an engine of sustained growth, and also as a driver of relative returns to capital and labor, with consequences for the evolution of wealth and income inequality. In equilibrium, both the economy's growth rate and inequality are endogenously determined.⁶

² Agenor (2011) provides an exhaustive survey of the theoretical literature on this issue. On the empirical side, the consensus remains that infrastructure contributes positively and significantly to output, though its exact magnitude is a subject of debate. See Bom and Ligthart (2010) for a review of the empirical literature.

³ This literature has explored issues such as capital market imperfections, the role of human capital, and technological progress, among others; see, for example, Banerjee and Newman (1993), Galor and Zeira (1993) and Acemoglu (1998).

⁴ In a recent contribution, García-Peñalosa and Turnovsky (2011) consider the case where the tax revenues are allocated to government consumption. Their work, however, is in context of the neoclassical Ramsey model and does not focus on the growth and distributional effects of infrastructure investment and its financing.

⁵ Recent empirical evidence points to the importance of the return to private capital as one of the determinants of inequality; see, for example, Atkinson (2003), Piketty (2011) and Checchi and García-Peñalosa (2010).

⁶ In this context, our work is related to Getachew (2010), who uses an OLG set-up with public investment and initial differences in skills as the source of heterogeneity. While Getachew (2010) focuses on the role of credit markets, our focus is on the interaction between the endogenous allocation of time between labor and leisure, the initial distribution of private wealth, the stock of public infrastructure, and various underlying tax policies used for financing public investment.

Given the complexity of the theoretical framework, the model is analyzed numerically. Specifically, we compare an increase in the rate of government investment on public capital, financed by the use of alternative fiscal instruments. A number of interesting results emerge:

- (i) Government spending on public capital leads to a persistent increase in wealth inequality over time, regardless of how it is financed. In contrast, the time path of income inequality is sensitive to the financing policy adopted, and in many cases is characterized by sharp intertemporal tradeoffs. For example, while government investment financed by a lump-sum or consumption tax leads to a short-run decline in income inequality, this is completely reversed over time, leading to an increase in the long-run dispersion of income. This is somewhat surprising, since lump-sum taxes are a non-distortionary source of financing and government spending creates a larger stock of a non-excludable and non-rival public good. We also find that more than two-thirds of the long-run increase in income inequality can be attributed to an increase in labor income inequality, consistent with the recent empirical findings of Atkinson et al. (2011).
- (ii) The growth–income inequality relationship generated by government spending depends critically on (a) how externalities impinge on allocation decisions, (b) the underlying financing policies, and (c) the time period of consideration—i.e. short run, transition path, or the long run. These results underscore the ambiguity in the growth–inequality relationship that is characteristic in the empirical literature.⁷
- (iii) Public investment generates sharp trade-offs between average welfare and its distribution: while government expenditure on infrastructure improves average welfare, it also increases its dispersion. However, spending financed by taxing consumption or labor income is associated with less adverse tradeoffs.

The rest of the paper is organized as follows. Section 2 lays down the analytical framework and Section 3 derives the macroeconomic equilibrium for the aggregate economy. Section 4 derives the distributional dynamics and characterizes the evolution of the different measures of inequality. Section 5 conducts numerical policy experiments and discusses their implications. Section 6 conducts an extensive robustness check of the benchmark results. Finally, Section 7 concludes.

2. Analytical framework

The analytical framework is that of a closed-economy with heterogeneous agents in which both private and public capital are accumulated, with the evolution of the economy being characterized by transitional dynamics and endogenous growth, as in Futagami et al. (1993) and Turnovsky (1997).⁸

2.1. Firms and technology

All firms are identical and are indexed by j . The representative firm produces output in accordance with the CES production function:

$$Y_j = A[\alpha(X_P L_j)^{-\rho} + (1-\alpha)K_j^{-\rho}]^{-1/\rho} \quad (1a)$$

where K_j and L_j represent the individual firm's capital stock and employment of labor, respectively, and $s \equiv 1/(1+\rho)$ represents the elasticity of substitution in production between capital and effective units of labor. In addition, production is influenced by an aggregate composite externality, X_P , (infrastructure) which we take to be a geometric weighted average of the economy's aggregate stocks of private and public capital (K and K_G , respectively):

$$X_P = K^\varepsilon K_G^{1-\varepsilon}, \quad 0 \leq \varepsilon \leq 1 \quad (1b)$$

that is, “raw” labor interacts with the composite production externality to create labor efficiency units, which in turn interact with private capital to produce output. The production function has constant returns to scale in both the private factors and in the accumulating factors, and accordingly, sustains an equilibrium of endogenous growth. The composite externality represents a combination of the role of private capital, (proxying knowledge), as in Romer (1986), together with public capital as in Futagami et al. (1993) and subsequent authors, and can be justified in two ways. First, as will become evident below, it helps provide a plausible calibration of the aggregate economy, something that is generically problematic in the conventional one-sector

⁷ Empirical studies that have explored the causality between growth and income inequality have generally yielded conflicting results. For example, while Alesina and Rodrik (1994), Persson and Tabellini (1994), and Perotti (1996) find an inverse relationship, Li and Zou (1998) and Forbes (2000) have documented a positive link, while Barro (2000) finds a positive relationship for developing countries and a negative one for developed economies. The diversity of these results is unsurprising given that both growth and income inequality are endogenous outcomes and their co-movement will depend upon the structural changes to which they are responding.

⁸ The solution procedure for this model follows Turnovsky and García-Peñalosa (2008), where it is discussed at length, and therefore details are omitted here insofar as possible. We should, however, emphasize that their analysis is very different in that it employs a Ramsey model, rather than an endogenous growth model. It is also addresses very different issues, being concerned with structural changes, such as changes in technology, and indeed abstracts from fiscal issues that we are addressing here.

endogenous growth model. Second, the notion that an economy's infrastructure contributing to labor efficiency comprises a combination both public and private components is itself a plausible representation of reality.⁹

All firms are also assumed to face identical competitive production conditions, and hence will choose exactly the same levels of employment of labor and private capital, i.e., $K_j = K$, and $L_j = L$, for all j , where K and L denote the average economy-wide levels of private capital and labor employment, respectively. Letting $z \equiv K_G/K$ denote the ratio of the economy-wide stock of public capital to private capital, we can write $y \equiv Y/K$, the average product of aggregate private capital as

$$y \equiv y(z, l) = A[1 - \alpha + \alpha\{(1-l)z^{1-\varepsilon}\}^{-\rho}]^{-1/\rho} \quad (2)$$

where $l = 1 - L$ denotes the average allocation of time to leisure in the economy. With both factors being paid their respective private marginal products, the economy-wide returns to capital and labor, determined in competitive factor markets, may be expressed as

$$r = r(z, l) \equiv (1 - \alpha)A^{-\rho}y(z, l)^{1+\rho} \quad (3a)$$

$$w = \omega(z, l)K; \quad \omega(z, l) \equiv \alpha A^{-\rho}y(z, l)^{1+\rho}z^{-\rho(1-\varepsilon)}(1-l)^{-(1+\rho)} \quad (3b)$$

Thus, as long as $\varepsilon < 1$, the real wage rate and the return to private capital depend on the ratio of public to private capital and the average allocation of time to work (or leisure).¹⁰

2.2. Consumers

There is a continuum of infinitely-lived consumers, indexed by i , who are identical in all respects except for their initial endowments of private capital, K_{i0} .¹¹ Each consumer is also endowed with one unit of time that can be allocated to either leisure, l_i , or work, $L_i = 1 - l_i$. Consumer i maximizes utility over an infinite horizon from his flow of consumption, C_i , and leisure, using the following CES utility function:

$$U_i = \int_0^\infty \frac{1}{\gamma} [C_i^{-\gamma} + \theta(X_U l_i)^{-\gamma}]^{-\gamma/\gamma} e^{-\beta t} dt \quad (4a)$$

where $q \equiv 1/(1+\gamma)$ denotes the intra-temporal elasticity of substitution between consumption and leisure in the utility function, and $e \equiv 1/(1-\gamma)$ represents the inter-temporal elasticity of substitution. Each consumer's utility is also affected by an aggregate composite externality, X_U , which is a geometric weighted average of the economy's aggregate stocks of public and private capital:

$$X_U = K^\varphi K_G^{1-\varphi}, \quad 0 \leq \varphi \leq 1 \quad (4b)$$

this composite externality in Eq. (4b) interacts with the time allocated to leisure by consumer i to generate utility benefits, which in turn are weighted by θ in yielding overall utility.

Several reasons motivate specifying the preferences as in Eqs. (4a) and (4b). The first is that the conventional Cobb–Douglas formulation of utility has the undesirable implication that for plausible values of the intertemporal elasticity of substitution ($0 < e < 1$), consumption and leisure are Edgeworth “substitutes”. Generalizing the utility function to CES allows them to be complements or substitutes depending upon whether $e \gtrless q$.¹² But for the CES function to have the homogeneity properties required to sustain endogenous growth, the externality must interact with leisure in the form we have specified. Second, the notion that the utility derived from leisure depends upon amenities due to the provision of both public and private capital is in fact a plausible one. As originally emphasized by Arrow and Kurz (1970), and more recently by Agenor (2008); Economides et al. (2011) and Chatterjee and Ghosh (2011), most public goods, including infrastructure, education, healthcare, law and order, etc., play a dual role in private allocation decisions by simultaneously affecting both productivity and utility. Furthermore, as we will demonstrate below, the endogenous labor–leisure choice plays an important role in influencing the dynamics of inequality. Therefore, it is important to ensure that any public and private externalities that impinge on this choice – whether they arise from the supply side or the demand side – are accounted for.¹³

⁹ Note that the production function Eq. (1a) and the composite externality in Eq. (1b) nest both the traditional linear “AK” endogenous growth model as in Romer (1986) ($\varepsilon = 1$) and the stock version of the Barro (1990) model ($\varepsilon = 0$), as in Futagami et al. (1993).

¹⁰ If $\varepsilon = 1$ the factor returns depend only on leisure, as public capital does not affect production.

¹¹ Private capital can be viewed as an amalgam of physical and human capital, as in Romer (1986).

¹² The conventional Cobb–Douglas utility function is of the form: $(C_i l_i^\gamma)^{1/\gamma}$. Two goods are said to be Edgeworth complements or substitutes according to whether their cross partial derivatives are positive or negative. Estimates of the (intra-temporal) elasticity of substitution between consumption and leisure are sparse. However, in a well known study Stern (1976) estimates a value of 0.4, well below the value of 1 implicit in the conventional Cobb–Douglas specification. His finding that optimal tax policy is sensitive to this elasticity suggests that generalizing the utility function to the CES form is potentially important.

¹³ Chatterjee and Ghosh (2011) provide several examples of the dual role played by public goods in affecting both utility and productivity. They discuss the productivity and utility-enhancing role of roads and highways, schools, power and water services, among others.

Each agent chooses C_i , l_i , and his rate of capital accumulation, \dot{K}_i to maximize Eq. (4a) subject to Eq. (4b), their initial endowment of capital, $K_{i,0}$, and the following flow budget constraint

$$\dot{K}_i = (1 - \tau_k)rK_i + (1 - \tau_w)w(1 - l_i) - (1 + \tau_c)C_i - T \quad (5)$$

where τ_k , τ_w , and τ_c are the tax rates on the agent's capital income, labor income, and consumption expenditures, respectively, and T represents a lump-sum tax levied by the government. In making these decisions the agent takes the real wage rate and the return on private capital, determined in competitive factor markets, as given, and treats all tax and policy variables as exogenous.

Optimizing with respect to C_i , l_i , and K_i yields the following standard first-order conditions

$$[C_i^{-\nu} + \theta(X_U l_i)^{-\nu}]^{-(\gamma/\nu)-1} C_i^{-\nu-1} = \lambda_i(1 + \tau_c) \quad (6a)$$

$$\theta X_U^{-\nu} [C_i^{-\nu} + \theta(X_U l_i)^{-\nu}]^{-(\gamma/\nu)-1} l_i^{-\nu-1} = \lambda_i(1 - \tau_w)\omega(z, l)K \quad (6b)$$

$$(1 - \tau_k)r(z, l) = \beta - \frac{\dot{\lambda}_i}{\lambda_i} \quad (6c)$$

$$\lim_{t \rightarrow \infty} \lambda_i K_i e^{-\beta t} = 0 \quad (6d)$$

where λ_i is agent i 's shadow value of private capital. Dividing Eq. (6b) by Eq. (6a) yields the marginal rate of substitution between consumption and leisure, which turns out to be identical for all agents:

$$\frac{C_i}{l_i} = \Omega(z, l)K, \Omega(z, l) \equiv [(1 - \tau_w)\omega(z, l)z^{\nu(1-\phi)} / \theta(1 + \tau_c)]^{1/(1+\nu)} \quad (7)$$

2.3. Government

The government provides the stock of public capital, which is assumed to be non-rival and non-excludable, and evolves according to

$$\dot{K}_G = G = gY, \quad 0 < g < 1 \quad (8)$$

where G is the flow of new public investment, which is tied to aggregate output Y . Therefore, g represents the fraction of aggregate output allocated to public investment by the government, and is the key policy parameter in the model.¹⁴ The government finances its investment by tax revenues and maintains a balanced budget at all points of time:

$$G = \tau_k rK + \tau_w w(1 - l) + \tau_c C + T \quad (9)$$

dividing Eq. (9) by K , while noting Eq. (7), we can write this in the form

$$gY(z, l) = \tau_k r(z, l) + \tau_w \omega(z, l)(1 - l) + \tau_c \Omega(z, l)l + \tau_Y(z, l) \quad (10)$$

where lump-sum tax revenues are expressed as a proportion τ ($0 < \tau < 1$) of aggregate output, namely $T = \tau Y$. It is clear from Eq. (10) that if the tax and expenditure rates, τ_k , τ_w , τ_c , and g are maintained constant, then as z and l progress along the transitional path the fraction of output levied as lump-sum taxes, τ , will continually vary in order for the government budget to remain in balance.

3. Macroeconomic equilibrium

In general, the economy-wide *average* of a variable, X_i is represented by $(1/N) \sum_i^N X_i \equiv \bar{X}$. Because of the homogeneity of the utility function and perfect factor markets, we can show that all individuals choose the same growth rates for consumption and leisure, implying that average consumption, \bar{C} , and leisure, \bar{l} , will also grow at the same rates; i.e.,

$$\frac{\dot{C}_i}{C_i} = \frac{\dot{\bar{C}}}{\bar{C}}, \quad \frac{\dot{l}_i}{l_i} = \frac{\dot{\bar{l}}}{\bar{l}}, \quad \text{for each } i \quad (11)$$

as a result, the system can be aggregated perfectly over agents.¹⁵ Each individual, however, will choose different *levels* of consumption and leisure, depending upon his resources; in particular,

$$l_i = \pi_i \bar{l} \text{ and } \frac{1}{N} \sum_i^N \pi_i = 1 \quad (12)$$

¹⁴ For simplicity we abstract from depreciation of either form of capital.

¹⁵ The relationship Eq. (11) is critical in facilitating the aggregation, and is due to Gorman (1953); See also Caselli and Ventura (2000). It is obtained by taking the time derivative of Eqs. (6a) and (7), and noting (6c); see Turnovsky and García-Peñalosa (2008) for more details.

where π_i is relative leisure chosen by agent i , and is to be determined; see Eq. (20) below. Summing Eqs. (7) and (8) over all agents, while noting Eq. (10), yields the growth rate of aggregate private capital

$$\frac{\dot{K}}{K} = (1-\tau_k)r + [(1-\tau_w)\omega(z,l)(1-l) - (1+\tau_c)\Omega(z,l)l - \tau y(z,l)] \quad (13)$$

combining Eq. (13) with Eq. (10) yields the aggregate goods market clearing condition

$$\frac{\dot{K}}{K} = (1-g)y(z,l) - \Omega(z,l)l \quad (13')$$

Given the homogeneity of the underlying utility and production functions in the capital stocks, the long-run equilibrium of this economy is a balanced growth path along which all aggregate variables grow at a common rate and average leisure is constant. The transitional dynamics of the aggregate economy are driven by the evolution of the ratio of public to private capital, z , and leisure, l .

$$\frac{\dot{z}}{z} = g \frac{y(z,l)}{z} - [(1-g)y(z,l) - \Omega(z,l)l] \quad (14a)$$

$$\frac{\dot{l}}{l} = \frac{H(z,l)}{J(z,l)} \quad (14b)$$

where the functions $H(z,l)$ and $J(z,l)$ are described in Appendix A.

Eq. (14a) asserts that the growth of the public to private capital ratio equals the differential growth rates of its components. Eq. (14b) is more involved and is obtained by combining Eq. (11), with the time derivatives of Eqs. (6a) and (7). It describes the adjustment in leisure that is necessary to equalize returns on consumption and capital along the transition path.¹⁶

3.1. Steady state and aggregate dynamics

Assuming that the system is stable, the aggregate economy will converge to a balanced growth path characterized by a constant public to private capital ratio, \tilde{z} , and leisure, \tilde{l} . Setting $\dot{z} = \dot{l} = 0$ in Eqs. (14a) and (14b) determines \tilde{z} and \tilde{l} , such that public capital, private capital, and consumption, all grow at a common rate, given by

$$\tilde{\psi} = \frac{(1-\tau_k)r(\tilde{z},\tilde{l}) - \beta}{1-\gamma} \equiv g \frac{y(\tilde{z},\tilde{l})}{\tilde{z}} \quad (15)$$

given \tilde{z} and \tilde{l} , Eq. (7) then determines the steady-state consumption-private capital ratio, \tilde{c} . Finally, the transversality condition Eq. (6d) together with Eq. (6c) implies $\tilde{\psi} + \beta - \tilde{r}(\tilde{z},\tilde{l})(1-\tau_k) - \beta < 0$, i.e., $\tilde{\psi} < \tilde{r}(1-\tau_k)$, which combined with Eq. (13) in steady state, yields

$$\tilde{c} > \frac{(1-\tau_w)\omega(\tilde{z},\tilde{l})(1-\tilde{l}) - \tau y(\tilde{z},\tilde{l})}{1+\tau_c} \quad (16)$$

for the long-run growth rate to be sustainable, consumption expenditure (inclusive of tax) must exceed after-tax labor income (inclusive of lump-sum taxes), so that some (net) capital income is allocated to consumption. This viability condition imposes a restriction on leisure that is necessary to constrain the growth rate and is important in characterizing the distributional dynamics.

The aggregate transitional dynamics for the economy are obtained by linearizing (14) around the steady state values of \tilde{z} and \tilde{l} . The stable transition path of the aggregate economy can be described by

$$z(t) = \tilde{z} + [z(0) - \tilde{z}]e^{\mu t} \quad (17a)$$

$$l(t) = \tilde{l} + \frac{a_{21}}{(\mu - a_{22})}[z(t) - \tilde{z}] \quad (17b)$$

where μ is the stable (negative) eigenvalue corresponding to the linearized dynamic system, and a_{ij} are the corresponding coefficients of the linearized matrix.¹⁷ Our numerical simulations reveal that the slope of the saddle path is negative, so that along the transition path the evolution of leisure is inversely related to that of the public-private capital ratio. Intuitively, an increase in public to private capital raises the productivity of private capital, raising the wage rate and inducing agents to increase their labor supply and to reduce their leisure.¹⁸ Finally, the consumption-private capital ratio

¹⁶ Details of these calculations are available from the authors on request.

¹⁷ Given the analytical complexity of the model, we have conducted extensive numerical simulations over the plausible ranges for all of the model's deep structural parameters to ensure saddle-point stability of the system.

¹⁸ The exception is if $\varepsilon = \varphi = 1$ (externality is fully private), so that $a_{21} = 0$ and $l(t)$ immediately jumps to \tilde{l} .

evolves according to

$$c(t) - \bar{c} = \left[\Omega_z(\bar{z}, \bar{l}) \bar{l} + \{ \Omega_l(\bar{z}, \bar{l}) \bar{l} + \Omega(\bar{z}, \bar{l}) \} \left(\frac{a_{21}}{\mu - a_{22}} \right) \right] [z(t) - \bar{z}] \quad (17c)$$

the dynamic time paths described in Eqs. (17a–17c) represent the average (mean) behavior of this heterogeneous agent economy. Since both infrastructure and private capital represent stocks that are being accumulated, we rule out instantaneous jumps in z . However, leisure, the consumption-capital ratio, and the various growth rates can respond instantaneously to new information.

4. Distributional dynamics

The fact that the aggregate economy's behavior characterized in Section 3 is independent of any distributional aspects is a consequence of the homogeneity of the utility function and the perfect aggregation that this permits. The next step is to characterize the behavior of a cross-section of agents, and to determine the evolution of that cross-section relative to that of the average (mean) agent. Specifically, we focus on the distributions of private capital (wealth), income, and welfare.

4.1. Distribution of private capital (wealth)

To derive the dynamics of the relative capital stock of individual i , $k_i \equiv K_i/K$ (the agent's relative wealth) we combine Eqs. (5) and (13). To facilitate this, it is convenient to define:

$$\Delta(z, l) \equiv (1 - \tau_w)\omega(z, l) - \tau_y(\bar{z}, \bar{l}); \Gamma(z, l) \equiv [(1 + \tau_c)\Omega(z, l) + (1 - \tau_w)\omega(z, l)] > 0$$

this enables us to express the evolution of relative wealth (capital) in the convenient form

$$\dot{k}_i(t) = -\Gamma(z, l)(l_i - \bar{l}) + [\Gamma(z, l)l - \Delta(z, l)](k_i(t) - 1) \quad (18)$$

using this notation, the viability condition Eq. (16) can be expressed as $\Gamma(\bar{z}, \bar{l})\bar{l} > \Delta(\bar{z}, \bar{l})$ implying that the dynamic Eq. (18) is locally unstable near the steady state. A key element of a stable (bounded) solution includes the steady-state to Eq. (18), which implies a positive relationship between the agent's steady state share of the private capital stock and leisure:

$$\bar{l}_i - \bar{l} = \left[\bar{l} - \frac{\Delta(\bar{z}, \bar{l})}{\Gamma(\bar{z}, \bar{l})} \right] (\bar{k}_i - 1) \quad (19)$$

thus, the transversality condition implies that an individual who in the long run has above-average private capital, given by $\bar{k}_i - 1$, also enjoys above-average leisure, i.e., $\bar{l}_i - \bar{l} > 0$.¹⁹ Using Eq. (12), this equation also yields agent i 's (constant) allocation of leisure time:

$$\pi_i - 1 = \left(1 - \frac{\Delta(\bar{z}, \bar{l})}{\Gamma(\bar{z}, \bar{l})\bar{l}} \right) (\bar{k}_i - 1) \quad (20)$$

linearizing Eq. (20) around the steady-state levels \bar{z} , \bar{l} , and \bar{k}_i , while noting Eqs. (17–19) imply

$$\dot{k}_i = \delta_1(\bar{z}, \bar{l})(\bar{k}_i - 1)[z(t) - \bar{z}] + \delta_2(\bar{z}, \bar{l})(k_i(t) - \bar{k}_i) \quad (21)$$

where $\delta_1(\bar{z}, \bar{l})$ and $\delta_2(\bar{z}, \bar{l}) > 0$ are constants defined in Appendix A. Eq. (21) highlights how the evolution of the economy-wide ratio of public to private capital affects the evolution of relative wealth, both directly, and indirectly through $l(t)$. The bounded solution to Eq. (21) is of the form

$$k_i(t) - 1 = (\bar{k}_i - 1) \left[1 + \frac{\delta_1}{\mu - \delta_2} [z(t) - \bar{z}] \right] = (\bar{k}_i - 1) \left[1 + \frac{\delta_1}{\mu - \delta_2} (z_0 - \bar{z}) e^{\mu t} \right] \quad (22)$$

setting $t=0$ in (22) gives

$$k_i(0) - 1 \equiv k_{i,0} - 1 = (\bar{k}_i - 1) \left[1 + \frac{\delta_1}{\mu - \delta_2} (z_0 - \bar{z}) \right] \quad (22')$$

Given the steady-state of the aggregate economy, and his initial endowment of relative wealth, $k_{i,0}$, Eq. (22') determines the agent's steady-state relative stock of capital, $(\bar{k}_i - 1)$, which together with Eq. (22) then yields its entire time path, $k_i(t)$ and, further, with Eq. (20) determines the agent's (constant) relative leisure, π_i .²⁰

Since all distributional variables are expressed relative to the mean, we can measure their dispersion in canonical form, by using the coefficient of variation.²¹ Given the linearity of Eqs. (22) and (22') in k_i , we can immediately transform these

¹⁹ This is consistent with various sources of empirical evidence that finds a negative relationship between wealth and relative labor supply; see for example, Holtz-Eakin et al. (1993), Cheng and French (2000), and Algan et al. (2003).

²⁰ The ranking of agents according to their wealth remains unchanged throughout the transition.

²¹ Several measures of inequality have been proposed, of which the Gini coefficient and the coefficient of variation are the most prevalent; see e.g. Atkinson (1970) and Ray (1997). Ray has enunciated four principles that desirable measures should satisfy, and which both these measures indeed meet.

equations into corresponding relationships for the coefficient of variation for the distribution of capital, which serves as a convenient measure of wealth inequality. Therefore,

$$\sigma_k(t) = \left[1 + \frac{\delta_1}{\mu - \delta_2} (z(t) - \tilde{z}) \right] \tilde{\sigma}_k, \quad (23a)$$

where $\sigma_k(t)$ denotes the coefficient of variation for relative wealth at time t , and $\tilde{\sigma}_k$ is the corresponding measure at the steady-state. Setting $t=0$ in Eq. (23a), the relationship between the initial distribution of wealth and its steady-state distribution is given by

$$\tilde{\sigma}_k = \left[1 + \frac{\delta_1}{\mu - \delta_2} (z_0 - \tilde{z}) \right]^{-1} \sigma_{k,0} \quad (23b)$$

Thus Eqs. (23a) and (23b) completely characterize the evolution of wealth inequality, given its initial distribution, $\sigma_{k,0}$, and the initial stock of the infrastructure to private capital ratio, z_0 .²²

4.2. Labor income inequality

Given that there is no heterogeneity in labor skills in our model, labor income inequality is purely driven by the distribution of hours worked by households. Wage income for the i th household relative to the mean wage income is given by

$$w_i(t) - 1 = \frac{l(t) - l_i(t)}{1 - l(t)} = \frac{l(t)}{1 - l(t)} (1 - \pi_i) \quad (24)$$

using Eq. (20), the evolution of inequality in labor income is therefore given by

$$\sigma_w(t) = \frac{l(t)}{1 - l(t)} \left(1 - \frac{\Delta(\tilde{z}, \tilde{l})}{\Gamma(\tilde{z}, \tilde{l}) \tilde{l}} \right) \tilde{\sigma}_k \quad (24')$$

where $\sigma_w(t)$ denotes the coefficient of variation of relative wage income at time t . From Eq. (24'), we see that labor income inequality is determined by (i) the evolution of the average labor–leisure choice and (ii) the steady-state distribution of relative wealth. Given the viability condition from Eq. (19), i.e., $\Gamma(\tilde{z}, \tilde{l}) \tilde{l} > \Delta(\tilde{z}, \tilde{l})$, and the steady-state distribution of wealth, an increase in average labor supply in the economy will increase labor income inequality. Since capital-poor agents allocate more time to labor than the capital-rich, an increase in average labor supply causes their wage incomes to increase at a slower rate relative to that of the capital-rich, due to diminishing returns.

4.3. Distribution of (after-tax) income

We define after-tax relative income for the i th household as

$$y_i(t) = \frac{(1 - \tau_k)rK_i + (1 - \tau_w)wK(1 - l_i(t))}{(1 - \tau_k)rK + (1 - \tau_w)wK(1 - l)} \quad (25)$$

after-tax income inequality can then be expressed as

$$\sigma_y(t) = \left[\zeta(t) + \frac{(\tau_w - \tau_k)s_k(t)}{s_k(t)(1 - \tau_k) + (1 - s_k(t))(1 - \tau_w)} (1 - \zeta(t)) \right] \sigma_k(t) \quad (26a)$$

$$\zeta(t) \equiv s_k(t) + [1 - s_k(t)] \frac{l(t)}{1 - l(t)} \left[1 - \frac{\Delta(\tilde{z}, \tilde{l})}{\Gamma(\tilde{z}, \tilde{l}) \tilde{l}} \right] \left[1 + \frac{\delta_1}{\mu - \delta_2} (z(t) - \tilde{z}) \right]^{-1} \quad (26b)$$

where $\sigma_y(t)$ denotes the coefficient of variation of relative after-tax income at time t , and $s_k(t) \equiv r(z, l)/y(z, l)$ is the equilibrium share of output received by capital. While wealth inequality, $\sigma_k(t)$, evolves gradually, the initial jump in leisure, $l(0)$, which affects short-run income inequality, $\sigma_y(0)$, through its effect on labor income inequality, implies that a structural or policy shock causes an initial jump in income inequality, after which it evolves continuously. As a result, short-run income inequality, $\sigma_y(0)$, may over (under)-shoot its long-run equilibrium, $\tilde{\sigma}_y$.

(footnote continued)

In addition, Atkinson compares the inequality rankings yielded by various measures and finds that the coefficient of variation and Gini coefficient are generally pretty close. In the light of this, given its convenience, we adopt the coefficient of variation as our inequality measure.

²² The fact that the long-run distribution depends upon the initial distribution reflects a hysteresis property resulting from the “zero root” associated with Eq. (11). This turns out to have important implications for wealth and income inequality that are explored in another context by Atolia et al. (2012).

4.4. Distribution of welfare

Economic welfare is another key indicator of the impact of government policies on national well-being, and given the unequal distribution of private wealth and income in the economy, it is important to study its distribution. Recalling the utility function Eq. (4a), the instantaneous level of welfare for individual i at time t is

$$W_i = \frac{1}{\gamma} [C_i^{-\nu} + \theta(z^{1-\varphi} l_i K)^{-\nu}]^{-(\gamma/\nu)} = \frac{1}{\gamma} [\Omega(z, l)^{-\nu} + \theta z^{\nu(\varphi-1)}]^{-(\gamma/\nu)} (l_i K)^\gamma \quad (27)$$

while the average level of instantaneous welfare is given by

$$W = \frac{1}{\gamma} [\Omega(z, l)^{-\nu} + \theta z^{\nu(\varphi-1)}]^{-\gamma/\nu} (lK)^\gamma \quad (27')$$

at each instant of time, agent i 's relative welfare remains constant, so that his intertemporal relative welfare is constant as well. Using Eq. (20) we can express relative welfare in the form

$$w_i \equiv \frac{U_i}{U} = \frac{W_i}{W} = \left(\frac{l_i}{l} \right)^\gamma = \left[1 + \left(1 - \frac{\Delta(\tilde{z}, \tilde{l})}{\Gamma(\tilde{z}, \tilde{l})} \right) (\tilde{k}_i - 1) \right]^\gamma \quad (28)$$

by applying the monotonic transformation $(w_i)^{1/\gamma} \equiv u(v_i)$, we obtain an expression for the relative welfare of individual i expressed in terms of equivalent units of wealth. The dispersion of welfare across agents is then given by its coefficient of variation, σ_u ²³:

$$\sigma_u = \left(1 - \frac{\Delta(\tilde{z}, \tilde{l})}{\Gamma(\tilde{z}, \tilde{l})} \right) \tilde{\sigma}_k \quad (29)$$

5. Fiscal policy, growth, and inequality: a numerical analysis

Given the complexity of the model, we analyze it using numerical simulations. The objective is to determine the effect of an increase in infrastructure investment by the government on growth and the various distributional measures described above. In doing so, we compare the dynamic adjustment of the economy under four alternative financing schemes, namely where the long-run increase in government investment is fully financed by a (i) lump-sum tax (τ), (ii) capital income tax (τ_k), (iii) labor income tax (τ_w), or (iv) consumption tax (τ_c). We begin with the following parameterization of a benchmark economy:

Preferences	$\gamma = -1.5, \beta = 0.04, \theta = 1.75, \nu = 0$
Production	$A = 0.6, \alpha = 0.6, \rho = 0$
Externalities	$\varphi = \varepsilon = 0.6$
Fiscal	$g = 0.05, \tau = 0.05$

The preference and production functions are non-controversial. Setting $\nu=0$ and $\rho=0$ yields the conventional case, where utility is of the constant elasticity form and production is Cobb–Douglas, so that the respective elasticities of substitution are both unity. The rate of time preference $\beta=0.04$ is standard, while setting $\gamma = -1.5$ yields an intertemporal elasticity of substitution of 0.4, which is consistent with the bulk of the empirical estimates; see Guvenen (2006). The relative weight of leisure in utility, $\theta=1.75$ implies an equilibrium value of leisure, $\tilde{l}=0.714$, which is consistent with empirical evidence from the RBC literature; see e.g. Cooley (1995). Finally, the scale parameter A is set to yield a plausible equilibrium growth rate of 2.29%.

The less familiar aspects of our parameterization concern the specification of the composite externalities in production and utility and are guided by the following considerations. For the Cobb–Douglas specification, the representative firm's production function is of the form $Y_i = A(K_i)^{1-\alpha}(L_i)^\alpha K^{\alpha\varepsilon}(K_G)^{\alpha(1-\varepsilon)}$. The conventional Romer (1986) model corresponds to $\varepsilon=1$, and for $\alpha=0.6$ implies that the external effect of the aggregate capital stock (K) is significantly more productive than is the firm's own capital (K_i). The stock version of the Barro (1990) model corresponds to $\varepsilon=0$, which with $\alpha=0.6$ yields an implausibly large output elasticity for public capital. Neither of these parameterizations is realistic. Setting $\varepsilon=0.6$, however, helps in resolving both problems. First, the firm's own capital stock is now more productive than the externality (0.40 vs. 0.36), while the elasticity of government capital is reduced to 0.24, thus placing it within the plausible range reported by Bom and Ligthart (2010). With the externality constrained in this way, we set $\varphi=\varepsilon=0.6$, since we find no compelling reason to assume that there should be any systematic difference in the construction of the two externalities in the benchmark economy. We do, however, perform a sensitivity analysis with respect to these parameters in Section 6.

²³ Eq. (29) also measures the dispersion of consumption and leisure across agents.

Table 1

A. Benchmark steady-state equilibrium, $g=0.05$, $\varepsilon=\varphi=0.6$ (composite externality), $q=s=1$				
Financing policy	\tilde{z}	\tilde{l}	\tilde{y}	$\tilde{\psi}$ (%)
Lump-sum tax-financing, $\tau=0.05$	0.531	0.714	0.243	2.29
B. Increase in government spending: aggregate and distributional effects. Benchmark specification g =from 0.05 to 0.08				
i. Steady-state aggregate effects				
Policy change	$d\tilde{z}$	$d\tilde{l}$	$d\tilde{y}$	$d\tilde{\psi}$
Lump-sum tax-financed increase in g , $d\tau=0.030$	0.259	−0.01	0.206	
Capital income tax-financed increase in g , $d\tau_k=0.075$	0.353	−0.006	0.101	
Labor income tax-financed increase in g , $d\tau_w=0.05$	0.268	0.002	0.168	
Consumption tax-financed increase in g , $d\tau_c=0.037$	0.265	−0.001	0.179	
ii. Distributional effects (short-run and long-run percentage changes) ^a				
Policy change	Wealth inequality, $d\sigma_k$		Income inequality, $d\sigma_y$	
	$d\sigma_k(0)$	$d\tilde{\sigma}_k$	$d\sigma_y(0)$	$d\tilde{\sigma}_y$
Lump-sum tax-financed increase in g	0	2.736	−2.602	4.996
Capital income tax-financed increase in g	0	3.527	−9.174	−0.149
Labor income tax-financed increase in g	0	2.805	−0.110	7.933
Consumption tax-financed increase in g	0	2.952	−3.117	4.955

^a All distributional effects are reported as percentage changes relative to their pre-shock levels: $d\sigma_j = [(\sigma_j(t) - \tilde{\sigma}_{j,0}) / \tilde{\sigma}_{j,0}] \times 100$, $j = k, y, u$.

The benchmark government spending ratio, g , is assumed to be 5% of GDP, which is roughly consistent with evidence on the rate of public infrastructure spending for most OECD countries. Table 1A summarizes the benchmark equilibrium, with an equilibrium ratio of public–private capital of 0.53 and output–private capital ratio of around 0.24.

5.1. Increase in government spending on infrastructure

We consider the effect of an unanticipated and permanent increase in g from its benchmark rate from 5% to 8% of GDP, and compare the dynamic responses under the four financing schemes noted above. In all cases we assume that the economy starts from an initial benchmark equilibrium in which government expenditure is fully financed by lump-sum taxes, and all distortionary tax rates are zero, i.e. $\tau_c = \tau_w = \tau_k = 0$, so that $g_0 = \tau_0 = 0.05$ in Eq. (10). For the distortionary taxes, we assume that the corresponding tax rate is set such that it fully finances the long-run change in government expenditure (see Table 1B). Thus, during the transition as the tax base changes, residual lump-sum tax financing must be employed to ensure that the budget remains balanced at all times.

5.1.1. Aggregate effects

Table 1B(i) shows the effect of an increase in government spending on the steady-state of the aggregate economy. In all cases, the direct stimulus to public investment causes the equilibrium ratio of public to private capital, \tilde{z} , to increase. Except when spending is financed by a tax on labor income, leisure falls in the long run, as the higher spending raises the marginal product of labor through the composite externality in the production function. In contrast, when g is financed by a tax on labor income, the time allocated to leisure increases, as the higher tax rate reduces the after-tax return on labor. But in all cases the effects are small. For all forms of financing, the productive benefits of public capital spending and the consequent private capital accumulation ensure that the equilibrium growth rate increases. They dominate any negative tax effects, although in the case of capital income tax-financing with its direct adverse impact on the return to capital, the positive growth effects are small. Overall, the differential impacts on growth, leisure and the ratio of public to private capital reflect the varying degrees of distortions associated with the different tax rates.²⁴

5.1.2. Distributional effects

Table 1B(ii) reports the short-run (instantaneous) and long-run effects on wealth and income inequality. All these effects are calculated as percentage changes in the coefficient of variation relative to its pre-shock steady-state level, i.e.,

$$d\sigma_j(t) = [(\sigma_j(t) - \tilde{\sigma}_{j,0}) / \tilde{\sigma}_{j,0}] \times 100, \quad j = k, y, u.$$

²⁴ We do not discuss the transitional adjustment paths for the aggregate economy, as these are well-known from the public investment-growth literature; see Turnovsky (1997) for an early example. The results are available upon request.

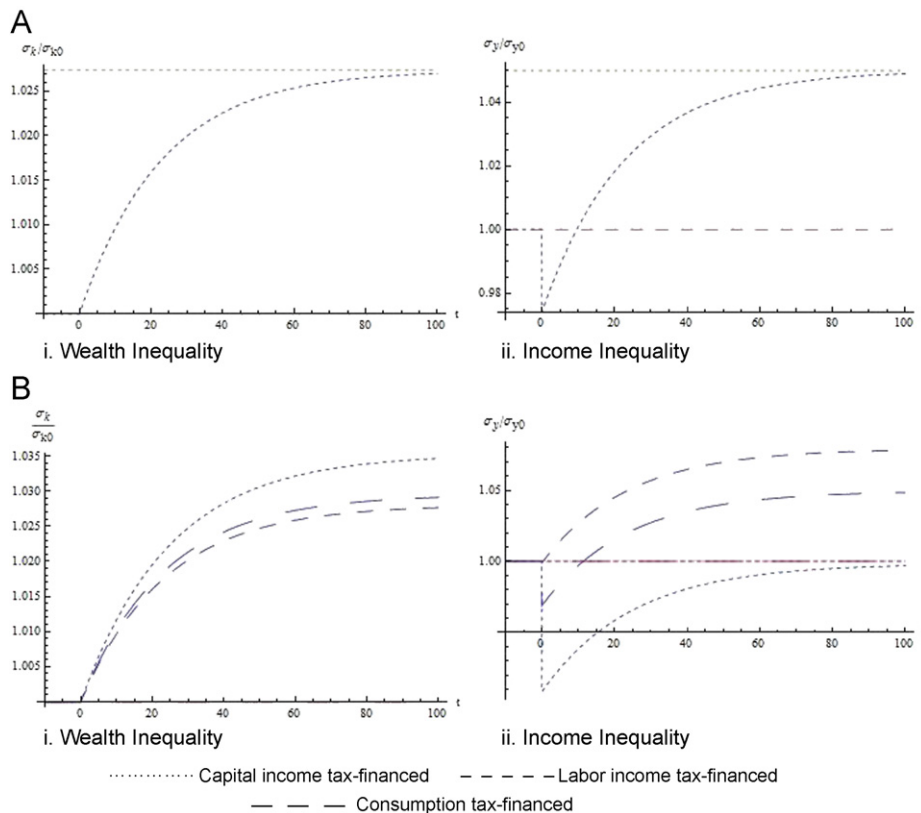


Fig. 1. Increase in government spending, g , from 0.05 to 0.08. Benchmark case: $s=1$, $q=1$, $\varphi=\varepsilon=0.6$. (A) Lumpsum tax-financed increase in spending. (B) Distortionary tax-financed increase in spending.

row 1 reports the case where the increase in government spending is financed by a lump-sum tax. Being non-distortionary, this policy isolates the pure effect of government spending on the distributional measures. Since the stock of private capital, its initial distribution, and the stock of public capital are initially given, wealth inequality does not change on impact. It does so only gradually, increasing by about 2.7% in the long run. In the short run, income inequality declines by 2.6% relative to its pre-shock level. However, over time this decline is reversed, with long-run income inequality increasing by about 5%, thus highlighting how government investment generates a sharp intertemporal trade-off for the distribution of income.²⁵

The result that the increase in long-run income inequality is greater than the corresponding increase in wealth inequality indicates that labor income inequality also increases over time. Using our benchmark parameterization and the fact that for the Cobb–Douglas case factor shares remain constant over time, we calculate that while wealth inequality increases by 2.7% in the long-run, labor income inequality rises by about 8.45%. In terms of relative importance, this implies that about 68% of the increase in long-run income inequality can be attributed to the increase in labor income inequality.²⁶

Fig. 1A illustrates the dynamic responses of the distributions of wealth and income to a lumpsum tax-financed increase in government spending. During the transition, the increasing stock of public capital raises the marginal product of private capital and encourages private capital accumulation. Since private capital is unequally distributed in the economy, capital-rich agents experience a larger increase in their income from capital investment than do capital-poor agents. Wealth inequality therefore increases in transition to the long-run. By raising the expected long-run return to capital and labor, the higher government spending also has a productivity impact on labor supply, causing the real wage to rise and labor supply to increase (not shown). In the short run, since capital-poor agents supply more labor relative to the capital-rich, their higher wage income compresses the dispersion of labor supply, thereby leading to an instantaneous decline in income inequality. In transition, however, this trend is reversed due to two reinforcing effects. First, the increase in wealth inequality increases the dispersion of income. Second, as the productivity benefits of the gradually accumulating stock of

²⁵ The short-run decline in income inequality following an increase in government spending on infrastructure is consistent with the findings of Wolff and Zacharias (2007), who document an inverse relationship between public expenditures and income inequality in the U.S. in 1989 and 2000. It should be noted, however, that their study does not examine the long-run consequences of government spending, and also does not distinguish between government consumption and investment spending.

²⁶ Atkinson et al. (2011) report that the rapid rise of incomes of the top 1 percent earners in China and India in the last thirty years has been driven mainly by an increase in their share of wage income.

infrastructure are realized along the transition path, average labor supply increases. Since capital-poor agents work more than the capital-rich, their labor incomes increase at a slower rate than those of the capital-rich, due to diminishing returns. This tends to widen the dispersion of labor income over time, consequently increasing income inequality.

Table 1B(ii) (rows 2–4) and Fig. 1B report the distributional responses to the government spending shock when financed by the three distortionary taxes. The results here depend on the interaction between two counter-acting effects along the transitional path. On the one hand, the higher public spending tends to increase the productivity of both capital and labor, thereby affecting the labor–leisure choice and raising average factor incomes. On the other hand, each distortionary tax permanently reduces the after-tax return on the variable it impinges on, which in turn has a dampening effect on productivity and consequently, the labor–leisure allocation decision.

Long-run wealth inequality increases in all three cases, with the largest increase of 3.5% arising when the spending is financed by taxing capital income, one effect of which is to reduce the after-tax return on capital and the average capital stock. This, combined with the higher spending on the public good, leads to a large increase in the ratio of public to private capital, which more than offsets the decline in after-tax return on capital. Again, capital-rich agents experience higher long-run returns on capital than the capital poor, and wealth inequality increases. In the case of the labor tax, the same effect now operates through the after-tax return on labor. The effects of the consumption tax are qualitatively similar to that of the lump-sum tax-financing case.

Capital tax-financing reduces income inequality both in the short run and the long run, with short-run inequality declining more than in the long-run. The long-run decline in income inequality under capital tax-financing reflects the redistributive effects of the financing policy, since wealth is the primary source of inequality in this economy. For spending financed by a labor income tax, income inequality increases after a small initial decline. Labor tax-financing policy reduces after-tax labor income and increases the dispersion of labor supply which, when combined with the higher wealth inequality, increases income inequality in the long-run. Consumption tax-financing works essentially like the lumpsum tax, with the dynamics for both being identical.

5.2. The growth–income inequality relationship

Table 2 reports the short-run and long-run relationships between growth and income inequality resulting from the policy shocks considered in Section 5.1. Whether this relationship is positive or negative is indicated by the signs in the

Table 2

Increase in government spending: the growth–inequality relationship^a. g =from 0.05 to 0.08. $q=s=1$.

A. Composite externality in utility and production, $\varepsilon=\varphi=0.6$ (benchmark case)				
Policy change	Short run change (%)		Long run change (%)	
	$d\psi(0)$	$d\sigma_y(0)$	$d\tilde{\psi}$	$d\tilde{\sigma}_y$
Lump-sum tax-financed increase in g	0.129	−2.602	0.206	4.996
Capital income tax-financed increase in g	0.044	−9.174	0.101	−0.149
Labor income tax-financed increase in g	0.096	−0.110	0.168	7.933
Consumption tax-financed increase in g	0.106	−3.117	0.179	4.955
B. Public good externality in utility function: $\varphi=0$, $\varepsilon=1$				
Policy change	Short run change (%)		Long run change (%)	
	$d\psi(0)$	$d\sigma_y(0)$	$d\tilde{\psi}$	$d\tilde{\sigma}_y$
Lump-sum tax-financed increase in g	−0.107	−4.964	0.025	3.373
Capital income tax-financed increase in g	−0.215	−11.631	−0.102	−2.199
Labor income tax-financed increase in g	−0.136	−2.511	−0.010	6.210
Consumption tax-financed increase in g	−0.128	−5.468	−0.0002	3.315
C. Public good externality in production function: $\varphi=1$, $\varepsilon=0$				
Policy change	Short run change (%)		Long run change (%)	
	$d\psi(0)$	$d\sigma_y(0)$	$d\tilde{\psi}$	$d\tilde{\sigma}_y$
Lump-sum tax-financed increase in g	0.409	−2.287	0.446	8.392
Capital income tax-financed increase in g	0.377	−9.087	0.386	4.060
Labor income tax-financed increase in g	0.375	0.113	0.408	11.531
Consumption tax-financed increase in g	0.385	−2.938	0.419	8.479

^a All distributional effects are reported as percentage changes relative to their pre-shock levels: $d\sigma_j = [(\sigma_j(t) - \bar{\sigma}_{j,0}) / \bar{\sigma}_{j,0}] \times 100$, $j = k, y, u$.

table. We also examine the sensitivity of this relationship to the magnitude of the two sources of externalities in our model, namely the composite externality in the utility and production functions. In addition to the benchmark case, ($\phi = \varepsilon = 0.6$), we consider two polar cases: (i) the only externality is a public good in the utility function ($\phi = 0, \varepsilon = 1$), and (ii) the only externality is a public good in the production function. The time paths followed by the growth rate and income inequality are illustrated in Fig. 2.

Overall, our findings underscore the ambiguity in the direction of the growth–inequality relationship that is characteristic of recent empirical studies. As Fig. 2 and Tables 2A–C indicate, the transition paths of GDP growth and income inequality are positively correlated in all cases. However, the short-run and steady-state relationships depend critically on (i) the composition of the different externalities in terms of their private capital–public capital mix, (ii) the tax policy used to finance government investment, and (iii) the time horizon, namely short run or long run. For example, in the presence of the composite externality in both the utility and production functions ($\phi = \varepsilon = 0.6$, Table 2A), growth and inequality are inversely related in the short run, with growth increasing and inequality declining. However, this correlation is reversed in the long run, except for the case of capital income tax-financing, where its redistributive effects reduce long-run income inequality. In the case where the public good externality enters only the utility function ($\phi = 0, \varepsilon = 1$, Table 2B), thereby approximating the presence of pure government consumption, growth and inequality are positively correlated in the short run, where they decline together, while in the long-run this correlation depends on the underlying financing policy. In this case, since government spending impinges only on utility, leisure increases in equilibrium, thereby lowering labor supply and the return to capital, and consequently, the growth rate. Finally, when the public good externality enters

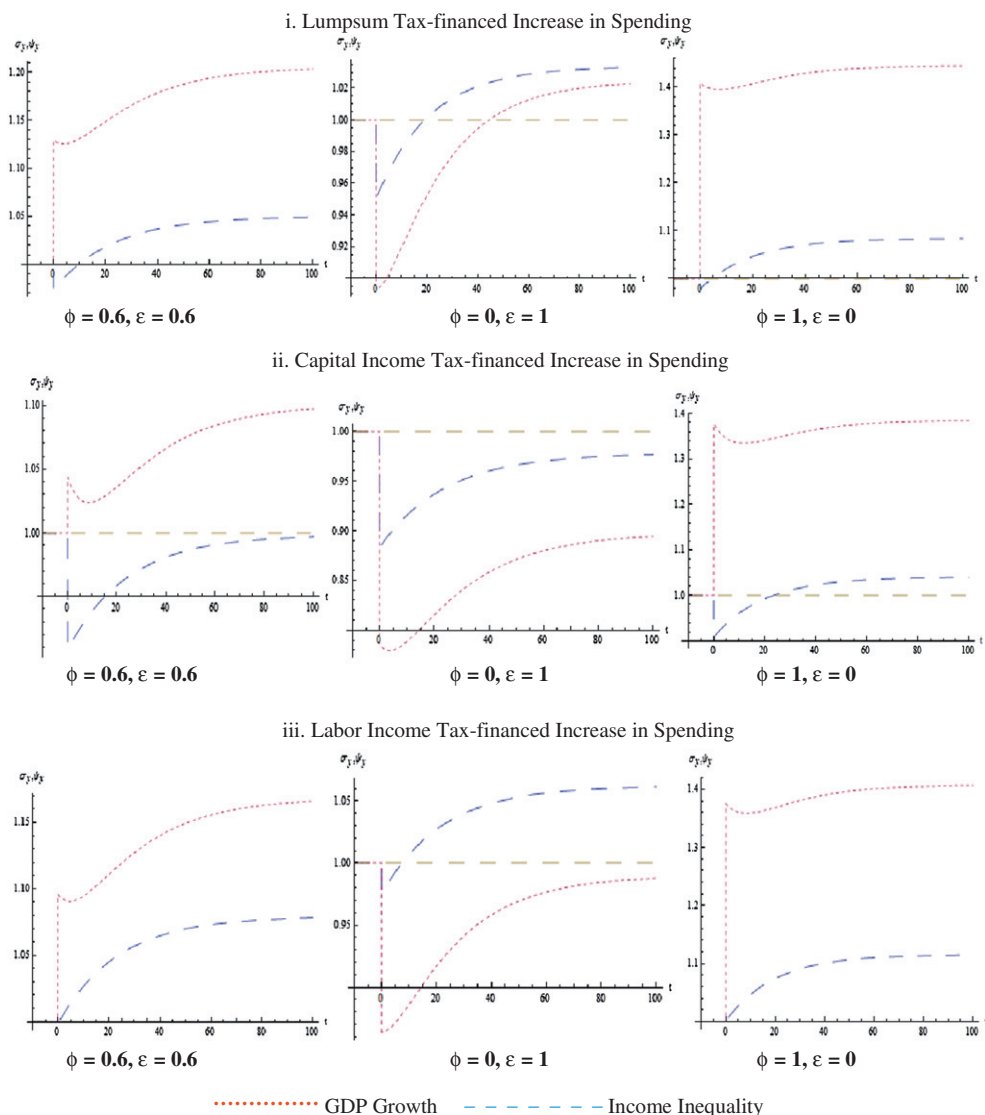


Fig. 2. The growth–income inequality relationship. Sensitivity to externality parameters (ϕ, ε).

Table 3Increase in government spending: trade-off between aggregate welfare and its dispersion.^a $g=0.05$ to 0.08 . $q=s=1$.

A. Composite externality in utility and production, $\varepsilon=\varphi=0.6$ (benchmark case)		
Policy change	$d\tilde{W}$ (%)	$d\tilde{\sigma}_u$ (%)
Lump-sum tax-financed increase in g	4.012	5.415
Capital income tax-financed increase in g	1.790	3.620
Labor income tax-financed increase in g	3.139	2.996
Consumption tax-financed increase in g	3.398	2.946
B. Public good externality in utility function: $\varphi=0$, $\varepsilon=1$		
Policy change	$d\tilde{W}$ (%)	$d\tilde{\sigma}_u$ (%)
Lump-sum tax-financed increase in g	6.830	5.773
Capital income tax-financed increase in g	5.041	3.872
Labor income tax-financed increase in g	5.930	3.312
Consumption tax-financed increase in g	6.198	3.299
C. Public good externality in production function: $\varphi=1$, $\varepsilon=0$		
Policy change	$d\tilde{W}$ (%)	$d\tilde{\sigma}_u$ (%)
Lump-sum tax-financed increase in g	3.384	6.300
Capital income tax-financed increase in g	1.227	4.929
Labor income tax-financed increase in g	2.554	3.926
Consumption tax-financed increase in g	2.801	3.902

^a The dispersion of welfare is reported as percentage change relative to its pre-shock level: $d\tilde{\sigma}_u = [(\tilde{\sigma}_u - \tilde{\sigma}_{u,0})/\tilde{\sigma}_{u,0}] \times 100$.

only the production function ($\varphi=1$, $\varepsilon=0$, Table 2C), thereby approximating pure government investment, the correlation between growth and inequality is negative in the short-run (growth increases and inequality falls, except for labor tax-financing where short-run inequality increases slightly), and positive in the long-run (both growth and inequality increase).

5.3. Average welfare and its dispersion

While evaluating the effects of public policies, its consequences for welfare are of critical importance. With heterogeneous agents, we consider two elements, namely average welfare (of the mean agent) and its dispersion (welfare inequality) as measured by Eq. (29). The results are summarized in Table 3 for the four modes of financing and for three alternative compositions of the externalities.

In all cases we find that increasing government investment raises average welfare, but also increases welfare inequality. In the benchmark case ($\varepsilon=\varphi=0.6$) we see that while lump-sum tax financing yields the largest increase in average utility (4.01%), it also generates the largest increase in welfare inequality (5.42%). To the extent that the policymaker is concerned with this tradeoff, he may evaluate the financing options in terms of increased inequality per unit of average welfare gain. On this basis consumption tax-financing would be the preferred option, followed by labor income tax-financing, with capital income tax-financing being the worst. This ranking continues to apply in the polar cases as well.

The other point to observe is that the increase in welfare inequality per unit of average welfare gain is highly sensitive to the structure of the externality, with the tradeoff between average welfare and its dispersion being much worse when $\varphi=1, \varepsilon=0$. This is because with the externality being only in utility, this generates the biggest dispersion in leisure, which was seen in Eq. (29) to be the ultimate driving force behind welfare inequality.

6. Sensitivity analysis

Given the complex nature of the interactions in our model, it is important to examine the robustness of our results to changes in the specification of the key parameters. In this section, we briefly summarize the results of a sensitivity analysis, conducted with respect to three aspects of the model's structure: (i) the relative magnitude of the composite externality parameters, φ and ε , (ii) the intratemporal elasticity of substitution between private capital and effective labor in the production function, $s=1/(1+\rho)$, and (iii) the intratemporal elasticity of substitution between consumption and leisure in the utility function, $q=1/(1+\nu)$.²⁷

First, we have considered all possible comparisons between ε and φ , i.e., $\varepsilon > \varphi$, $\varepsilon < \varphi$, and $\varepsilon = \varphi$, ranging between 0 and 1 and find that our basic qualitative results from Table 1 remain robust to these variations in the externality parameters. Second,

²⁷ To keep the discussion brief, we do not report the detailed results; they are available upon request.

with respect to the elasticity of substitution between capital and effective labor in the production function, we consider three cases, i.e., $s=0.4$, 0.8 , and 1.2 . Again, the patterns observed in our benchmark experiments remain unchanged, except for a decline in wealth inequality when the elasticity of substitution is low, i.e., $s=0.4$. With a low elasticity of substitution, a large increase in private investment is required for any given increase in public investment. This reduces the proportionate return on private capital (due to diminishing returns) and, since the capital-rich invest more than the capital poor, also reduces wealth inequality over time. Finally, we consider changes in the intratemporal elasticity of substitution between consumption and leisure in the utility function by varying q over the values 0.4 , 0.8 , and 1.2 . Once again, the patterns observed in our benchmark experiments remain unchanged.

7. Conclusions

This paper has examined an important, but neglected policy issue, namely the nature of the growth–inequality relationship arising from government investment policies. Two broad sets of issues have been analyzed: (i) The effects of pro-growth policies, specifically government investment in infrastructure and its financing, on wealth and income inequality, and (ii) the trade-offs generated by these policies between average welfare and its dispersion across agents.

These questions have been studied using a general equilibrium growth model with heterogeneous agents, where the heterogeneity is due to the initial endowments of private capital. Our results suggest that government spending on public capital will increase wealth inequality over time, irrespective of how it is financed. The consequences for income inequality, however, are sensitive to how public investment is financed and may be characterized by sharp intertemporal tradeoffs, with income inequality declining in the short run, but increasing over time. This underscores the point that pro-growth policies may not be effective at reducing inequality. The growth–inequality relationship is shown to depend critically on the relative magnitude of externalities, underlying financing policies, and the time period of consideration. Finally, we show that though public investment improves average welfare, it also causes an increase in its dispersion. These results are generally robust to variations in the economy's key structural parameters.

The analytical framework in this paper can be readily extended to examine the distributional consequences of other important public policy issues, such as privatization and pricing of infrastructure goods, different types of public investment, such as education, healthcare, etc., and foreign aid programs. Our results on the trade-offs between changes in average welfare and its dispersion raise the important issue of optimal government spending in a heterogeneous agent economy. Finally, we note that the mechanism through which the labor–leisure choice interacts with private and public capital is critical for the dynamics of growth and inequality. While we have highlighted a specific channel through which this interaction occurs, there may be other plausible ones with different implications: for example, where time allocated to leisure is spent on improving the agent's health or educational status, or where infrastructure investment may augment the skill level of workers. All these represent interesting areas of research.

Appendix A

A1. The evolution of leisure is given by Eq. (14b):

$$\frac{\dot{l}}{l} = \frac{H(z,l)}{J(z,l)}$$

where,

$$H(z,l) \equiv (1-\tau_k)r(z,l) - \beta - (1-\gamma)\frac{\dot{K}}{K} + \left\{ \frac{\theta[z^{-(1-\varphi)}\Omega]^v(v+\gamma)(1-\varphi)}{1+\theta[z^{-(1-\varphi)}\Omega]^v} - \left[\frac{(1-\gamma)+(1+v)\theta[z^{-(1-\varphi)}\Omega]^v}{1+\theta[z^{-(1-\varphi)}\Omega]^v} \right] \frac{\Omega_z z}{\Omega} \right\} \frac{\dot{z}}{z},$$

$$J(z,l) \equiv 1-\gamma + \left[\frac{(1-\gamma)+(1+v)\theta[z^{-(1-\varphi)}\Omega]^v}{1+\theta[z^{-(1-\varphi)}\Omega]^v} \right] \frac{\Omega_l l}{\Omega},$$

and \dot{K}/K and \dot{z}/z are given by Eqs. (13) and (14a), respectively.

A2. The linearized coefficients corresponding to the dynamic system Eqs. (14) and (17) are:

$$a_{11} \equiv gy_z - [(1-g)y_z - \Omega_z]z - [(1-g)y - \Omega_l]l, \quad a_{12} \equiv gy_l - [(1-g)y_l - \Omega_l l - \Omega]z$$

$$a_{21} \equiv \left\{ (1-\tau_k)r_z - (1-\gamma)[(1-g)y_z - \Omega_z]l + \left(\frac{\Phi(v+\gamma)(1-\varphi)}{1+\Phi} + \left[\frac{(1-\gamma)+(1+v)\Phi}{1+\Phi} \right] \frac{\Omega_z z}{\Omega} \right) \frac{a_{11}}{z} \right\} \frac{l}{J}$$

$$a_{22} \equiv \left\{ (1-\tau_k)r_l - (1-\gamma)[(1-g)y_l - \Omega_l l - \Omega] + \left(\frac{\Phi(v+\gamma)(1-\varphi)}{1+\Phi} + \left[\frac{(1-\gamma)+(1+v)\Phi}{1+\Phi} \right] \frac{\Omega_z z}{\Omega} \right) \frac{a_{12}}{z} \right\} \frac{l}{J}$$

and $\Phi \equiv \theta[z^{-(1-\varphi)}\Omega]^v$. The system will be locally saddlepoint stable if and only if $a_{11}a_{22} - a_{12}a_{21} < 0$.

A3. In Eq. (21), the equation of motion for relative wealth is given by

$$\dot{k}_i = \delta_1(\tilde{z}, \tilde{l})(\tilde{k}_i - 1)[z(t) - \tilde{z}] + \delta_2(\tilde{z}, \tilde{l})[k_i(t) - \tilde{k}_i]$$

where,

$$\delta_1(\tilde{z}, \tilde{l}) \equiv \frac{1}{\Gamma(\tilde{z}, \tilde{l})} (A(\tilde{z}, \tilde{l})\Gamma_z(\tilde{z}, \tilde{l}) - A_z(\tilde{z}, \tilde{l})\Gamma(\tilde{z}, \tilde{l})) + \left(\frac{A(\tilde{z}, \tilde{l})}{\Gamma(\tilde{z}, \tilde{l})} (\Gamma(\tilde{z}, \tilde{l}) + \Gamma_l(\tilde{z}, \tilde{l})\tilde{l}) - A_l(\tilde{z}, \tilde{l}) \right) \left(\frac{a_{21}}{\mu - a_{22}} \right), \text{ and } \delta_2(\tilde{z}, \tilde{l}) \equiv \Gamma(\tilde{z}, \tilde{l})\tilde{l} - A(\tilde{z}, \tilde{l}) > 0.$$

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