# Institutional Development, Technology Adoption and Redistribution: A Political Economy Perspective

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Abstract

We examine technology adoption and growth in a political economy framework where two alternative mechanisms of redistribution are on the menu of choice for the economy. One of these is a lump-sum transfer given to agents in the economy. The other is in the form of expenditure directed towards institutional reform aimed at bringing about a reduction in the cost of technology adoption in the presence of uncertainty. The choice over these mechanisms is examined under three alternative approaches to collective decision making. In the first setting, voting takes place to determine the proportion of revenue allocated to adoption-cost-reducing institutional expenditure. In the second setting, the government chooses this proportion to maximize a 'Benthamite' social welfare function, i.e. the sum of utilities of agents in the economy. The third setting applies the Rawlsian social welfare function, which is the most "egalitarian" in that this proportion is chosen to maximize the minimum level of utility attained in the heterogeneous agent economy. We find that the extent of uncertainty, working through the political economy mechanism, has a *positive* impact on long run average wealth levels in the economy in all settings. The voting mechanism leads to the fastest transition to sustained balanced growth in all cases, while the slowest transition is experienced in the case of the Rawlsian economy. Expenditures on institutional development are higher in the voting and Benthamite economies relative to the Rawlsian economy. All economies converge to the same inequality and growth rates in the long run. Transitional inequality, however, is highest in the Rawlsian framework.

## 1. Introduction

Central to the literature on political economy macroeconomics is the recognition that policies and institutions are determined by politico-economic influences. This *endogenous* nature of policies is highlighted in models that consider conflict over a policy parameter such as the tax rate on capital (as in Alesina and Rodrik 1994), the inflation rate (as in Huffman 1997, Albanesi 2007 and Dolmas et. al 2000), or the policy on social security (such as Tabellini 2000). Conflict over the policies arises due to the presence of inequality, which in turn influences macroeconomic outcomes through a desire for redistribution. Another strand within this literature focuses on policies that are the key to the process of development, such as those enabling the adoption of modern technologies. In this literature, conflict arises as some agents have vested interests in existing technologies, and suffer economic losses when new technologies are adopted (as in Krusell and Rios-Rull, 1996 and Acemoglu and Robinson 2000), or losses in political power (as in Acemoglu and Robinson 2002).

Common to the above mentioned papers is the fact that political conflict arises over a single dimension of policy, such as tax rates, social security or technology adoption. In this paper, however, we recognize the possibility of conflict arising due to the presence of several competing mechanisms of redistribution and growth on the menu of choice of agents in an economy, with each agent or groups of agents impacted differently, depending on the mechanism in question. This can lead to conflict over the *instrument* of policy that is used for redistribution and development. Furthermore, there are several institutional arrangements of collective decision making that may be used to resolve this conflict, which could also lead to different outcomes for an economy.

The aim of this paper, therefore, is to take an exploratory step in the direction of addressing such issues in the context of technology adoption and uncertainty. We construct an overlapping-generations economy with inequality in wealth, in which intra-generational redistribution can be achieved through two instruments of policy. One instrument is a *direct* mechanism of redistribution, achieving it through a lump-sum transfer to all agents in the economy, which is funded via a linear tax on the wealth/resources of agents. The second instrument, aimed at cost-reducing institutional development that facilitates technology adoption in the presence of risk and uncertainty, must also be financed through the taxation system. Conflict arises over the proportion of tax revenues that may be allocated to each of these instruments.

The choice of this proportion is then examined under three different mechanisms of collective decision making. In the first scenario, this proportion is determined through a majority voting process. In the second setting we have a "planned economy" whereby the government in any period chooses this proportion to maximize a 'Benthamite' social welfare function, which is the sum of expected lifetime utilities of all agents born in that period. The third setting involves another planned economy in which a government chooses the proportion devoted to institutional development by maximizing a 'Rawlsian' 'maximin' social welfare function; this entails maximizing the utility of the worst-off agent in the generation born in that period.[1,2]

In part, the motivation for considering the above mentioned paradigms of social choice stems from two strands of empirical literature, one which examines the link between *democracy and development*, and another which examines the link between *redistribution and development*. In both strands of literature the evidence on the link in question is inconclusive. (See, for example Persson and Tabelleni 2006 for a discussion of democracy and development, and the survey on redistribution and growth by Zweimuller 2000). This is understandable given the wide spectrum of institutional settings observed in world economies, which renders the measurement of concepts such as 'democracy' and 'redistribution' a challenging task. The paradigms we consider give us a frame of reference or lens to interpret the literature. For example, the voting model captures a perfectly functioning or idealized notion of a 'democracy' while the two planned economies are stylized, idealized versions of real world planned economies with different objectives. World economies may arguably be interpreted as falling "in-between" pairs of these stylized settings in terms of their process of collective decision making. For example, one can have a democracy with an emphasis on social planning, and socialist economies with a decentralized, market based economic policies.[3]

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[1] Note that policies chosen in the planned economies described here are not necessarily "optimal policies" in the sense described in the overlapping generations literature. For a discussion of optimality in the context of overlapping generations models see de la Croix and Michel (2002). Here we borrow social welfare functions from the social choice and welfare literature applied in the context of a government that exists for a single period and is forward looking only to the extent of considering the collective welfare of a generation of agents over their lifetime.

[2] For a discussion of Benthamite and Rawlsian social welfare functions see d'Aspremont and Gevers (2002) and references therein.

[3] For example, China is not a democracy, and yet has experienced shifts in institutional structure, particularly at the local government level where democratic processes such as elections are in place. (See Mohanty, 2007). India, in early stages of its post-colonial development had, on the other hand, a strong emphasis on social planning.

The inconclusive nature of the redistribution-and-growth discussion also justifies considering political economy underpinnings stemming from conflict over competing mechanisms of redistribution. Furthermore, this is a more realistic context in which barriers to technology adoption can arise. For example, historically there are relatively few instances in which technological change has been blocked by economic agents (Acemoglu and Robinson 2000). However, as inferred from the voluminous redistribution-and-growth literature, and policy debates in various countries, trade-offs between different mechanisms of redistribution arise frequently in the context of economic reform.

While there are typically many forms of redistributive expenditures that can be made with a government's revenue, a simple starting point conceptualizing this idea is the case of two competing mechanisms. We therefore consider two types of mechanisms, one which is a *direct* transfer of resources from the rich to the poor, and another which is *indirect*, such as revenue spent on institutional development that eventually achieves redistribution and growth *via* a reduction of costs incurred in adopting high-return technologies associated with risk. In a dynamic context, both these mechanisms impact on growth, which leads to further redistribution given a larger "size of cake" to be divided among economic agents in subsequent periods of development.

To characterize the idea of technology adoption, we have two technologies in our model, and both are characterized by risk. However, the second technology offers alleviation of risk at a fixed cost, which we interpret as the expense associated with entering a financial intermediary system whereby the pooling of risks allows for a form of insurance in the event an unfavourable shock. The presence of uncertainty in our model adds another, previously unexplored yet relevant dimension in the political economy literature on technology adoption. There are, for example, several empirical studies that emphasize the presence of risk and uncertainty as a barrier to technological change. (See, for example, Dercon and Christiansen 2011). However, the theoretical literature has devoted limited attention to this issue, particularly in a political economy context. While there are a large number of models that focus on uncertainty and technology adoption in the context of a microeconomic framework (see the survey of Hoppe, 2002) the macroeconomic literature has typically focussed on other barriers to technology adoption, such as institutional or skill-specific fixed costs (Greenwood and Yorukoglu 1997;Parente and Prescott, 1994) or politico-economic barriers that arise in the absence of uncertainty (Krusell and Rios-Rull, 1996; Acemoglu 2000; Desmet and Parente 2013).

The results of our model, both analytical and numerical, show that uncertainty interacts with the political economy aspects in interesting ways. We have "uncertainty driven growth" similar to Oikawa (2010), although the mechanism of our paper is different. Essentially, uncertainty interacts with the political economy mechanism by creating a desire for redistribution in the form of institutional development facilitating the reduction of costs associated with risky technology adoption. In all settings considered we find uncertainty facilitates faster adoption as well as *diffusion* of technologies. We interpret 'diffusion' to have occurred at the point where institutional development has taken place to the extent that no further redistributive revenues are allocated to it, and the economy has converged to the sustained, balanced growth path.

Preferences in our model are not single-peaked; however, we are able to characterize the political equilibrium in the case of the voting mechanism analytically and show that the median voter is pivotal. While initial conditions are identical in the "democracy" as well as the planned economies[4], as are the long run outcomes such as average growth rates and inequality, there are some striking differences in the transitional dynamics and the timing of convergence to the balanced growth path. Typically the "best" outcomes occur in the democracy, in the sense that technology diffusion and transition to the balanced growth path is at least as fast or faster than the planned economies, with average long run wealth levels being at least as high or higher than in planned economies. Transitional inequality in the democracy, however, is at least as high or higher in the Benthamite economy. Interestingly, the 'egalitarian' Rawlsian framework produces the highest transitional inequality and the slowest adoption and diffusion of technology, leading to the slowest transition to the balanced growth path.

The intuition for this seemingly paradoxical result is as follows. In the initial stages of transition, preferences of most agents are in favour of redistribution in the form of the direct lump-sum transfer, since a large proportion of the agents are poor and unable to access the

[4] Note, again, that we are using the label "democracy" for ease of reference. As mentioned above world economies with a focus on planning can also be democratic, and our labels "Benthamite" and "Rawlsian" are suggestive of the approach to implementing reform rather than a setting that is necessarily totalitarian in scope.

better technology regardless of the redistribution that takes place. The Rawlsian economy typically favours the poorest agent, even when the distribution shifts over time and the majority prefer redistribution via the institutional development expenditure. This slows down the adoption and diffusion process, Since wealth levels of richer agents are rising relatively slowly, the "size of the cake" to be redistributed is smaller. This means redistribution on the transition path in the Rawlsian economy is lower than that of the democracy, in which the median agent's preference is pivotal. The Benthamite economy, on the other hand, either favours the median agent or the richer agents, given its preference for redistribution that maximizes the *sum* of utilities of agents. This can translate into either lower or equal average wealth levels relative to the democracy.

The remainder of the paper is organized as follows. Section 2 describes the framework and presents analytical results. Section 3 presents a numerical illustration of the theory discussed in the previous section, and some additional results that are difficult to characterize analytically. Section 4 concludes, and proofs of results from Section 2 are presented in the Appendix.

## 2. The Economic Environment.

We consider a two-period overlapping-generations economy with *N-agents* whose wealth holdings are heterogeneous. A new generation is born every period and time is discrete, with $t$ = 0, 1, 2,..... Each agent is born with a unit of unskilled labour endowment that can earn them a subsistence wage $\overline{w}$. Each agent $i$ born in period $t$ also inherits wealth $W_{it}$ from their parents in the form of bequests.

The economy has two technologies, one subject to high risk (hereafter referred to as Technology B) and another, that is only accessed through financial intermediaries, who are able to minimize the risk by pooling risks of all agents (henceforth Technology F). The total return on Technology B has two components and is given by $\vartheta_t = \eta + \varepsilon_{i,t}$, where $\eta > 0$ is a time-invariant and non-stochastic component and $\varepsilon_{i,t}$ is is a shock experienced by agent $i$ in time period t. In what follows, however, we supress the agent-specific subscript in our notation, given that all the variables our analysis below refers to a specific agent, unless otherwise specified. The only exceptions apply to the economy-wide average level of wealth, indicated by $\overline{W}_t$, or functions of this variable such as government revenues, per-capita transfers to agents, or aggregate expenditures of any kind which vary with time but are not agent-specific.

If the agent faces a bad shock, and this occurs with the probability $p$, then $\varepsilon_t = \varepsilon_l < 0$, while if the agent faces a good shock $\varepsilon_t = \varepsilon_h > 0$. We assume that $E[\varepsilon_t] = 0$ and $|\varepsilon_l| = |\varepsilon_h| < \eta$. The return on Technology F is similar to that of Technology B when the agent faces a good shock i.e. $\vartheta_t = \eta + \varepsilon_h$. However, when the agent faces a bad shock, the return on Technology F is $\phi$ where $\eta + \varepsilon_l < \phi < \eta$.

This modelling approach is somewhat similar to that of Townsend and Ueda (2006, 2010). As in those studies, agents who decide to use financial intermediaries deposit all their wealth with financial intermediaries. However, we assume that agents cannot borrow to adopt a certain technology. Rather, financial intermediaries invest on behalf of all the agents who deposit funds with them and offer the returns as described above, depending on the type of shock that an agent faces. Financial intermediaries charge a once-off fixed entry fee $\psi > 0$. This fee implicitly represents the registration and other fees that financial intermediaries incur including any mark-up they charge on customers. Thus if an agent uses financial intermediaries, his/her return at any time $t$ is given by $R(\vartheta_t) = \max(\vartheta_t, \phi)$.

There is also a government in the economy. The government supervises the financial intermediaries.[5] The government raises its revenue by levying a constant tax rate of $\tau$ on the heterogeneous agents' total endowment. The distribution of the agents' total endowment is described by a density function $f(W)$ with support $(0, \kappa)$. The total revenue that the government raises in any period $GR_t$ is described by:

$$GR_t = \tau\left(\int_0^{\kappa} \left[W f(W)\, dW\right]\right) = \tau \overline{W_t} \tag{1}$$

The government then uses a proportion $g_t = \alpha\tau\overline{W_t}$ of the funds to reduce the cost associated with registering a financial intermediary and to fund its regulatory activities. The latter cost may, for example, include things such as the cost of training a financial regulator, engaging in research and other activities aimed at improving the financial system. Thus $\psi$ is decreasing in

[5] We assume that there are extortionist elements in the financial system that would charge exorbitant fees without appropriate supervision. Note that we do not explicitly model financial regulation.

$g_t$ which in turn depends on *α*. The remainder of the revenue $tr_t = (1-\alpha)\tau\overline{W_t}$ is given to all the young agents in the form of a lump-sum transfer. It is this competing mechanism of re-distribution that underpins the political economy results of our paper.[6]

We assume that the functional form for $\psi\,(g)$ satisfies the following properties:

*(i)* $\psi'(g) < 0\,; \psi''(g) \geq 0.$

(ii) $\psi\,(g)_{g\to\infty} = 0$

A form which satisfies the above, and is used to derive our results is given by: $\psi\,(g_t) = \left(\frac{\overline{\psi}}{(1+g_t)}\right)$, where $\psi\,(0) = \overline{\psi}$.

We consider three approaches to collective decision making regarding the value of α. The first case is a 'democracy' whereby agents vote on their preferred value of α, and the majority rule is used to decide the value of α that will be implemented. In the second case, the government uses a Benthamite social welfare function, and the value of α that maximizes this function is chosen. In the third case the government uses the Rawlsian social welfare function which maximizes the minimum of the utilities across all agents in the economy.

We assume that the tax rate τ is exogenously determined by the government, and is the same across all of the cases considered We first discuss the case of the 'democracy' which is a benchmark that can be used to discuss the other two cases as well, given that the preferences of agents in all economies is the same.

*Case 1: Majority voting to determine α*

In the 'democracy' the agents vote on the proportion α that they prefer to be allocated towards cost-reducing financial development expenditure. Voting takes place at the 'first stage' of each period *t* and the political outcome is determined by majority rule. In the "second stage" of period *t*, after considering the political outcome, agents decide whether they should use financial intermediaries or not. These decisions are made in the presence of

[6] Of course, a competing mechanism of redistribution could be modelled in several ways. For example the government may choose to spend the remaining revenues on health, education or other forms of redistribution. Here we choose the 'lump sum transfer' as it is a tractable way of making the point of the paper, in addition to capturing the idea that 'direct' mechanisms of redistribution such as transfers compete with 'indirect' mechanisms such as those directed towards health, education research and development.

uncertainty; the realization of the shock occurs after the voting on $\alpha$ and technology adoption, consumption and bequest plans are made. The timing of events is as characterised by the figure below:

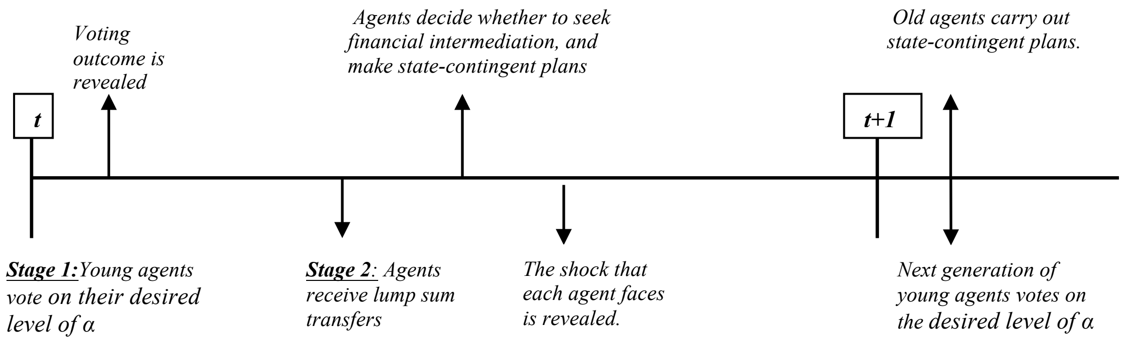


Figure 2.1

The economy produces output *(Y)* using capital *(K)*. The production functions *G(K)* assume a simple *"AK"* specification, which suggests that capital is a composite good consisting of both human and physical capital. Specifically, the production functions for Technology B is $G(K) = BK$ and for Technology F is $G(K) = FK$, where $B$ and $F$ denote the respective total factor productivity parameters associated with the two technologies, and $B < F$.

The agent does not consume in the first period of his life. The utilities of the agents use and those who do not use financial intermediaries are as described in equations (2) and (3), respectively:

$$U(c_{t+1}^{B,l}, c_{t+1}^{B,h}, b_{t+1}^{B,l}, b_{t+1}^{B,h}) = p\ln(c_{t+1}^{B,l}) + (1-p)\ln(c_{t+1}^{B,h}) + \theta p\ln(b_{t+1}^{B,l}) + \theta(1-p)\ln(b_{t+1}^{B,h}) \qquad (2)$$

$$U(c_{t+1}^{F,l}, c_{t+1}^{F,h}, b_{t+1}^{F,l}, b_{t+1}^{F,h}) = p\ln(c_{t+1}^{F,l}) + (1-p)\ln(c_{t+1}^{F,h}) + \theta p\ln(b_{t+1}^{F,l}) + \theta(1-p)\ln(b_{t+1}^{F,h}) \qquad (3)$$

In equations (2) and (3), $c_{t+1}$ and $b_{t+1}$ denote period 2 household consumption and bequests for the agent. Superscripts $B$ and $F$ simply imply that the agent adopts Technology B and Technology F, respectively, while superscripts $l$ and $h$ denote whether the agent faces a bad or good shock respectively. The parameter $\theta$ describes the extent of imperfect intergenerational altruism in the model. In every period each generation faces a problem regarding whether to use financial intermediaries or not. This decision depends on an agent's resource endowment and this in turn depends upon the resources they inherited from their parents through bequests.

Agents face different budget constraints depending on whether they use the financial intermediaries or not. The budget constraints for agents who do not use the financial intermediaries are as follows:

$$c_{t+1}^{B,l} = (1-\tau)(\eta+\varepsilon_l)(\overline{w}+W_t) - b_{t+1}^{B,l} + (1-\alpha)\tau\overline{W_t} \tag{4}$$

$$c_{t+1}^{B,h} = (1-\tau)\ (\eta+\varepsilon_h)(\overline{w}+W_t) - b_{t+1}^{B,h} + (1-\alpha)\tau\overline{W_t} \tag{5}$$

The resource endowments for agents depend on whether their parents used financial intermediaries or not, in addition to the idiosyncratic shocks faced by their parents. The resource endowment for agents whose parents did not use financial intermediaries is given by $W_t = W_t^{B,x} = b_t^{B,x}$ while the endowment of agents whose parents used financial intermediaries is given by $W_t = W_t^{F,x} = b_t^{F,x}$, where $x = h, l$.

For agents who use financial intermediaries, the budget constraints are described as follows:

$$c_{t+1}^{F,l} = (1-\tau)\phi(\overline{w}+W_t) - b_{t+1}^{F,l} + (1-\alpha)\tau\overline{W_t} - \psi(g_t) \tag{6}$$

$$c_{t+1}^{F,h} = (1-\tau)\ (\eta+\varepsilon_h)(\overline{w}+W_t) - b_{t+1}^{F,h} + (1-\alpha)\tau\ \overline{W_t} - \psi(g_t) \tag{7}$$

The agent's problem is make choices of $c_{t+1}$, $b_{t+1}$ that maximise his/her utility. More specifically, agents that do not seek financial intermediation maximise equation (2) subject to constraints (4) and (5). This yields the following optimal state-contingent consumptions and bequest plans:

$$c_{t+1}^{B,l} = \frac{1}{1+\theta} y_t^{B,l} \tag{8}$$

$$c_{it+1}^{B,h} = \frac{1}{1+\theta} y_t^{B,h} \tag{9}$$

$$b_{it+1}^{B,l} = \frac{\theta}{1+\theta} y_t^{B,l} \tag{10}$$

$$b_{it+1}^{B,h} = \frac{\theta}{1+\theta} y_t^{B,h} \tag{11}$$

In the above equations $y_t^{B,x} = (1-\tau)(\eta + \varepsilon_x)(\overline{w} + W_t) + (1-\alpha)\tau\overline{W}_t$, where $x = l, h$. Alternatively, an agent who uses financial intermediaries maximises equation (3) subject to constraints (6) and (7). This yields the following optimal state-contingent consumption and bequest plans.

$$c_{it+1}^{F,l} = \frac{1}{1+\theta} y_t^{F,l} \tag{12}$$

$$c_{it+1}^{F,h} = \frac{1}{1+\theta} y_t^{F,h} \tag{13}$$

$$b_{it+1}^{F,l} = \frac{\theta}{1+\theta} y_t^{F,l} \tag{14}$$

$$b_{it+1}^{F,h} = \frac{\theta}{1+\theta} y_t^{F,h} \tag{15}$$

In the above equations,

$$y_t^{F,l} = (1-\tau)\phi(\overline{w} + W_t) + (1-\alpha)\tau\overline{W}_t - \frac{\overline{\Psi}}{1+\alpha\tau\overline{W}_t};$$

$$y_t^{F,h} = (1-\tau)(\eta + \varepsilon_h)(\overline{w} + W_t) + (1-\alpha)\tau\overline{W}_t - \frac{\overline{\Psi}}{1+\alpha\tau\overline{W}_t}.$$

Note that an agent will seek financial intermediation *iff*

$$V^F(c_{t+1}^*, b_{t+1}^*) \geq V^B(c_{t+1}^*, b_{t+1}^*) \tag{16}$$

where $V^F$ and $V^B$ represent the *indirect* expected utility functions for the agents who use financial intermediaries and agents who do not use financial intermediaries respectively and the superscript $^*$ denotes the optimal choice of the variable in question. It can then be shown that (16) implies the following (See derivations in the Appendix):

$$(y_t^{F,l})^p (y_t^{F,h})^{1-p} \geq (y_t^{B,l})^p (y_t^{B,h})^{1-p} \tag{17}$$

Equation (17) is quite easy to interpret; it essentially suggests that an agent will adopt Technology F (i.e. use financial intermediaries) if the expected income, net of adoption costs, exceeds the expected income from adopting Technology B. Furthermore, we can show the following result.

**Proposition1**: There is a critical level of wealth $W^*$ such that agents with wealth above this level adopt Technology F.

For a proof see the Appendix. It is also possible to gain some insight on how people vote by analysing the total change of $W_t*$ with respect to changes in $\alpha$. At first glance, intuition suggests that agents are likely to prefer a high $\alpha$ in order to enter the financial intermediary system quickly. However, this decision is not clear-cut because agents also receive a lump-sum transfer payment $(1-\alpha)\tau\overline{W}_t$, which is decreasing in $\alpha$. However, in the case where bad shocks and good shocks occur with equal probability, we can show the following result.

**Proposition 2**: Consider the case of symmetric shocks, with p = 1-p = ½. Assume further that $\overline{W}_t > \dfrac{\sqrt{\Psi}-1}{\tau}$. It can be shown that:

(a) If $\alpha \in [0, \tilde{\alpha}]$ where $\tilde{\alpha} = \dfrac{\sqrt{\Psi}-1}{\tau\overline{W}_t}$, then $\dfrac{dW^*}{d\alpha} < 0$.

(b) For $\alpha \in (\tilde{\alpha}, 1]$ there are two possibilities:

(i) $\dfrac{dW^*}{d\alpha} < 0$, (so that, in combination with part (a) $\dfrac{dW^*}{d\alpha} < 0$ for all α in [0, 1]).

(ii) There exists $\hat{\alpha} \in (\tilde{\alpha}, 1]$ such that $\dfrac{dW^*}{d\alpha} < 0$ for $\alpha \in (\tilde{\alpha}, \hat{\alpha}]$ and $\dfrac{dW^*}{d\alpha} \geq 0$ for $\alpha \in (\hat{\alpha}, 1]$, (so that in combination with part (a) $\dfrac{dW^*}{d\alpha} < 0$ for $\alpha \in [0, \hat{\alpha}]$ and $\dfrac{dW^*}{d\alpha} \geq 0$ for $\alpha \in (\hat{\alpha}, 1]$).

Before we consider the implications of these results, a few remarks are in order for the assumptions in the statement of Proposition 2. Firstly, we believe the symmetric shocks case to be the most relevant and interesting case to analyse in the context of this model. This is because, to consider the impact of uncertainty, presented in the next section, we look at quantitative experiments based on "mean preserving" distributions of the shock. Furthermore, asymmetric shocks, in addition to being less analytically tractable, rig the model to produce either weaker or stronger versions of the outcomes in the symmetric case, without adding anything qualitatively different.

Secondly, the assumption $\overline{W}_t > \frac{\sqrt{\psi}-1}{\tau}$ reflects the idea that the economy is in a transitional phase, so that its average wealth is higher than the adoption costs associated with Technology F by a roughly proportional amount. This assumption also ensures an interior solution for the α that is optimal from the perspective of agents using Technology F.

Regarding the implications of Proposition 2, it is interesting to note that allocating all of the revenue raised by the government to cost-reducing R&D need not be efficient. Part b(i) of the proposition combined with part (a) essentially reflects this possibility, in that there is a critical proportion of revenue beyond which expenditures allocated to such activity do not reduce the critical wealth $W^*$ required by agents to adopt Technology F. However, this case is only one of the possibilities, so that cost-reducing R&D is potentially efficient in the entire range of α.

We now turn to the characterization of political economy outcomes in this economy. Given this is a heterogeneous agent model with a non-convexity in the agent's optimization problem, preferences in this economy need not be single peaked, as we will discuss shortly. We cannot therefore invoke the median-voter theorem in its classic form to characterize the outcomes of the model. However, we can get a very complete characterization of the political economy outcome, albeit only under the assumption that the range of α agents can vote on is restricted to the range in which cost-reducing R&D is efficient (i.e the range in which $W^*$ is decreasing in α).

In what follows, we impose this assumption in the remainder of this section. However, numerical simulations conducted in the subsequent section consider experiments which allow for a vote on the entire range of α. These experiments show that political economy outcomes are the same as those implied by the analytical results we are about to discuss. Intuitively, agents do not vote for a value of α that falls in the inefficient range; not only does this amount to a waste of resources, it also implies a smaller amount of redistribution in the form of the lump-sum transfer. Consider, for example, Figure 2.2 below:

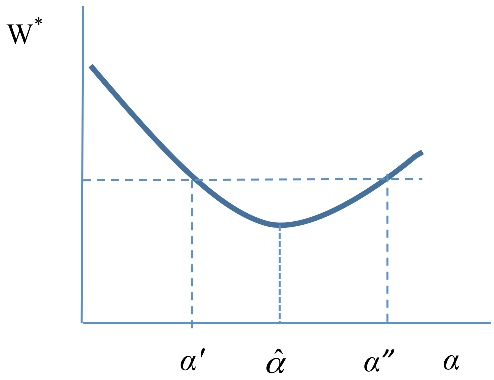


Figure 2.2

Here, the proportion α' of government revenues can achieve the same $W^*$ as α", but α' entails a smaller sacrifice of revenues received from the government in the form of the lump-sum transfer.

In the case of efficient R&D, we examine the political economy aspects by looking at three subsets of agents within the economy's distribution of wealth and examining how their indirect utility functions behave with changes in $\alpha$. Recall that the support of the economy's distribution is $[0, \kappa]$. We consider subsets within this range which are diagrammatically illustrated in Figure 2.3 below:

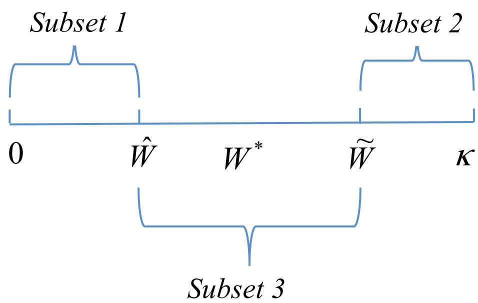


Figure 2.3

Note that W*, the critical level of wealth that makes it worthwhile to adopt F falls in Subset 3 of the interval [0, κ] shown in Figure 3. As discussed above we know that W* can vary with α, and in the case considered is decreasing in α. Without loss of generality, then, we can define the range $[\hat{W}, \tilde{W}]$ such that it covers the variation in W* as alpha varies in the permissible range. This means that as α increases towards its maximum value, W* moves to the left, towards $\hat{W}$. As α decreases towards 0, W* moves to the right towards $\tilde{W}$. The three subsets shown in Figure 2.3 are then described as follows:

(i) Subset 1: Agents with a level of wealth belonging to the interval (0, $\hat{W}$], which is substantially below $W$, so that changes in $\alpha$ do not reduce $W^*$ to the extent that it falls below $\hat{W}$.

(ii) Agents with a level of wealth belonging to the interval [$\tilde{W}$, κ) substantially above $W^*$ so that changes in $\alpha$ do not increase $W_t^*$ to the extent that it rises above $\tilde{W}_t$.

(iii) Agents in the range $\left(\hat{W}_t, \tilde{W}_t\right)$, whose technology adoption choice is affected by changes in $\alpha$ through its impact on W*.

We first consider the cases (i) and (ii), i.e. agents who belong to the bottom and top ends of the wealth distribution, with the bottom end adopting Technology B and the top end adopting Technology F. Preferences for these agents are single peaked with respect to $\alpha$. The preferred value of $\alpha$ in these cases is described in the following proposition:[7]

**Proposition 3**: (i) Agents with initial wealth levels in the interval $(0, \hat{W}_t]$ prefer $\alpha = 0$.

(ii) The preferred value of $\alpha$ for agents in the interval [$\tilde{W}_t$, κ) is given by:

$$\tilde{\alpha} = \begin{cases} \dfrac{\sqrt{\overline{\psi}} - 1}{\tau \overline{W}_t} & if \quad \tau \overline{W}_t > \sqrt{\overline{\psi}} - 1 > 0 \\ 0 & if \quad \overline{\psi} < 1 \\ 1 & if \quad \sqrt{\overline{\psi}} - 1 > \tau \overline{W}_t \end{cases} .$$

In the case of the middle group of agents we can show the following:[8]

**Proposition 4**: Agents with initial wealth levels in the interval $\left(\hat{W}, \tilde{W}\right)$ have preferences that are non-single peaked in $\alpha$. However, it can be shown that there exists a threshold level of wealth $W'$ (which can be distinct from $W^*$) such that agents above this level have a preferred

[7] See appendix 3 for a proof of this proposition, and the single peakedness of preferences for these agents.
[8] See the appendix for proofs of these propositions.

value of $\alpha$ which is the same as that of agents in the interval $[\widetilde{W}$, κ). Agents below this level have the same preferred value of α as those in the interval $(0, \hat{W}]$.

Propositions 3 and 4 essentially imply that the political outcome for $\alpha$ depends on the distribution of wealth in any given period and various parameters of the model, such as the average level of wealth in the economy, the adoption cost parameter $\overline{\psi}$ and the tax rate $\tau$, and the location of the median voter relative to the *second* threshold level of wealth $W'$ defined in Proposition 4. This threshold level splits the distribution of agents into two groups, one of which prefers $\alpha = \widetilde{\alpha}$, while the other prefers $\alpha$=0. Also note that as the average level of wealth in the economy grows over time, $\widetilde{\alpha}$ converges to zero as well.

Intuitively, in the early stages of development, when there are a substantial number of agents in the bottom end of the distribution, and the median voter is below $W'$, we would expect a vote for $\alpha$=0, given agents who prefer this value are in the majority. However, as redistribution through the lump sum transfers takes place the distribution changes over time, making it possible for a vote in favour of a positive value of α, as described by Propositions 3 part (ii). Eventually, however, as development takes place with the number of agents adopting F increasing over time, tax revenues $\tau\overline{W}_t$ grow and all agents prefer a value of α equal to 0.

It is also possible to reinforce the intuition regarding the transitional dynamics of the economy by looking at the difference equations (10), (11), (14) and (15) that determine the evolution of wealth over time. To simplify the analysis we look at the economy's "average" behaviour by taking expected values of these equations. Further, let $Z^B_{t+1} = EW^B_{t+1}$, $Z^F_{t+1} = EW^F_{t+1}$, where E represents the expectation operator, and let $Z_t = W_t; Z^*_t = W^*_t$.[9] We can then derive:

$$\begin{aligned} Z^B_{t+1} &= a_t + bZ_t \qquad if \quad Z_t < Z^*_t, \\ Z^F_{t+1} &= c_t + dZ_t \qquad if \quad Z_t \geq Z^*_t. \end{aligned} \tag{18}$$

In equation (18),

$a_t = (1-\tau)\eta\overline{w} + (1-\alpha)\tau\overline{W}_t$,

$b = (1-\tau)\eta$,

[9] Note that in the case of symmetric shocks, we can analytically derive W*, albeit the form it takes is cumbersome to write down. We cannot, however derive an expression when shocks are asymmetric.

$c_t = (1-\tau)\overline{w}\{p\phi + (1-p)(\eta + \varepsilon_h\} + (1-\alpha)\tau\overline{W}_t - (\overline{\psi}/(1+\alpha\tau\overline{W}_t))$, and

$d = (1-\tau)\{p\phi + (1-p)(\eta + \varepsilon_h)\}$.

As can be seen from (18), the expected bequest/wealth functions that describe the economy's evolution are non-autonomous difference equations with time-variant 'forcing terms' $a_t$ and $c_t$ which are also endogenous, given that *α* is chosen through a political process. However, we know that d > b and $a_t$ and $c_t$ are positive and increasing in the average level of wealth $\overline{W}_t$. Even if we assume that b<1, as long as d >1, we can see that a dynasty starting below the critical level of resources would eventually escape to the group of F adopters, provided the economy's average level of wealth, which impacts on the forcing terms $a_t$ and $c_t$, was growing over time.[10] The pattern for *α* would be roughly similar to what we have conjectured above. That is, in early stages there would be vote for a value of α=0, given that the majority of agents are below the threshold level of wealth $W_t'$. In the transitional stages, with more agents adopting F there would be a vote in favour of higher values of *α*. However, as the economy develops the average wealth would grow without bound, particularly once all agents have adopted F. Eventually, then, *α* would converge to a value close to zero.

Note that the above analysis was based on a given level of uncertainty. If we increase the 'extent of uncertainty' by increasing the variance of the shocks, our intuition suggests that the transitional process would be lengthened. However, this need not be the case since the political economy mechanism ensures that the agents in the economy will take into account the extent of uncertainty when voting for α. We attempt to address this issue by examining how the critical level of wealth required for adoption, $W^*$ changes with the negative and positive shocks to the economy. The analytical results capturing this effect are summarized in the proposition below.[11]

[10] The only scenarios in which there is a 'poverty trap' are as follows: (a) the case in which b < 1 and all agents in the economy have a resource endowment below the critical level, and (b) the case in which there are some agents above the critical level but both b and d are less than 1. However, we are interested in the case of transitional economies, and from that point of view we consider initial wealth distributions in which at least a few agents have resources above the critical level of wealth and d >1.

[11] For a proof see the Appendix.

**Proposition 5**: Consider $W^*$ as defined in Proposition 1. We can show that,

(i) $\dfrac{dW^*}{d\varepsilon_l} > 0$ and $\dfrac{dW^*}{d\varepsilon_h} < 0$;

(ii) The sign of $\dfrac{dW^*}{d\varepsilon_l} + \dfrac{dW^*}{d\varepsilon_h}$ is ambiguous. Specifically,

$$\frac{\partial W^*}{\partial \varepsilon_h} + \frac{\partial W^*}{\partial \varepsilon_l} \geq (\leq)\, 0 \quad iff \quad \frac{p}{y^{B,l}} + \frac{1-p}{y^{B,h}} - \frac{1-p}{y^{F,h}} \geq (\leq)\, 0.$$

Proposition 5 demonstrates that, ceteris paribus, an increase in size of the negative shock increases the critical level of wealth necessary for adopting the superior technology, while the opposite is true for the positive shock. However, part (ii) suggests the magnitude of the total impact is not necessarily symmetric; that is, keeping both shocks equal in absolute value, as assumed earlier, an increase in the absolute size of both shocks could either increase or decrease $W^*$.

*Case 2: The government maximizes a Benthamite Social Welfare Function (BSWF) to determine α*

Here, the timing of the announcement is the same as in the previous model, with agents' technology adoption, consumption and bequest plans made after α is announced. Budget constraints and utility functions have an identical form, as do the optimal consumption and bequest plans. Therefore, the form of the indirect utility functions are also identical. The only difference is the determination of α, which is given by

$$\alpha^B = \arg\max_{\alpha} \left\{ \sum_{i=1}^{N_B} V^B(\alpha) + \sum_{N_B+1}^{N} V^F(\alpha) \right\}.$$

Note that the underlying preferences of agents are the same as in the previous case. This means that, for a given initial distribution, agents' preferences over α are described by propositions 3 and 4 above. However, this economy will not necessarily pick the α chosen by the median voter. Recall that there are, effectively, two types of agents in the economy – those below W' who prefer α=0, and those above this level of wealth who prefer $\alpha = \tilde{\alpha}$. The problem of the Benthamite economy, in the most likely case, is to choose from one of these two values, rather than a range of values of α.[12] Since utility is increasing in wealth, the BSWF tends to give a higher weight to the preference of richer indivduals. It is therefore possible for this economy to choose an α that is different from the median agent's preferred value.

*Case 3: The government maximizes a Rawlsian Social Welfare Function (RSWF) to determine α*

Again, the timing conventions are the same as in the previous model. The proportion of revenues allocated to institutional development is announced first, followed by the technology adoption plans and finally the state-contingent consumption and bequest plans. The RSWF maximizes the minimum of the utilities attained by agents in the economy. Formally,

$$\alpha^{R} = \arg\max_{\alpha}\left\{\min\left[V_1^B(\alpha), V_2^B(\alpha), ..., V_{N_B}^B(\alpha), V_{N_B+1}^F(\alpha), ..., V_N^F(\alpha)\right]\right\}.$$

In contrast to the BSWF, and the voting mechanism, the RSWF favours the preference of the poorest agent in the economy. Depending on the wealth level of the poorest agent in the economy, this will either be α=0 or $\alpha = \tilde{\alpha}$. For a transitional economy this is likely to be α=0 since agents at the bottom end of the distribution are too poor to be able to adopt Technology F, regardless of the redistribution of resources in the economy. Put differently, for a given initial distribution the RSWF is more likely to generate the outcome of α=0.

Intuitively, the α chosen by a 'democracy' is likely to be the same as $\alpha^R$ if there is a sufficiently high level of inequality. In that case, the median voter would fall into the group of agents below the wealth level W' as defined in Proposition 4, so that in both economies the preferred α would equal zero. It is harder to glean what might occur in the Benthamite case, but it is clear that the nature of the distribution would matter. In the Benthamite case, the question is whether the sum of agents' utilities evaluated at α=0 or $\alpha = \tilde{\alpha}$ is the highest. Nevertheless, given the higher weight that is implicitly attached to the utility of richer agents, there is the possibility that $\tilde{\alpha}$ is chosen even in the case when the median agent's preferred α is zero.

[12] The IUF of agents below W' is the largest at α=0, while it is the largest at $\alpha = \tilde{\alpha}$ for agents below this level of wealth. The highest "weights" in the social welfare function are therefore associated with these values, making them the most likely candidates for the proportion that is eventually chosen.

The above discussion is based on the assumption that the initial distribution of wealth is identical in all three economies. Note that the next period's distribution will be identical across the three cases only if this period's outcome for α is identical. If not, the economies will move to a different transitional path, depending on the outcome for α. In order to get further insight as to what might happen, however, we need to resort to numerical experiments, which are presented in the next section. These experiments also help to analyse the impact of uncertainty, for which we have only a partial characterization based on Proposition 5.

### 3. Results Based on Numerical Experiments

We first present the analysis of a 'democracy' as it serves as a useful benchmark for discussing results in the case of planned economies. This is because the dynamic patterns in the three cases are similar and differences arise only in the timing of adoption and diffusion of technology and convergence to long-run levels of inequality and growth.

For the purpose of the numerical experiments, we start with a benchmark set of parameters and then vary some of these to glean insights on issues we are interested in, such as the impact of uncertainty, initial inequality on long-run and transitional outcomes for the democratic economy. We then present a comparison of three economies along the same dimensions. The benchmark parameters are: $\theta$=1; $\phi$ =2.5; $\eta$ = 3; p =0.5; $\overline{\psi}$ = 50; $\overline{w} = 10$ and $\tau$ = 0.25. The number of agents in the economy is 501, with their wealth levels drawn from an initial distribution which is lognormal with mean 2.5 and standard deviation 0.8. We sort this initial distribution so that agents are arranged in ascending order of their wealth levels, with the median agent represented by the 251st agent.[13]

Given $\eta$=3 and $\phi$=2.5, the assumptions set out in section 2 regarding uncertainty provide some restrictions on the size of shocks we can experiment with. Since $\eta + \varepsilon_l < \phi$ we must have $\varepsilon_l$ < -0.5. Furthermore, we have assumed symmetric shocks such that $E\varepsilon_t = 0$, and $|\varepsilon_l| = |\varepsilon_h| < \eta$, so our experiments involving varying the extent of uncertainty amount to

[13] A sensitivity analysis with various parameters suggests that results presented above are robust. That is, the results discussed below summarize, in a qualitative sense the long run and transitional outcomes that are typical in the model. Specifically, we conducted experiments for a wide range of initial distributions, standard deviation of the shock, tax rates and other parameters. The results confirm or are intuitively consistent with the theoretical outcomes of the model discussed in the previous section.

varying $\varepsilon_t$ such that $0.5 < |\varepsilon_t| < 3$. At the lower end of the range, a size of shock such that $|\varepsilon_t| = 0.5$ represents a loss of 16.6% of average income if the bad state occurs (and an equivalent gain if the good state is realized), with a standard deviation of shocks equal to 0.7. At the upper end of the range $|\varepsilon_t| = 3$ represents a 100% loss relative to average income in the bad state and a doubling of income in the good state, with a standard deviation of shocks equal to 4.25.

To begin with we consider the pattern of technology adoption over time, which is presented in Figure 3.1, for varying levels of uncertainty as represented by the standard deviations of the shocks. The figure shows that $N_F$, the number of agents adopting technology F is initially zero, followed by a complete and irreversible switch to the technology F. However, a higher extent of uncertainty seems to lead to a quicker timing of complete adoption, although there are some ranges of parameter for which uncertainty does not have any impact. For example as the standard deviation of shocks increases from 0.7 to 0.75 and then to 0.8, complete adoption occurs in periods 7, 6 and 5 respectively, but a further increase of uncertainty, as represented by a standard deviation of shocks equal to 0.85, does not lead to quicker adoption. Nevertheless, the impact of uncertainty is non-negative.[14] Broadly speaking, the intuition is as follows: a higher extent of uncertainty creates a desire for re-distribution via the institutional development expenditure, leading to a favourable vote for α, as reflected in Figure 3.2, which presents the α preferred by the majority over time.

[ Insert Figure 3.1 here]

However, the proportion of revenue allocated to institutional development falls immediately after the initial spike, which occurs when the transition to full adoption takes place. This decline is consistent with the theory and intuition presented in Section 2. Specifically, there is an initial phase in which the majority prefers α=0, since the median voter falls below W', the level of wealth defined in proposition 3. Subsequent distributional shifts ensure the arrival of a transitional phase in which $\tilde{\alpha} = (\sqrt{\overline{\psi}} - 1)/\tau\overline{W}_t$ is the preferred proportion of revenues allocated to cost-reducing institutional development expenditure. However, since the average wealth in the economy grows over time, this proportion falls, and

[14] We consider experiment is the entire range of ε that is permissible given our assumptions and the results parallel those presented here.

eventually converges to zero. We associate this convergence to zero with complete *diffusion* of technology F.

[Insert Figure 3.2 here]

Again, the impact of uncertainty is to increase the proportion of revenue allocated to institutional development in the initial period of the transitional phase. However, the convergence to zero also occurs faster, so that the diffusion of the technology is also facilitated by increases in uncertainty. This is because average wealth, as depicted in Figure 3.3, rises faster, the higher the extent of uncertainty in the economy. A larger proportion of revenues allocated to facilitates a faster transition to the sustained balanced growth path. Average growth (i.e the average of the growth rates experienced by all agents) following complete adoption and diffusion fluctuates within a band, which is wider and has a higher mean, higher the extent of uncertainty (see figure 3.4). Long run inequality, on the other hand, is higher in economies with a higher extent of uncertainty (see figure 3.5).

[Insert Figures 3.3, 3.4 and 3.5 here]

The qualitative pattern in other economies – i.e. the Benthamite and Rawlsian economies – is very similar with a few differences. Specifically, technology adoption in the latter cases need not follow an "all or nothing" pattern we observe in the democracy. There is, instead, an intermediate phase in which some agents adopt B, while others adopt F. See figures 3.6 and 3.7 which present the Benthamite and Rawlsian cases. For some levels of uncertainty, each of these economies transitions to a partial adoption before full adoption takes place, but the extent of partial adoption in the intermediate phase is much larger in the Benthamite economy.

[Insert Figures 3.6 and 3.7 here]

However, in quantitative terms there are some important differences across the three types of economies. See Figure 3.8 in which we present the dynamic pattern of α for the three cases, for different levels of uncertainty. Note that the pattern for α can be used to "predict" the patterns for other variables. In our analysis for the democracy the graph for α could have been used as an "indicator" for patterns observed in other variables – the timing of complete adoption occurred at the same time as the period in which α was the highest, and the fastest convergence to zero was associated with the highest average wealth level and the fastest convergence to the sustained, balanced growth path, as well as the highest long-run level of inequality. We find that these connections between the graph for α and other dynamic patterns in the economy are also found in the Benthamite and Rawlsian cases. As such, we are able to present the results more succinctly using only the graphs for α and comparing them across the economies.

Panels 1-4 of figure 3.8 present the dynamic patterns for $\alpha$, $\alpha^B$ and $\alpha^R$ for levels of uncertainty associated respectively with $|\varepsilon_t| = 0.7, 0.75, 0.80, 0.85$. Panels 1 and 4 are particularly interesting, in that the proportion allocated to institutional development in the initial period of the transitional phase is the highest in the Benthamite case, followed by the democracy and Rawlsian cases. This suggests a faster timing of complete adoption in the Benthamite case followed by the democracy and Rawlsian cases respectively. In panels 2 and 3, however the Benthamite economy and the democracy have identical outcomes. They have a higher level of α and faster complete adoption relative to the Rawlsian case.

[Insert Figure 3.8 here]

The fastest diffusion of technologies, however is difficult to read off Figure 3.8, given the small size and scale of the individual panels. Figures 3.9 and 3.10 therefore present magnified versions of Panel 1 of figure 3.8. These figures show that the fastest convergence to zero occurs in the case of the democracy, followed by the Benthamite and Rawlsian cases. This translates into the fact that the democracy experiences the fastest diffusion of Technology F and the fastest transition to sustained growth, as well as the highest level of long run wealth. To assess the dynamic pattern of long run inequality, the corresponding results are presented in Figure 3.11. Here we see that transitional inequality is highest in the Rawlsian case, followed by the democracy and Benthamite cases. Inequality, however, converges to the same level in all three cases.

[Insert Figures 3.9, 3.10 and 3.11 here]

In all of the above cases we assumed a given initial distribution of income. In Figures 3.12 and 3.13 we present experiments to glean the impact of initial inequality on the long run outcomes in the economy. In the three panels of Figure 3.12 we present the dynamic pattern for the proportion allocated to institutional development in the democracy. The solid line represents an initial distribution which is lognormal with mean 2.5 and standard deviation 0.8 and a Gini coefficient of 0.43. The underlying distribution for the dashed line is a mean preserving spread of the former distribution with a standard deviation of 1.1 and a gini coefficient of 0.55. It is clear that higher initial inequality leads to a greater initial expenditure on institutional development and faster diffusion of technology, in addition to a faster transition to the balanced growth path. Figure 3.13 illustrates that long run inequality levels are the same, regardless of the initial distribution of wealth. Results for the Benthamite and Rawlsian cases are analogous to those presented in Figures 3.12 and 3.13.

[ Insert Figures 3.12 and 3.13 here]

In summary, uncertainty reacts with the political mechanism in all cases, with higher uncertainty leading to higher long-run average wealth and inequality, and a faster adoption and diffusion of the better technology. In most cases, the democracy and Benthamite mechanisms lead to the same outcomes, while in some cases the democracy leads to the fastest diffusion and highest long run average wealth. In all cases the Rawlsian mechanism leads to the slowest adoption and diffusion of technology and the lowest long run average wealth. For a given level of uncertainty, the Rawlsian mechanism also leads to the highest transitional inequality. For a given set of parameters, and uncertainty levels, however, the long run inequality and growth patterns in all economies are the same.

## 4. Concluding Remarks

Empirical literature suggests a diversity of inequality and wealth patterns, in addition to varied timing of adoption and diffusion of technologies. The framework considered in this paper provides a potential explanation for this diversity. It also provides some insight into the inconclusive nature of the empirical literature on the link between democracy and growth and redistribution and growth.

Specifically, we examine technology adoption and growth in a political economy framework where two alternative mechanisms of redistribution are on the menu of choice for the economy. One of these is a lump-sum transfer given to agents in the economy. The other is in the form of expenditure directed towards institutional reform aimed at bringing about a reduction in the cost of technology adoption in the presence of uncertainty. The choice over these mechanisms is examined under three alternative approaches to collective decision making. In the first setting, voting takes place to determine the proportion of revenue allocated to adoption-cost-reducing institutional expenditure. In the second setting, the government chooses this proportion to maximize a 'Benthamite' social welfare function, i.e. the sum of utilities of agents in the economy. The third setting applies the Rawlsian social welfare function, which is the most "egalitarian" in that this proportion is chosen to maximize the minimum level of utility attained in the heterogeneous agent economy. We find that the extent of uncertainty, working through the political economy mechanism, has a positive impact on long run average wealth levels in the economy in all settings. The voting mechanism leads to the fastest transition to sustained balanced growth in all cases, while the slowest transition is experienced in the case of the Rawlsian economy. Expenditures on institutional development are higher in the voting and Benthamite economies relative to the Rawlsian economy. All economies converge to the same inequality and growth rates in the long run. Transitional inequality, however, is highest in the Rawlsian framework.

In light of these results a further exploration of the mechanisms of collective choice is a potential area of future research, particularly in the context of macroeconomic models. For example, there is a large literature on social choice suggesting alternative voting mechanisms lead to different outcomes, but the implications of these results have not been explored in the context of political economy macroeconomic settings. A deeper exploration of the implications of such mechanisms, as well as alternative social welfare constructs that have been proposed in the welfare economics literature, could lead to further insights into the issues addressed above.

## Appendix

### *Proof of Proposition 1*

It is easy to see that both the left-hand-side (LHS) and right-hand-side (RHS) of equation (17) are monotonically increasing in the agents inherited level of wealth $W_t$ . Looking at the slopes of $y_t^{B,l}, y_t^{B,h}, y_t^{F,l}, y_t^{F,h}$ with respect to $W_t$, the slope of $y_t^{B,l}$ is definitely less than $y_t^{F,l}$ while the slope of $y_t^{B,h}$ is the same as that of $y_t^{F,h}$. The LHS of (17) therefore has a steeper slope than the RHS given that is a geometric average of $y_t^{F,l}$ and $y_t^{F,h}$. The intercepts of these lines are lower than the $y_t^{B,l}, y_t^{B,h}$ lines respectively, given the negative terms involving the fixed costs. The LHS then cuts the RHS from below at the point of equality of (17). Therefore there exists a threshold level of wealth $W_t$* beyond which agents adopt F.

***Proof of Proposition 2***

Note that, as discussed in Section 2 of the paper, $W^*$ is implicitly defined by

$$\left(y^{F,l}(W^*)\right)^p \left(y^{F,h}(W^*)\right)^{1-p} = \left(y^{B,l}(W^*)\right)^p \left(y^{B,h}(W^*)\right)^{1-p}. \qquad (A1)$$

In the above,

$$y^{F,l}(W^*) = (1-\tau)\phi(\overline{w}+W^*) + (1-\alpha)\tau\overline{W} - \frac{\overline{\psi}}{1+\alpha\tau\overline{\overline{W}}} \ ;$$

$$y^{F,h}(W^*) = (1-\tau)(\eta+\varepsilon_h)(\overline{w}+W^*) + (1-\alpha)\tau\overline{W} - \frac{\overline{\psi}}{1+\alpha\tau\overline{\overline{W}}};$$

$$y^{B,l}(W^*) = (1-\tau)(\eta+\varepsilon_l)(\overline{w}+W) + (1-\alpha)\tau\overline{W};$$

$$y^{B,h}(W^*) = (1-\tau)(\eta+\varepsilon_h)(\overline{w}+W) + (1-\alpha)\tau\overline{W}.$$

Differentiating totally with respect to $W^*$ and α we get,

$$p\left(y^{F,l}\right)^{p-1}\left(y^{F,h}\right)^{1-p}\left[\frac{\partial y^{F,l}}{\partial W^*}dW^* + \frac{\partial y^{F,l}}{\partial \alpha}d\alpha\right] + (1-p)\left(y^{F,h}\right)^{-p}\left(y^{F,l}\right)^{p}\left[\frac{\partial y^{F,h}}{\partial W^*}dW^* + \frac{\partial y^{F,h}}{\partial \alpha}d\alpha\right]$$

$$= p\left(y^{B,l}\right)^{p-1}\left(y^{B,h}\right)^{1-p}\left[\frac{\partial y^{B,l}}{\partial W^*}dW^* + \frac{\partial y^{B,l}}{\partial \alpha}d\alpha\right] + (1-p)\left(y^{B,h}\right)^{-p}\left(y^{B,l}\right)^{p}\left[\frac{\partial y^{B,h}}{\partial W^*}dW^* + \frac{\partial y^{B,h}}{\partial \alpha}d\alpha\right].$$

Collecting terms multiplied by $dW^*$ and dα and rearranging yields:

$$\left[\begin{array}{l} p\left(y^{F,l}\right)^{p-1}\left(y^{F,h}\right)^{1-p}\dfrac{\partial y^{F,l}}{\partial W^*} + (1-p)\left(y^{F,h}\right)^{-p}\left(y^{F,l}\right)^{p}\dfrac{\partial y^{F,h}}{\partial W^*} \\ \qquad - p\left(y^{B,l}\right)^{p-1}\left(y^{B,h}\right)^{1-p}\dfrac{\partial y^{B,l}}{\partial W^*} - (1-p)\left(y^{B,l}\right)^{p}\left(y^{B,h}\right)^{-p}\dfrac{\partial y^{B,h}}{\partial W^*} \end{array}\right] dW^*$$

$$= \left[\begin{array}{l} p\left(y^{B,l}\right)^{p-1}\left(y^{B,h}\right)^{1-p}\dfrac{\partial y^{B,l}}{\partial \alpha} + (1-p)\left(y^{B,h}\right)^{-p}\left(y^{B,l}\right)^{p}\dfrac{\partial y^{B,h}}{\partial \alpha} \\ \qquad - p\left(y^{F,l}\right)^{p-1}\left(y^{F,h}\right)^{1-p}\dfrac{\partial y^{F,l}}{\partial \alpha} - (1-p)\left(y^{F,l}\right)^{p}\left(y^{F,h}\right)^{-p}\dfrac{\partial y^{F,h}}{\partial \alpha} \end{array}\right] d\alpha$$

Note that we have suppressed the argument $W^*$ in the terms $y^{F,l}$, $y^{B,l}$, $y^{F,h}$, $y^{B,h}$ for convenience; however it is important to recognize that all of the expressions inside the brackets in the above equation are evaluated at $W^*$. Furthermore, if we denote $\left(y^{F,l}(W^*)\right)^p \left(y^{F,h}(W^*)\right)^{1-p} = LHS(W^*)$ and $\left(y^{B,l}(W^*)\right)^p \left(y^{B,h}(W^*)\right)^{1-p} = RHS(W^*)$, we may express the above as:

$$\left[ p \frac{LHS}{y^{F,l}} \frac{\partial y^{F,l}}{\partial W^*} + (1-p) \frac{LHS}{y^{F,h}} \frac{\partial y^{F,h}}{\partial W^*} - p \frac{RHS}{y^{B,l}} \frac{\partial y^{B,l}}{\partial W^*} - (1-p) \frac{RHS}{y^{B,h}} \frac{\partial y^{B,h}}{\partial W^*} \right] dW^*$$

$$= \left[ p \frac{RHS}{y^{B,l}} \frac{\partial y^{B,l}}{\partial \alpha} + (1-p) \frac{RHS}{y^{B,h}} \frac{\partial y^{B,h}}{\partial \alpha} - p \frac{LHS}{y^{F,l}} \frac{\partial y^{F,l}}{\partial \alpha} - (1-p) \frac{LHS}{y^{F,h}} \frac{\partial y^{F,h}}{\partial \alpha} \right] d\alpha. \qquad (A2)$$

Since LHS and RHS are evaluated at $W^*$ and equal to each other as per equation (A1) we can cancel them out from equation (A2). Next, we define the following 'elasticities':

$$E_{Bl,W^*} = \frac{1}{y^{B,l}} \frac{\partial y^{B,l}}{\partial W^*}; \qquad E_{Bl,\alpha} = \frac{1}{y^{B,l}} \frac{\partial y^{B,l}}{\partial \alpha};$$

$$E_{Fl,W^*} = \frac{1}{y^{F,l}} \frac{\partial y^{F,l}}{\partial W^*}; \qquad E_{Fl,\alpha} = \frac{1}{y^{F,l}} \frac{\partial y^{F,l}}{\partial \alpha};$$

$$E_{Bh,W^*} = \frac{1}{y^{B,h}} \frac{\partial y^{B,h}}{\partial W^*}; \qquad E_{Bh,\alpha} = \frac{1}{y^{B,h}} \frac{\partial y^{B,h}}{\partial \alpha};$$

$$E_{Fh,W^*} = \frac{1}{y^{F,h}} \frac{\partial y^{F,h}}{\partial W^*}; \qquad E_{Fh,\alpha} = \frac{1}{y^{F,h}} \frac{\partial y^{F,h}}{\partial \alpha}.$$

Then, $$\frac{dW^*}{d\alpha} = \frac{pE_{Bl,\alpha} + (1-p)E_{Bh,\alpha} - pE_{Fl,\alpha} - (1-p)E_{Fh,\alpha}}{pE_{Fl,W^*} + (1-p)E_{Fh,W^*} - pE_{Bl,W^*} - (1-p)E_{Bh,W^*}}. \qquad (A3)$$

Now consider the terms in the denominator of (A3). Based on the assumptions of the model we can show that

$$E_{Fl,W^*} = \frac{1}{y^{F,l}} \frac{\partial y^{F,l}}{\partial W^*} = \frac{(1-\tau)\phi}{y^{F,l}} > 0; \; E_{Fh,W^*} = \frac{1}{y^{F,h}} \frac{\partial y^{F,h}}{\partial W^*} = \frac{(1-\tau)(\eta + \varepsilon_h)}{y^{F,h}} > 0;$$

$$E_{Bl,W^*} = \frac{1}{y^{B,l}} \frac{\partial y^{B,l}}{\partial W^*} = \frac{(1-\tau)(\eta + \varepsilon_l)}{y^{B,l}} > 0; \; E_{Bh,W^*} = \frac{1}{y^{B,h}} \frac{\partial y^{B,h}}{\partial W^*} = \frac{(1-\tau)(\eta + \varepsilon_h)}{y^{B,h}} > 0.$$

It is easy to see that $E_{Fh,W^*} \geq E_{Bh,W^*}$ given that $y^{B,h} \geq y^{F,h}$. Comparing $E_{Fl,W^*}$ and $E_{Bl,W^*}$ we see that $E_{Fl,W} \geq (\leq) E_{Bl,W}$ iff

$$\frac{(1-\tau)\phi}{(1-\tau)\phi(\overline{w}+W)+(1-\alpha)\tau\overline{W}-\dfrac{\overline{\psi}}{1+\alpha\tau\overline{W}}} \geq (\leq) \frac{(1-\tau)(\eta+\varepsilon_l)}{(1-\tau)(\eta+\varepsilon_l)(\overline{w}+W)+(1-\alpha)\tau\overline{W}}.$$

With some straightforward algebraic manipulation of the above we get:

$E_{Fl,W} \geq (\leq) E_{Bl,W}$ iff $(1-\alpha)\tau\overline{W}(\phi-\eta-\varepsilon_l) \geq (\leq) \dfrac{-(\eta+\varepsilon_l)\overline{\psi}}{1+\alpha\tau\overline{W}}$.

Looking at the term on the right hand side it is obvious that it is negative. The left hand side term, on the other hand is positive. Therefore $E_{Fl,W} > E_{Bl,W}$.

Putting all these results together, it is evident that the denominator of (A3) is positive. Therefore,

$$\frac{dW^*}{d\alpha} \geq (\leq)\, 0 \quad iff \quad pE_{Bl,\alpha} + (1-p)E_{Bh,\alpha} - pE_{Fl,\alpha} - (1-p)E_{Fh,\alpha} \geq (\leq)\, 0.$$

Note that $E_{BL,\alpha} = -\tau\overline{W}/y^{B,l}$, $E_{Bh,\alpha} = -\tau\overline{W}/y^{B,h}$, $E_{Fl,\alpha} = \left(-\tau\overline{W} + \dfrac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2}\right)\Big/ y^{F,l}$ and $E_{Fh,\alpha} = \left(-\tau\overline{W} + \dfrac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2}\right)\Big/ y^{F,h}$. Making these substitutions and rearranging, we get:

$$\frac{dW^*}{d\alpha} \geq (\leq) 0 \quad iff \quad -\left\{\frac{p}{y^{B,l}} + \frac{1-p}{y^{B,h}}\right\} \geq (\leq) \left[\frac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1\right]\left\{\frac{p}{y^{F,l}} + \frac{1-p}{y^{F,h}}\right\}. \qquad (A4)$$

Since the terms inside the curly brackets are positive, we know that the left hand side of the inequality is negative and the sign of the right hand side depends on the expression inside the square bracket. In what follows, we therefore consider two cases, described below.

Case 1: $\left[\dfrac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1\right] \geq 0$. It is easy to show that this occurs when $\alpha \in [0, \tilde{\alpha}]$ where $\tilde{\alpha} = \dfrac{\sqrt{\overline{\psi}} - 1}{\tau\overline{W}}$.

Case 2: $\left[\dfrac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1\right] < 0$. This case, likewise, can be shown to occur when $\alpha \in (\tilde{\alpha}, 1]$.

First, consider Case 1. In this case the right hand side of (A4) is non-negative while the left hand side is unambiguously negative, so the left hand side is less than the right hand side. We therefore have the result of part (a) of proposition 1. That is,

$$\frac{dW^*}{d\alpha} < 0 \quad if \quad \alpha \in [0, \tilde{\alpha}], \text{ where } \tilde{\alpha} = \frac{\sqrt{\overline{\psi}} - 1}{\tau \overline{W}}.$$

Next, consider Case 2. In this case both the left and right hand side of A(4) are negative, so

$$\frac{dW^*}{d\alpha} \leq (\geq) 0 \quad iff \quad \left| \left\{ \frac{p}{y^{B,l}} + \frac{1-p}{y^{B,h}} \right\} \right| \geq (\leq) \left| \left[ \frac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1 \right] \right| \left| \left\{ \frac{p}{y^{F,l}} + \frac{1-p}{y^{F,h}} \right\} \right|. \qquad (A5)$$

Assuming symmetric shocks and using properties of the modulus, this is equivalent to

$$\frac{dW^*}{d\alpha} \leq (\geq) 0 \quad iff \quad \left[ \frac{\left(y^{B,h} + y^{B,l}\right)/2}{\left(y^{F,h} + y^{F,l}\right)/2} \right] \left( \frac{y^{F,l} y^{F,h}}{y^{B,l} y^{B,h}} \right) \geq (\leq) \left| \frac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1 \right|. \qquad (A5')$$

The above inequality can be further simplified by recognizing that, evaluated at W*, $\left(y^{F,l}\right)^{1/2}\left(y^{F,h}\right)^{1/2} = \left(y^{B,l}\right)^{1/2}\left(y^{B,h}\right)^{1/2}$ from (A1), which further implies that, given all variables in question are positive, $\left(y^{F,l} y^{F,h}\right)^{1/2} = \left(y^{B,l} y^{B,h}\right)^{1/2} \Leftrightarrow y^{F,l} y^{F,h} = y^{B,l} y^{B,h}$. Therefore,

$$\frac{dW^*}{d\alpha} \leq (\geq) 0 \quad iff \quad \frac{\left(y^{B,h} + y^{B,l}\right)/2}{\left(y^{F,h} + y^{F,l}\right)/2} \geq (\leq) \left| \frac{\overline{\psi}}{(1+\alpha\tau\overline{W})^2} - 1 \right|. \qquad (A6)$$

In (A6), the left hand side represents the average income when adopting the B technology, relative to average income when adopting the F technology, evaluated at W*. We know that $y^{F,h} < y^{B,h}$. However, at W* the geometric average of income under the two technologies is equal, which can happen if and only if $y^{F,l} > y^{B,l}$. It is therefore difficult to establish which of these averages is greater. Nevertheless, we know the ratio on the left hand side of (A6) is greater than zero regardless of the value of α. It is also likely to be close to 1. Evaluated at the lower end of the range, i.e. at $\tilde{\alpha}$, we can see that the left hand side will be greater than the right hand side, since the right hand side evaluated at $\tilde{\alpha}$ is zero.

Secondly, the numerator of the left hand side is decreasing in α, while the denominator is also decreasing in the range $(\tilde{\alpha}, 1]$. However the numerator is decreasing at a faster rate ($\tau\overline{W}$) than the denominator ($\tau\overline{W} - [\overline{\psi}\tau\overline{W}/(1+\alpha\tau\overline{W})^2]$), so the left hand side of (A6) is decreasing, starting from a point slightly greater or less than 1. In contrast, the right hand side is increasing in this range, starting from a point close to zero and bounded above by a value less than 1.[15]

As such, there are two possibilities, given that both sides are represented by continuous functions of α. These are described by Figure A1 and Figure A2 below:[16]

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[15] As will become evident from the analysis of the optimal solution for alpha in later propositions a condition for an interior solution requires $\sqrt{\overline{\psi}} - 1 < \tau\overline{W}$. This implies that at α=1 $\overline{\psi}/(1+\alpha\tau\overline{W})^2 < 1$.

[16] Note that we have drawn the LHS with its value greater that 1 when evaluated at $\tilde{\alpha}$. We could just as easily have drawn it differently, with the curve starting at a point below 1. But the possibilities would still remain the same – either the two curves would intersect in the range, or the LHS would always lie above the RHS.

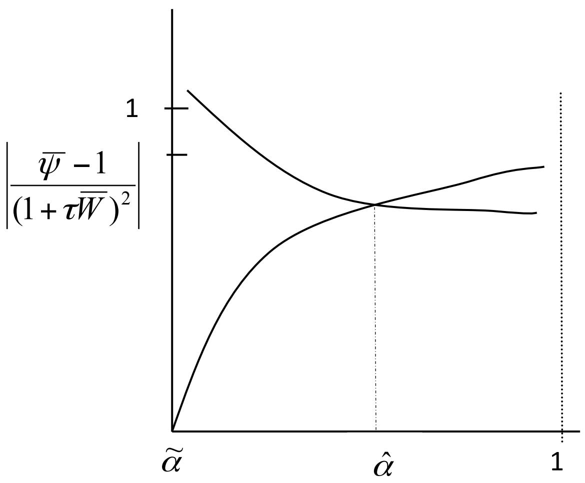


Figure A1

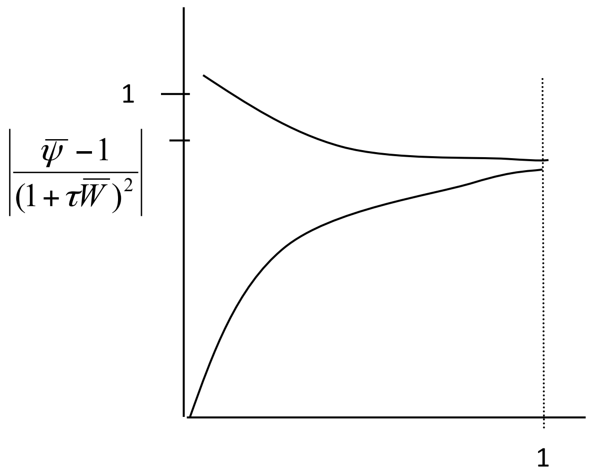


Figure A2

In the case of Figure A1, there exists an intermediate value of α in the range $\alpha \in (\tilde{\alpha}, 1]$, denoted $\hat{\alpha}$ such that the left hand side of (A6) is greater than the right hand side of (A6) for α less than this value, while the converse is true for α greater than this value. This proves the second part of part(b) of Proposition 2. Likewise, Figure A2 proves the first part.

***Proof of Proposition 3***

We consider the changes in indirect utility functions with respect to *α*

As discussed in the paper, agents with $W_{it} < \hat{W}$ will adopt *Technology B*. These are agents for which the critical value of wealth required to adopt F does not drop below $\hat{W}$ regardless of increases in α within [0,1]. Thus their preferences are characterised by equation (2), which is reproduced below for convenience.

$$p\ln(c_{t+1}^{B,l}) + (1-p)\ln(c_{t+1}^{B,h}) + \theta p\ln(b_{t+1}^{B,l}) + \theta(1-p)\ln(b_{t+1}^{B,h})$$

Recognising that $b_{t+1} = \theta c_{t+1}$, we can substitute for $b_{it+1}$ and using the laws of logarithms and then simplifying, we can obtain the following indirect utility function:

$$p(1+\theta)\ln(c_{t+1}^{B,l}) + (1-p)(1+\theta)\ln(c_{t+1}^{B,h}) + \theta\ln\theta$$

Now we can substitute for $c_{t+1}^{B,l}$ and $c_{t+1}^{B,h}$ using their optimal consumptions equations (10) and (11) to obtain the following:

$$V^B(\alpha) = p(1+\theta)\ln\left(\frac{y_t^{B,l}}{1+\theta}\right) + (1-p)(1+\theta)\ln\left(\frac{y_t^{B,h}}{1+\theta}\right) + \theta\ln\theta \quad ,$$

The above can be rearranged to get:

$V^B(\alpha) = p(1+\theta)\ln\left(y_t^{B,l}\right) + (1-p)(1+\theta)\ln\left(y_t^{B,h}\right) + \theta\ln\theta + (1+\theta)\ln(1+\theta)$

Now differentiating with respect to $\alpha$ and simplifying we can get the FOC for $IUF^B$

$$\frac{\partial V^B(\alpha)}{\partial \alpha} = -\tau \overline{W}_t \left( \frac{p(1+\theta)}{y_t^{B,l}} + \frac{(1-p)(1+\theta)}{y_t^{B,h}} \right) < 0$$

Given that the term in brackets is positive under our assumptions, the indirect utility function is decreasing everywhere, with a single peak at $\alpha = 0$, which is the value of α that maximizes their utility. Agents with wealth levels below $W_t < \hat{W}$ therefore vote for α = 0.

Likewise, for agents with initial wealth in the range $[\widetilde{W}_t, \kappa]$, the indirect utility function is given by:

$V^F(\alpha) = p(1+\theta)\ln\left(y_t^{F,l}\right) + (1-p)(1+\theta)\ln\left(y_t^{F,h}\right) + \theta\ln\theta + (1+\theta)\ln(1+\theta)$.

The first order condition for maximization with respect to α is then expressed as:

$$\frac{\partial V^F(\alpha)}{\partial \alpha} = \left( -\tau \overline{W}_t + \frac{\psi \tau \overline{W}_t}{(1+\alpha\tau\overline{W}_t)^2} \right)\left( \frac{p(1+\theta)}{y_t^{F,l}} + \frac{(1-p)(1+\theta)}{y_t^{F,h}} \right) = 0.$$

Given the term in the second bracket is positive under our assumptions, the above can be satisfied *iff*

$$\frac{\psi}{\left(1+\alpha\tau\overline{W}_t\right)^2} = 1.$$

Finding the optimal value of α then amounts to solving the quadratic equation $1-\psi+\alpha^2\left(\tau\overline{W}_t\right)^2 + 2\alpha\tau\overline{W}_t = 0$. The economically meaningful, positive root is given by: $\alpha^* = \frac{2\tau\overline{W}_t\sqrt{\psi} - 2\tau\overline{W}_t}{2(\tau\overline{W}_t)^2}$. Given the conditions for an interior solution are satisfied, the remainder of Proposition 1 follows. A maximum for these agents is achieved at α in the range [0,1], with the single peak at $\alpha^*$.

**Proof of Proposition 4**

Consider an agent with wealth level W' falling in the interval $\left[\hat{W}, \widetilde{W}\right]$. By construction, $W^*$ falls within this interval for a given value of α. Without loss of generality suppose that W* is situated currently to the right of W'. However, since $W^*$ is monotonically decreasing in α in the range considered in our model – i.e. the range in which R&D causes W* to fall, its minimum value coincides with $\hat{W}$ and its maximum value coincides with $\widetilde{W}$. Then there must exist an $\alpha' \in [0,1]$ or $\alpha' \in [0, \hat{\alpha}]$ such that for $\alpha > \alpha'$ W* falls below W' and the agent is better off adopting Technology F for values of α above this value.[17]

[17] Recall from the result of proposition 2 that the "efficient" range of α – in which W* falls with α – can be either [0,1] or [0, $\hat{\alpha}$ ] where $\hat{\alpha} > \widetilde{\alpha} = \frac{\sqrt{\psi}-1}{\tau\overline{W}}$. As assumed above, we have restricted the vote on α to the

Note, however that the agent does not necessarily prefer these values of α over the range of values to the left of $\alpha'$ - it is simply that the indirect utility level for the agent *evaluated at values above* $\alpha'$ yields a higher utility in the case she adopts F. The preferences of such agents over α are then determined by an amalgamation of the two indirect utility funtions $V^B$ and $V^F$, with the former applicable below $\alpha'$, while the latter comes into play above $\alpha'$. To visualize this consider the preferences shown in Figure A3, which is obviously non-single peaked going by the characterization of preferences over α that is implied by Proposition 3. (Recall that proposition 3 characterized the preferences for B and F adopters separately – here the preferences are a mix of the two given that there is a critical value of α beyond which F can be adopted).

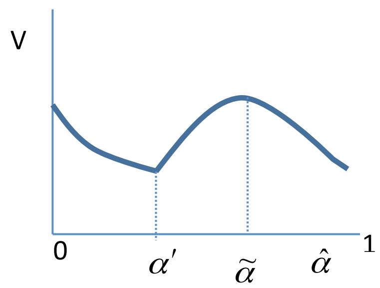


Figure A3

Note that the figure above is only indicative of the general shape the indirect utility functions may take; we do not know which of the two 'peaks' is higher than the other. Typically, depending on the parameters of the model, and the agent's wealth, we could have the agent's preferred value at either the right or the left. In order to find which value of α the agent will vote for, we have to compare the indirect utility function $V^B$ evaluated at at α=0 with the indirect utility function $V^F$ evaluated at $\alpha = \tilde{\alpha}$. This amounts, essentially, to comparing the LHS of equation (A1) evaluated at $\alpha = \tilde{\alpha}$ with the RHS of the same inequality evaluated at α=0. To do so, we define the following variables:

$$x_1 = y^{B,l}\big|_{\alpha=0} = (1-\tau)(\eta+\varepsilon_l)(\overline{w}+W)+\tau\overline{W};$$
$$x_2 = y^{B,h}\big|_{\alpha=0} = (1-\tau)(\eta+\varepsilon_h)(\overline{w}+W)+\tau\overline{W};$$
$$x_3 = y^{F,l}\big|_{\alpha=\tilde{\alpha}} = (1-\tau)\phi(\overline{w}+W)+\tau\overline{W}-2\sqrt{\overline{\psi}}+1;$$
$$x_4 = y^{F,h}\big|_{\alpha=\tilde{\alpha}} = (1-\tau)(\eta+\varepsilon_h)(\overline{w}+W)+\tau\overline{W}-2\sqrt{\overline{\psi}}+1.$$

Whether the agent prefers α=0 or $\alpha = \tilde{\alpha}$ then depends on the direction of the inequality below:

$$(x_1)^p(x_2)^{1-p} \gtreqless (x_3)^p(x_4)^{1-p}.$$

We can see that the slope of $x_2$ and $x_4$ with respect to $W$ is positive and identical. Also, the slopes of the other two variables with respect to W are also positive. However, since the

efficient range so that W* changes monotonically in this range, towards $\hat{W}$ as α increases and towards $\tilde{W}$ as α decreases.

slope of $x_3$ with respect to $W$ is greater than the slope of of $x_1$ with respect to W, the slope of the RHS is greater than that of the LHS.

Secondly, given that $x_2 > x_4$, a sufficient condition for an agent to prefer α=0 is derived by comparing $x_1$ and $x_3$. It is easy to see that if

$$W < \frac{2\sqrt{\psi} - 1}{(1-\tau)(\phi - \eta - \varepsilon_l)} - \overline{w}$$

then $x_1 > x_3$ so that the LHS is greater than the RHS. Agents with a wealth level below this value will then definitely prefer α=0. However for W above this value $x_3$ increases at a faster rate as W increases at a faster rate than $x_1$ given that $\eta + \varepsilon_l < \phi$. The LHS therefore cuts the RHS from below at a critical level of wealth $W'$ beyond which the RHS becomes greater than the LHS and agents prefer $\alpha = \tilde{\alpha} = \frac{\sqrt{\psi} - 1}{\tau \overline{W}}$.

**Proof of Proposition 5**

Consider again $W^*$ as implicitly defined by equation (A1) of this Appendix. Differentiating implicitly with respect to $W^*$ and $\varepsilon_l$ we get:

$$\left[\begin{array}{l} p\left(y^{F,l}\right)^{p-1}\left(y^{F,h}\right)^{1-p}\dfrac{\partial y^{F,l}}{\partial W^*} + (1-p)\left(y^{F,h}\right)^{-p}\left(y^{F,l}\right)^{p}\dfrac{\partial y^{F,h}}{\partial W^*} \\ \qquad - p\left(y^{B,l}\right)^{p-1}\left(y^{B,h}\right)^{1-p}\dfrac{\partial y^{B,l}}{\partial W^*} - (1-p)\left(y^{B,l}\right)^{p}\left(y^{B,h}\right)^{-p}\dfrac{\partial y^{B,h}}{\partial W^*} \end{array}\right] dW^*$$

$$= \left[\begin{array}{l} p\left(y^{B,l}\right)^{p-1}\left(y^{B,h}\right)^{1-p}\dfrac{\partial y^{B,l}}{\partial \varepsilon_l} + (1-p)\left(y^{B,h}\right)^{-p}\left(y^{B,l}\right)^{p}\dfrac{\partial y^{B,h}}{\partial \varepsilon_l} \\ \qquad - p\left(y^{F,l}\right)^{p-1}\left(y^{F,h}\right)^{1-p}\dfrac{\partial y^{F,l}}{\partial \varepsilon_l} - (1-p)\left(y^{F,l}\right)^{p}\left(y^{F,h}\right)^{-p}\dfrac{\partial y^{F,h}}{\partial \varepsilon_l} \end{array}\right] d\varepsilon_l .$$

We have already shown that the term multiplying $dW^*$ is positive. For convenience, we denote this as T1. Also notice that in the term multiplying $d\varepsilon_l$ we have:

$$\frac{\partial y^{B,l}}{\partial \varepsilon_l} = (1-\tau)(\overline{w} + W^*); \quad \frac{\partial y^{B,h}}{\partial \varepsilon_l} = \frac{\partial y^{F,l}}{\partial \varepsilon_l} = \frac{\partial y^{F,h}}{\partial \varepsilon_l} = 0.$$

Therefore,

$$\frac{dW^*}{d\varepsilon_l} = \frac{p(y^{B,l})^{p-1}(y^{B,h})^{1-p}(1-\tau)(\overline{w} + W^*)}{T1} > 0.$$

Likewise, we can show

$$\frac{\partial W^*}{\partial \varepsilon_h} = \frac{(1-p)(y^{B,h})^{-p}(y^{B,l})^{p}\dfrac{\partial y^{B,h}}{\partial \varepsilon_h} - (1-p)(y^{F,h})^{-p}(y^{F,l})^{p}\dfrac{\partial y^{F,h}}{\partial \varepsilon_h}}{T1}.$$

This can be written as:

$$\frac{\partial W^*}{\partial \varepsilon_h} = \frac{(1-p)\left[\frac{(y^{B,h})^{1-p}(y^{B,l})^p}{y^{B,h}} - \frac{(y^{F,h})^{1-p}(y^{F,l})^p}{y^{F,h}}\right](1-\tau)(\overline{w}+W^*)}{T1}.$$

Note that the numerators of the two terms inside the square bracket are identical when evaluated at W*. Also $y^{B,h} > y^{F,h}$. Therefore the expression inside the square bracket is negative. Given all other terms including T1 are positive, we conclude:

$$\frac{\partial W^*}{\partial \varepsilon_h} < 0.$$

We now turn to the second part of proposition 5. It can be shown that:

$$\frac{\partial W^*}{\partial \varepsilon_h} + \frac{\partial W^*}{\partial \varepsilon_l} = \frac{\left[\frac{p(y^{B,h})^{1-p}(y^{B,l})^p}{y^{B,l}} + \frac{(1-p)(y^{B,h})^{1-p}(y^{B,l})^p}{y^{B,h}} - \frac{(1-p)(y^{F,h})^{1-p}(y^{F,l})^p}{y^{F,h}}\right](1-\tau)(\overline{w}+W^*)}{T1}.$$

Cancelling out terms that that are equivalent when evaluated at W*,

$$\frac{\partial W^*}{\partial \varepsilon_h} + \frac{\partial W^*}{\partial \varepsilon_l} \geq (\leq)\ 0 \quad iff \quad \frac{p}{y^{B,l}} + \frac{1-p}{y^{B,h}} - \frac{1-p}{y^{F,h}} \geq (\leq)\ 0.$$

We know that the last two terms add up to a negative amount while the first term is positive. The sign of the sum of the partial derivatives of W* with respect to the positive and negative shocks is therefore ambiguous.

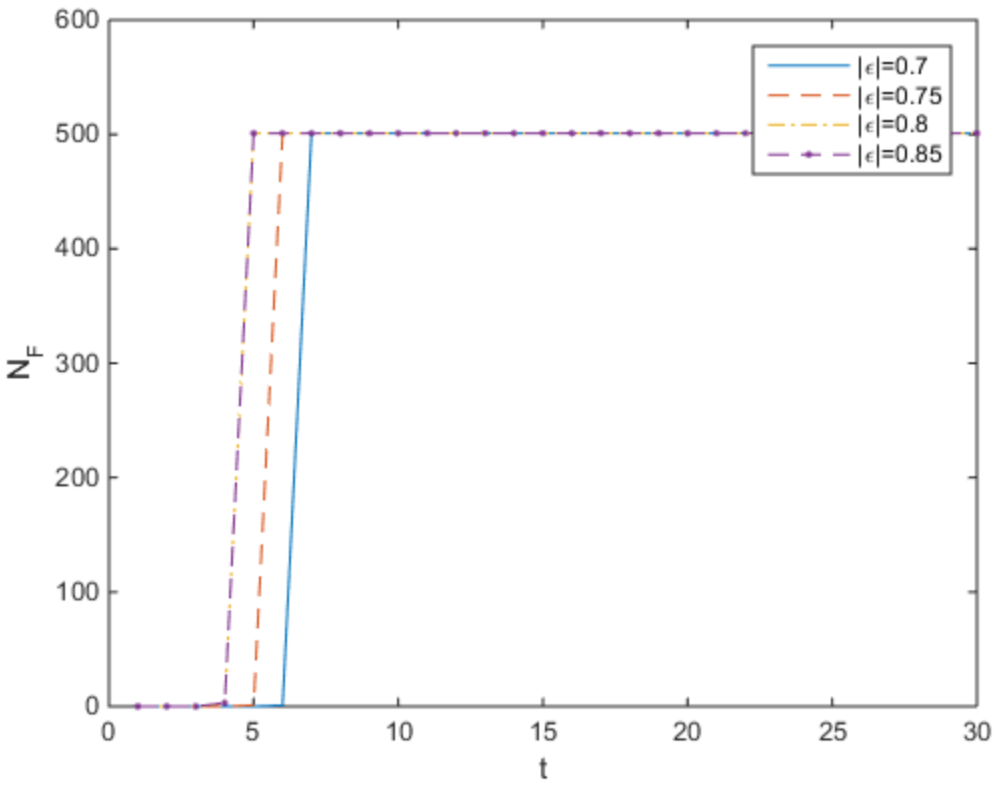


Figure 3.1: Number of F adopters over time: voting mechanism

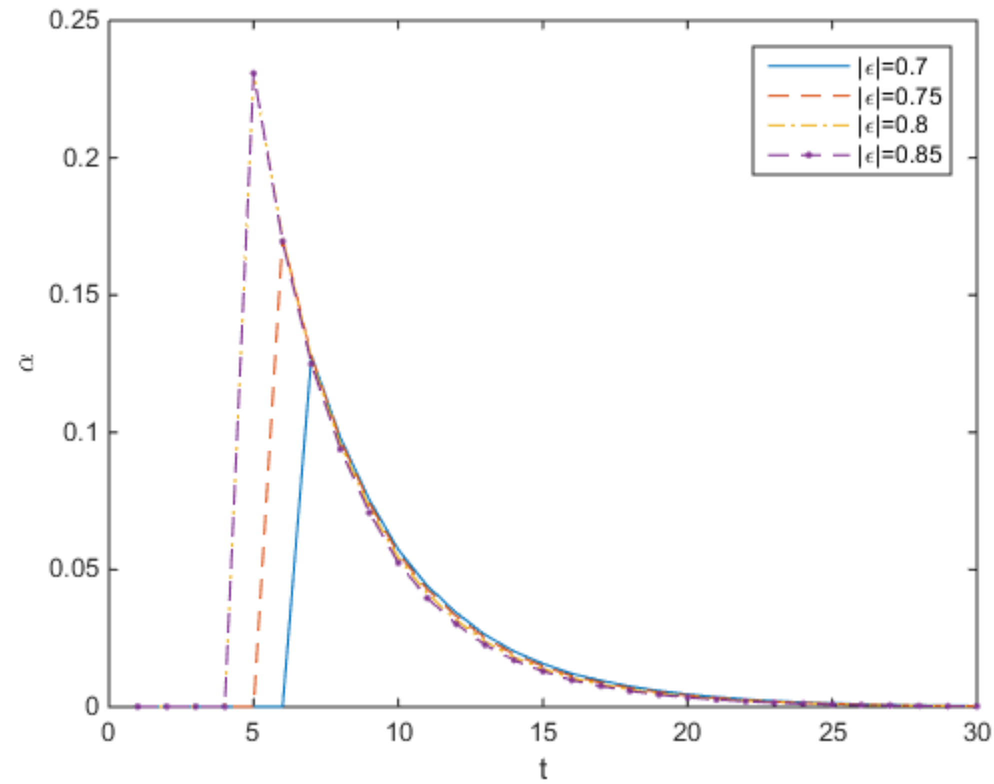


Figure 3.2: Proportion of revenues allocated to cost-reducing R&D: voting mechanism

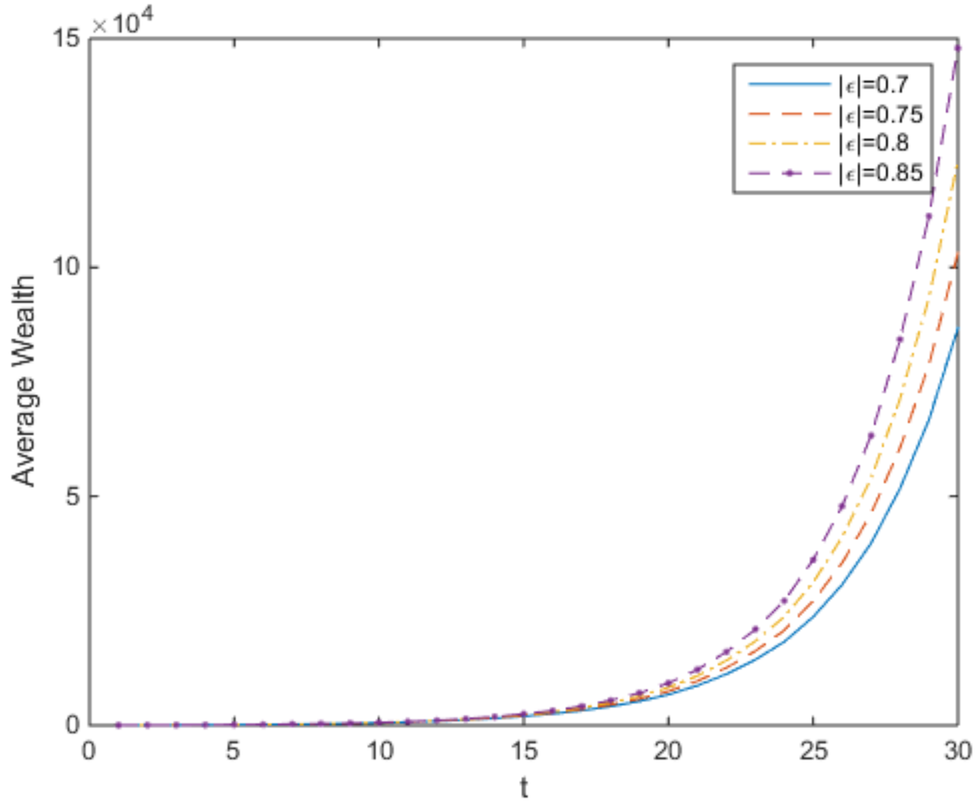


Figure 3.3: Average wealth overtime: voting mechanism

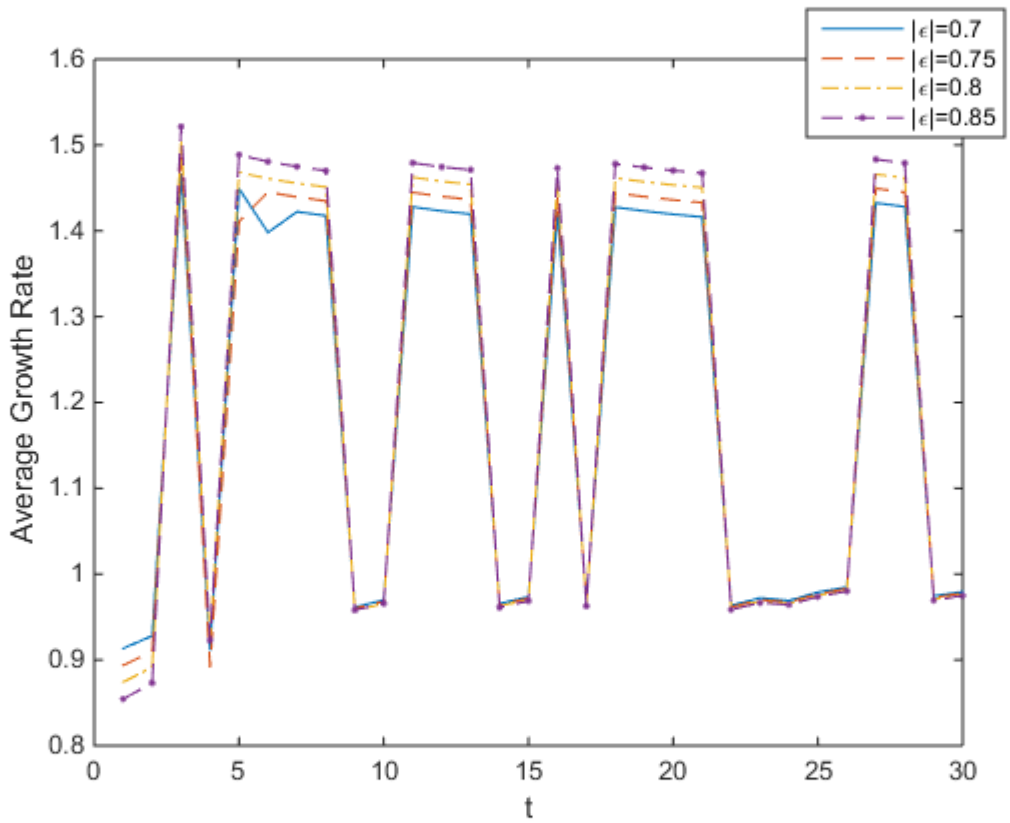


Figure 3.4: Average growth rates over time: voting mechanism

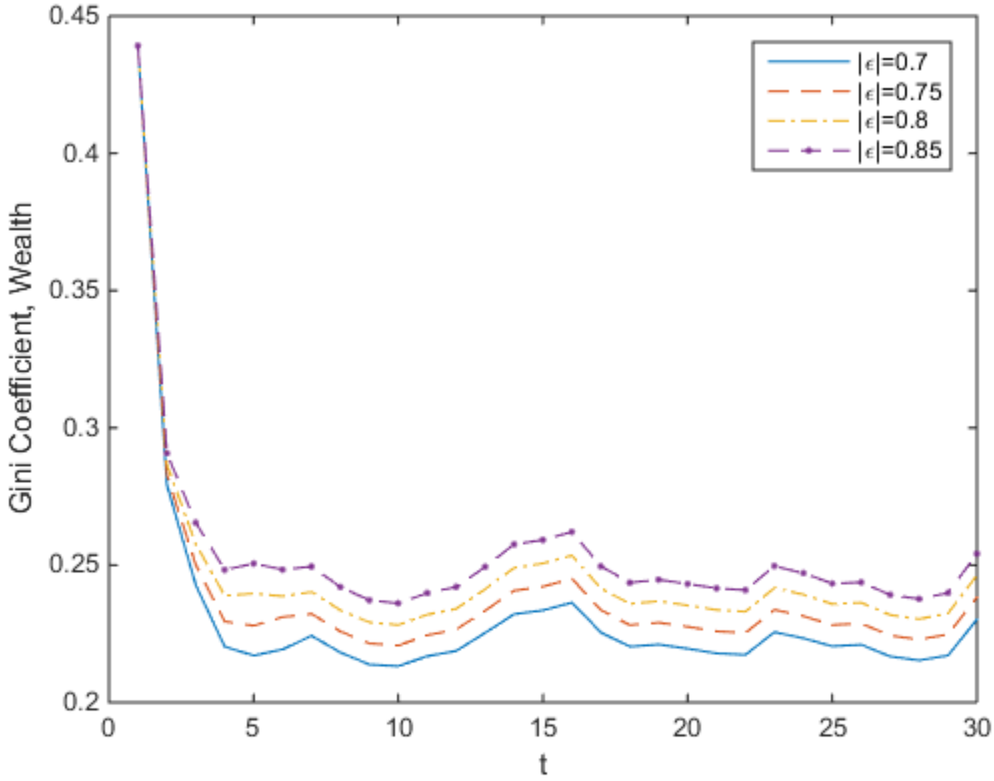


Figure 3.5: Gini coefficient of wealth over time: voting mechanism

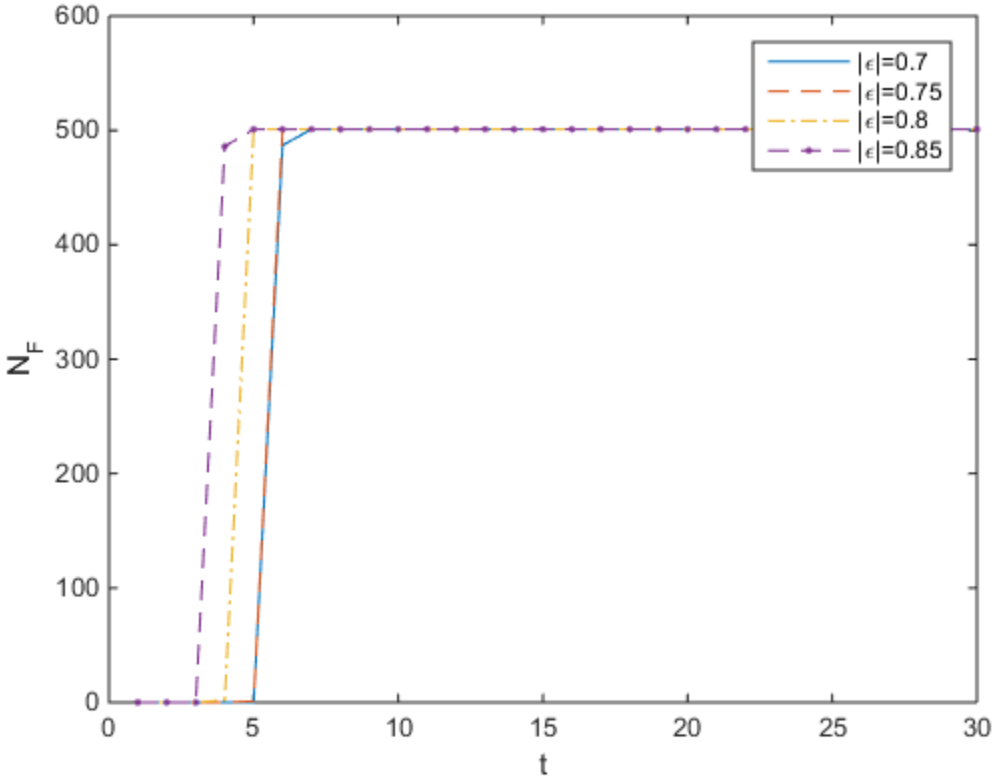


Figure 3.6: Number of F adopters, Benthamite case

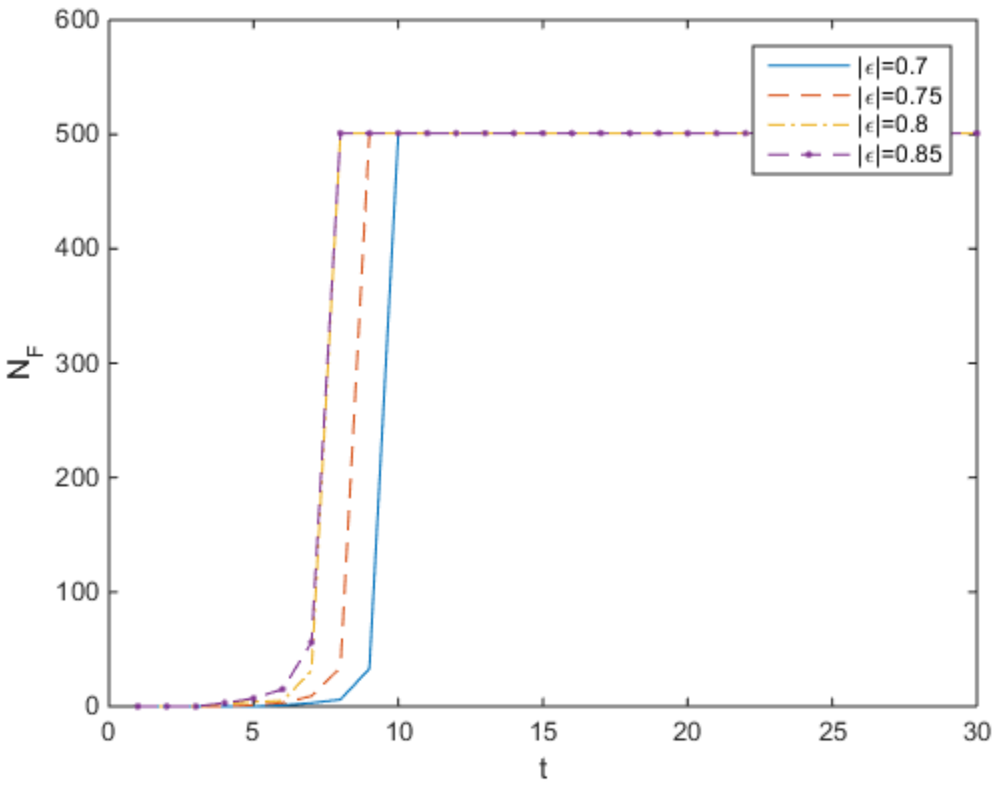


Figure 3.7: Number of F adopters, Rawlsian case

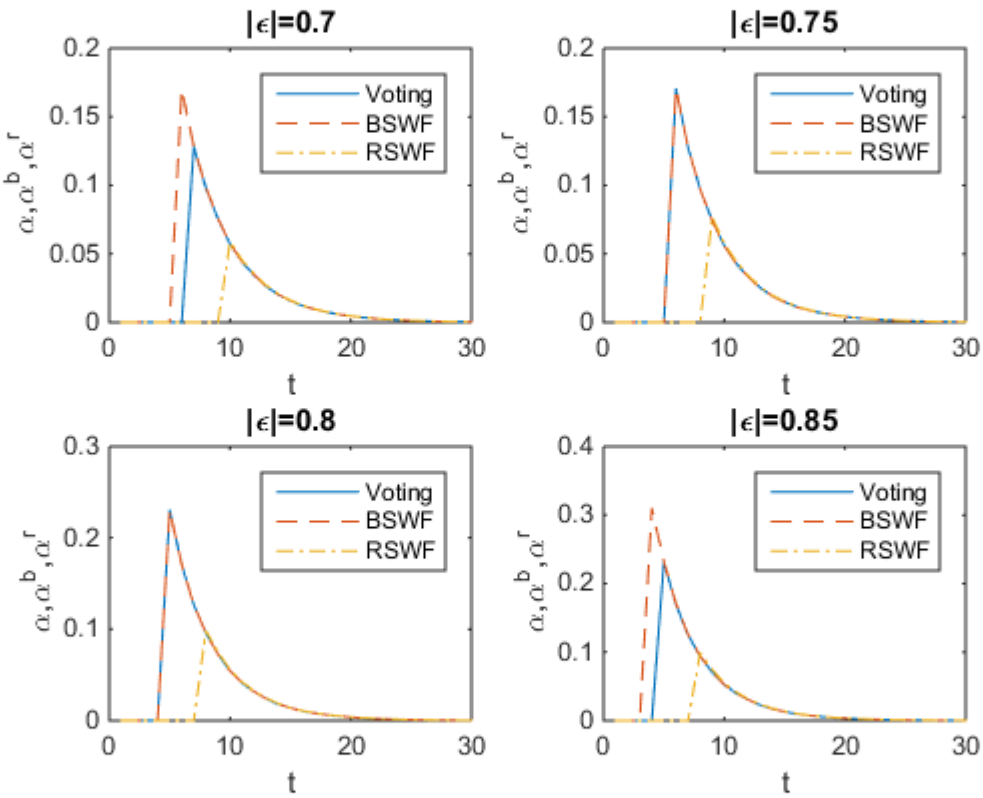


Figure 3.8: Cost reducing R&D over time, various choice mechanisms.

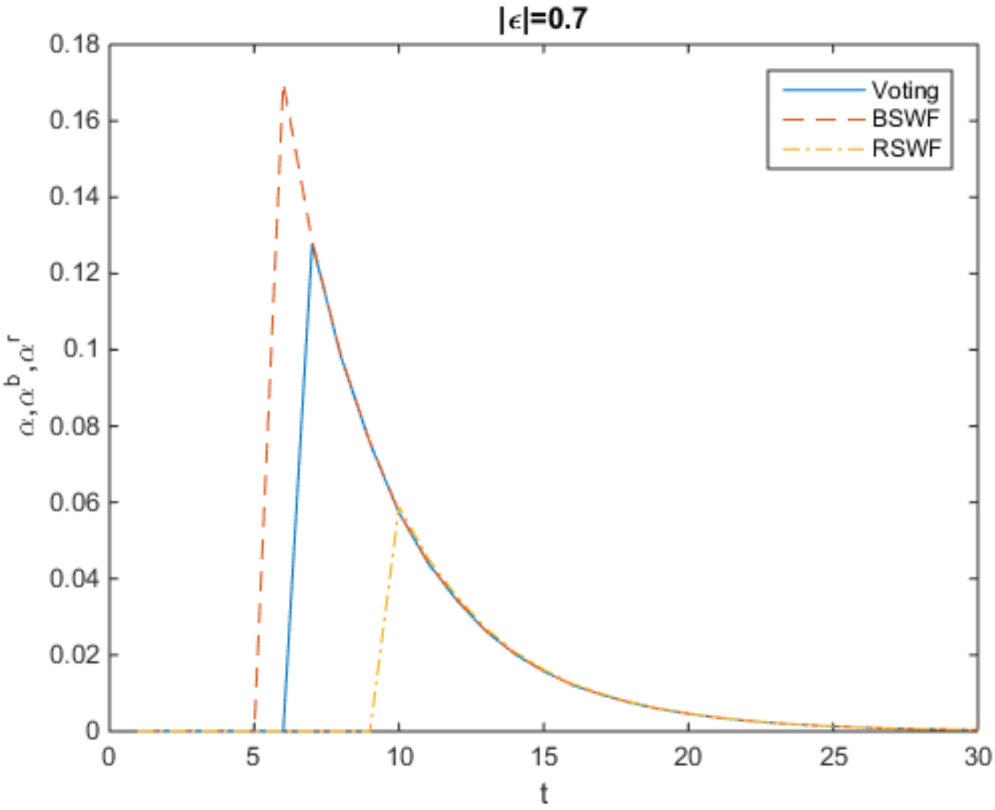


Figure 3.9: Magnified version of figure 3.8 panel (i)

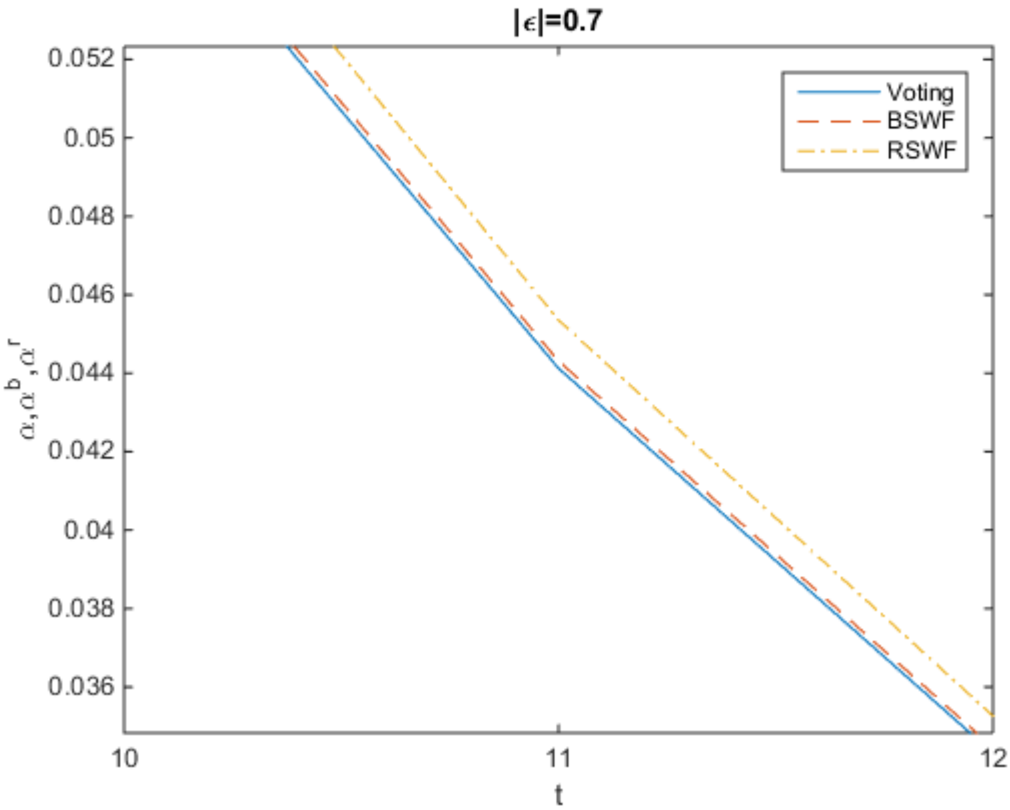


Figure 3.10: Further magnification of figure 3.8 panel (i)

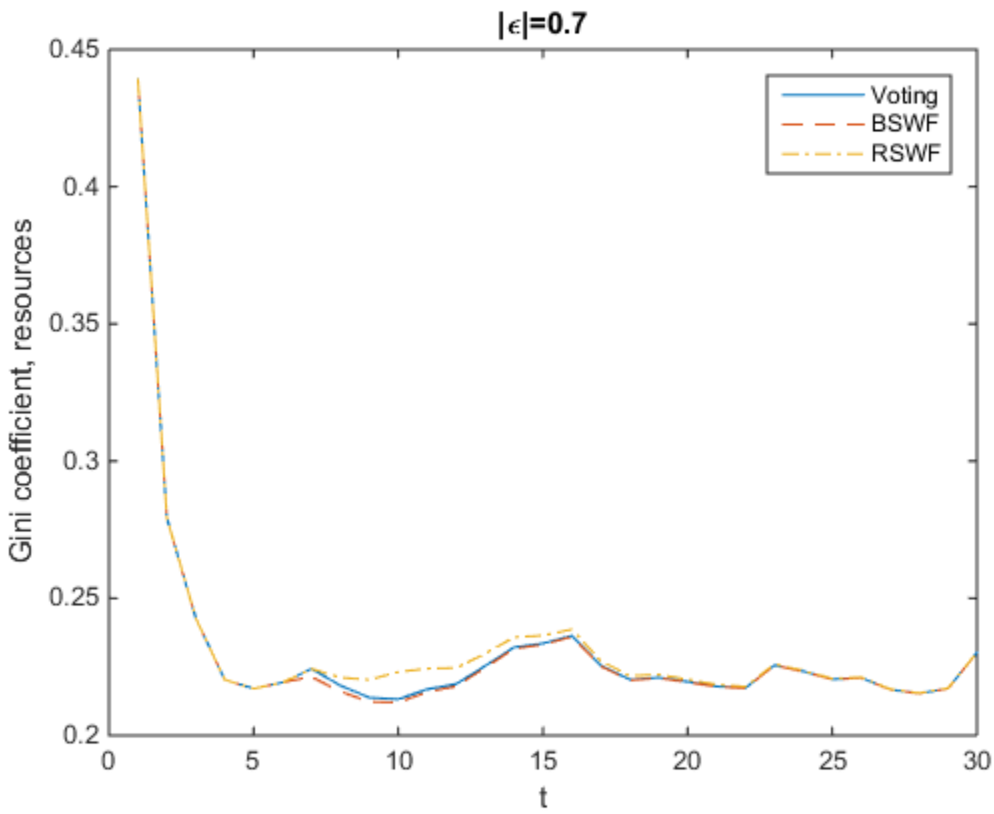


Figure 3.11: Inequality over time, various mechanisms

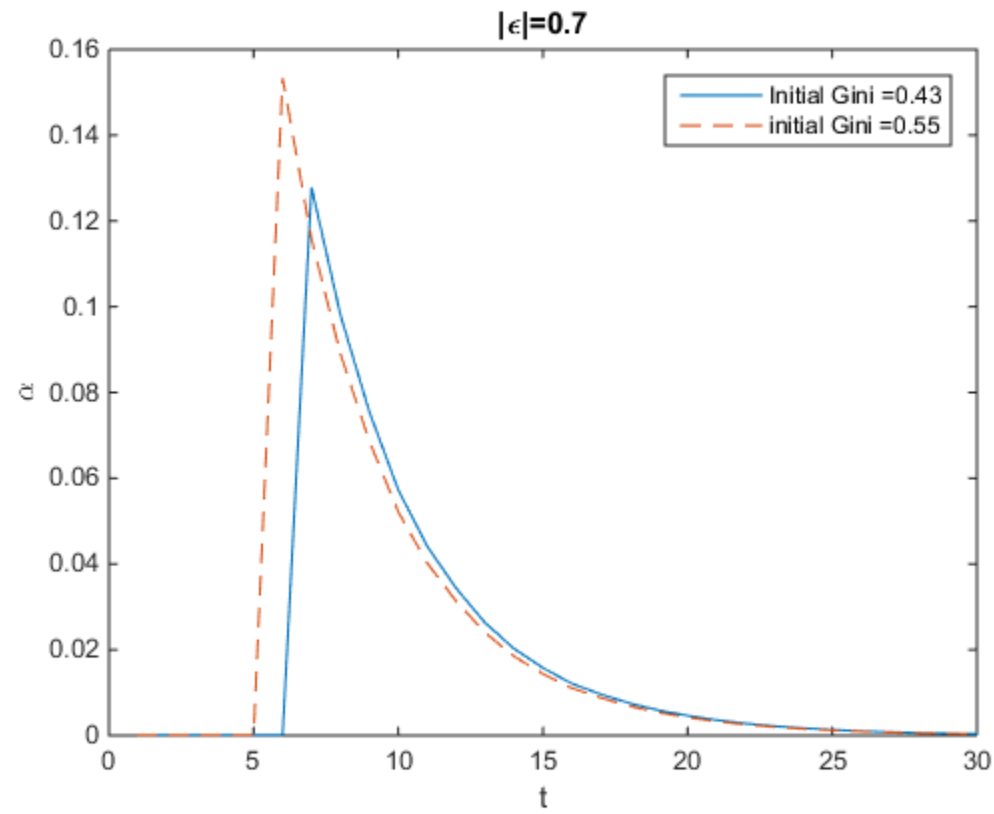


Figure 3.12: Cost reducing R&D over time, different initial distributions

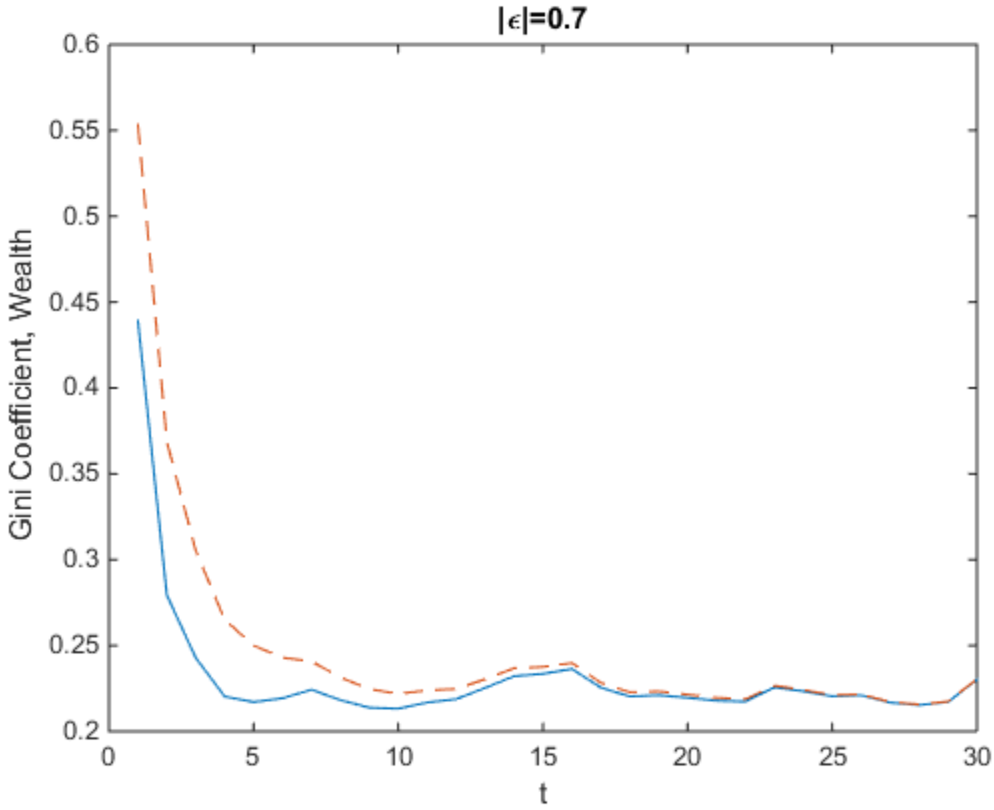


Figure 3.13: Inequality over time, different initial distributions

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