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Abstract

This study explores the conflict of interests between workers and capitalists in a Schumpeterian economy. We consider the limit on the market power of monopolistic firms as a policy instrument and derive its optimal levels for workers and capitalists, respectively. Because monopolistic profit provides incentives for innovation, workers may prefer monopolistic firms to have some market power, but they prefer less powerful monopolistic firms than capitalists. Workers' preferred level of monopolistic power is decreasing in their discount rate and increasing in innovation productivity and the quality step size. Capitalists' preferred level of monopolistic power is increasing in the quality step size. We use the difference in levels preferred by workers and capitalists to measure the severity of their conflict of interests, which becomes less severe when workers' discount rate falls or innovation productivity rises. Finally, at a small (large) quality step size, enlarging the step size mitigates (worsens) their conflict.

JEL classification: O30, O40, E11
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1 Introduction

The conflict of interests between workers and capitalists is a core element in Marxian economics. In this study, we explore this conflict of interests between workers and capitalists in a canonical Schumpeterian growth model. According to Dutt (1990), the degree of monopolistic power can capture the rate of capitalists' exploitation on workers. Therefore, we consider the limit on the market power of monopolistic firms as a policy instrument and derive its optimal levels for workers and capitalists, respectively. Our results can be summarized as follows.

Workers may prefer monopolistic firms to have some market power, but they prefer less powerful monopolistic firms than capitalists. Therefore, strengthening the bargaining power of workers relative to capitalists would reduce the markup of monopolistic firms, which in turn stifles innovation and economic growth. For workers, their preferred level of monopolistic power is decreasing in their discount rate and increasing in innovation productivity and the quality step size, whereas for capitalists, their preferred level of monopolistic power is increasing in the quality step size. We use the difference in the levels of monopolistic power preferred by workers and capitalists to measure the severity of their conflict of interests. We find that their conflict becomes less severe when the discount rate falls or innovation productivity rises. As for the quality step size, its effect on the severity of their conflict is U-shaped. Specifically, at a small (large) quality step size, enlarging the size of quality improvement mitigates (worsens) their conflict of interests. The intuition of these results can be explained as follows.

Because monopolistic profit provides incentives for innovation, even workers may prefer monopolistic firms to have some market power. However, an increase in monopolistic profit reduces the labor share of income, so workers prefer a lower level of monopolistic power than capitalists, who benefit from monopolistic profit. Given that the benefit of monopolistic profit for workers comes solely from innovation, a fall in their discount rate or a rise in innovation productivity would enable workers to benefit more from economic growth. In this case, their preferred level of monopolistic power increases towards the capitalists' preferred level, and hence, the tension between workers and capitalists falls.

A larger step size of quality improvement increases the preferred levels of monopolistic power for both workers and capitalists. For workers, a larger quality step size affects their utility via its positive effect on economic growth. For capitalists, a larger quality step size affects their utility via the monopolistic profit that they receive. The increase in the growth effect is particularly strong at a small quality step size, whereas the increase in the profit effect is particularly strong at a large quality step size. Therefore, at a small (large) quality step size, enlarging the size of quality improvement closes (widens) the gap between the different levels of monopolistic power preferred by workers and capitalists.

This study relates to the literature on Marxian growth theory; see Harris (1978), Marglin (1984) and Dutt (1990) for early studies and Dutt (2011), Dutt and Veneziani (2019, 2020) and Cogliano *et al.* (2021) for more recent studies. Studies in this literature follow the tradition of Solow (1956) by considering physical/human capital accumulation as the engine of economic growth. We complement the interesting studies in this literature by exploring Marxian class struggle in a Schumpeterian growth model in which the economy is characterized by monopolistic competition and features market-driven innovation as the engine of economic growth. Kalecki (1971) emphasized the importance of imperfect competition in the analysis of class struggle and wrote that "only by [...] penetrating the world of imperfect competition [...] are we able to draw any reasonable conclusion on the impact of bargaining for wages on the distribution of income."

This study also relates to the literature on innovation and economic growth. The seminal study in this literature is Romer (1990), who also emphasizes the importance of imperfect competition and develops the first R&D-based growth model in which economic growth is due to the development of new products by profit-seeking entrepreneurs. Then, Aghion and Howitt (1992) develop the Schumpeterian growth model in which economic growth is driven by the quality improvement of products; see also Segerstrom *et al.* (1990) and Grossman and Helpman (1991) for other early studies and Aghion *et al.* (2014) for a survey. Subsequent studies apply the Schumpeterian growth model to explore various policy instruments, including patent breadth that also determines the market power of monopolistic firms. For example, Li (2001) explores the effects of patent breadth on economic growth, whereas Goh and Olivier (2002), Chu (2011) and Iwaisako (2020) derive optimal patent breadth for a representative household. Chu (2010), Chu and Cozzi (2018) and Chu *et al.* (2021) analyze the effects of patent breadth on income inequality in the presence of heterogeneous households. This study contributes to this literature by exploring the political economics behind the market power of monopolistic firms and comparing the different levels of monopolistic power preferred by workers and capitalists.

The rest of this study is organized as follows. Section 2 presents the model. Section 3 derives the optimal levels of monopolistic power for workers and capitalists and then explores their difference. Section 4 extends the model to allow for heterogeneous workers and heterogeneous capitalists. Section 5 concludes.

2 A Schumpeterian growth model with Marxian class struggle

The Schumpeterian growth model is developed by Aghion and Howitt (1992). In this model, innovation is driven by the quality improvement of products. Here we follow the treatment in Grossman and Helpman (1991). Given that the Schumpeterian growth model has been studied extensively, we omit some of the details in this section. The key modification is that we replace the representative household by two distinct classes: workers and capitalists.

2.1 Capitalists and workers

Capitalists and workers, indexed by $i \in \{c, w\}$ respectively, have the following lifetime utility function:

$$U^i = \int_0^\infty e^{-\rho t} \ln c_t^i dt, \tag{1}$$

where the parameter $\rho > 0$ is the discount rate. c_t^c denotes consumption of capitalists at time t whereas c_t^w denotes consumption of workers. Workers supply one unit of labor to earn wage income w_t, and they simply consume their wage income, such that $c_t^w = w_t$.

Capitalists own assets and do not work. The asset-accumulation equation is given by

$$\dot{a}_t = r_t a_t - c_t^c, \tag{2}$$

where a_t is the value of assets (i.e., the share of monopolistic firms) and r_t is the interest rate. Dynamic optimization yields the consumption path of capitalists as

$$\frac{\dot{c}_t^c}{c_t^c} = r_t - \rho. \tag{3}$$

2.2 Final good

Competitive firms use the following Cobb-Douglas aggregator to produce final good y_t:

$$y_t = \exp\left(\int_0^1 \ln x_t(j) dj\right), \tag{4}$$

in which $x_t(j)$ for $j \in [0,1]$ denotes a unit continuum of differentiated intermediate goods. Maximizing profit, we derive the conditional demand function for $x_t(j)$ as

$$x_t(j) = \frac{y_t}{p_t(j)}, \tag{5}$$

where $p_t(j)$ denotes the price of $x_t(j)$.

2.3 Intermediate goods

The economy features a unit continuum of monopolistic industries that produce intermediate goods. Each monopolistic industry is dominated by a temporary industry leader (who owns the latest quality improvement in the industry) until the arrival of the next innovation. The industry leader in industry j produces the differentiated intermediate good $x_t(j)$. The production function of the industry leader in industry $j \in [0,1]$ is

$$x_t(j) = z^{q_t(j)} l_t(j), \tag{6}$$

where the parameter $z > 1$ is the quality step size, $q_t(j)$ is the number of quality improvements that have occurred in industry j as of time t, and $l_t(j)$ is production labor employed in industry j.

Given the productivity level $z^{q_t(j)}$, the marginal cost of the leader in industry j is $w_t / z^{q_t(j)}$. From the Bertrand competition between the current industry leader and the previous industry leader, the profit-maximizing price for the current industry leader is

$$p_t(j) = \mu \frac{w_t}{z^{q_t(j)}}, \tag{7}$$

where $\mu \in (1, z]$ is the markup ratio. Grossman and Helpman (1991) and Aghion and Howitt (1992) assume that the markup μ is equal to the quality step size z. Here we consider $\mu \leq z$ as a policy parameter that is decided by the government, which uses its authority to limit the market power of monopolistic firms.[1]

The wage payment in industry j is

$$w_t l_t(j) = \frac{1}{\mu} p_t(j) x_t(j) = \frac{1}{\mu} y_t, \tag{8}$$

and the monopolistic profit in industry j is

$$\pi_t(j) = p_t(j) x_t(j) - w_t l_t(j) = \frac{\mu - 1}{\mu} y_t. \tag{9}$$

Equation (8) shows that $w_t l_t / y_t$ is decreasing in the markup μ, which is interpreted as capitalists' exploitation on workers in Marxian economics.

2.4 R&D

Equation (9) shows that $\pi_t(j) = \pi_t$. Therefore, the value of inventions is symmetric across industries such that $v_t(j) = v_t$ for $j \in [0, 1]$.[2] Then, the no-arbitrage condition that determines v_t is

$$r_t = \frac{\pi_t + \dot{v}_t - \lambda_t v_t}{v_t}. \tag{10}$$

Intuitively, the no-arbitrage condition equates the interest rate r_t to the rate of return on v_t given by the sum of monopolistic profit π_t, capital gain $\dot{v}_t$ and expected capital loss $\lambda_t v_t$, where λ_t is the arrival rate of innovation. When the next innovation occurs, the previous technology becomes obsolete.[3]

Competitive entrepreneurs devote R_t units of final good to perform innovation in each industry. We specify the arrival rate of innovation as

$$\lambda_t = \frac{\varphi R_t}{Z_t}, \tag{11}$$

where $\varphi > 0$ is an R&D productivity parameter and Z_t denotes the aggregate level of technology, which captures an increasing-difficulty effect of R&D. The free-entry condition for R&D is

$$\lambda_t v_t = R_t \Leftrightarrow \frac{\varphi v_t}{Z_t} = 1, \tag{12}$$

where the second equality uses (11).

[1] Li (2001) interprets $\mu < z$ as incomplete patent breadth.
[2] See Cozzi *et al.* (2007) for a theoretical justification for the symmetric equilibrium.
[3] See Cozzi (2007) for a discussion on the Arrow replacement effect.

2.5 Economic growth

Aggregate technology Z_t is defined as

$$Z_t \equiv \exp\left(\int_0^1 q_t(j)dj \ln z\right) = \exp\left(\int_0^t \lambda_\omega d\omega \ln z\right), \tag{13}$$

which uses the law of large numbers and equates the average number of quality improvements $\int_0^1 q_t(j)dj$ that have occurred as of time t to the average number of innovation arrivals $\int_0^t \lambda_\omega d\omega$ up to time t. Differentiating the log of Z_t with respect to time yields the growth rate of technology given by

$$g_t \equiv \frac{\dot{Z}_t}{Z_t} = \lambda_t \ln z. \tag{14}$$

Substituting (6) into (4) yields the aggregate production function given by

$$y_t = \exp\left(\int_0^1 q_t(j)dj \ln z + \int_0^1 \ln l_t(j)dj\right) = Z_t, \tag{15}$$

where we have used the symmetry condition and the resource constraint: $l_t(j) = l_t = 1$. Therefore, the growth rate of final good y_t is also g_t, which is determined by λ_t as in (14).

Using $\dot{c}_t^c/c_t^c = g_t$ and (3) in (10), we derive the balanced-growth value of an invention as

$$v_t = \frac{\pi_t}{\rho+\lambda} = \frac{\mu-1}{\mu}\frac{Z_t}{\rho+\lambda}, \tag{16}$$

which uses (9) and (15). Equation (16) shows that v_t is increasing in level of markup μ. Substituting (16) into (12) yields

$$\lambda^* = \frac{\mu-1}{\mu}\varphi - \rho, \tag{17}$$

which is the steady-state arrival rate of innovation. Equation (17) shows that the steady-state arrival rate λ^* of innovation is increasing in the markup μ. Therefore, the steady-state growth rate is

$$g^* = \lambda^* \ln z = \left(\frac{\mu-1}{\mu}\varphi - \rho\right)\ln z, \tag{18}$$

which is also increasing in the markup μ.[4]

3 Conflict between workers and capitalists

We now derive the optimal levels of markup for capitalists and workers, respectively. Given that the economy is always on the balanced growth path,[5] we can rewrite (1) as

$$U^i = \frac{1}{\rho}\left(\ln c_0^i + \frac{g^*}{\rho}\right) \tag{19}$$

[4]This result originates from Li (2001), who analyzes patent breadth in the Schumpeterian model.

[5]It can be shown that the economy always jumps to a balanced growth path; see the appendix.

for $i \in \{c, w\}$. The resource constraint on final good is given by

$$y_t = c_t^c + c_t^w + R_t. \tag{20}$$

Using (8) and (15), we derive the consumption of workers as

$$c_t^w = w_t l_t = \frac{y_t}{\mu} = \frac{Z_t}{\mu}, \tag{21}$$

which is decreasing in the markup μ. Using (11) and (17), we derive the level of R&D as

$$R_t = \frac{\lambda_t Z_t}{\varphi} = \left(\frac{\mu - 1}{\mu}\varphi - \rho\right)\frac{Z_t}{\varphi}. \tag{22}$$

Substituting (15), (21) and (22) into (20) yields

$$c_t^c = y_t - c_t^w - R_t = \frac{\rho}{\varphi} Z_t, \tag{23}$$

which is independent of the markup μ. It is useful to note that $c_t^c = \pi_t - R_t$ is independent of μ because both π_t and R_t are increasing in μ.

Substituting (18) and (21) into (19) yields the welfare function of capitalists as

$$U^c = \frac{1}{\rho}\left[\ln\left(\frac{\rho Z_0}{\varphi}\right) + \left(\frac{\mu - 1}{\mu}\varphi - \rho\right)\frac{\ln z}{\rho}\right], \tag{24}$$

where the initial level Z_0 is exogenous. U^c is monotonically increasing in μ due to its positive effect on economic growth. Therefore, the capitalists prefer the maximum level of markup, such that

$$\mu^c = z, \tag{25}$$

which is increasing in the quality step size.[6] Substituting (18) and (23) into (19) yields the welfare function of workers as

$$U^w = \frac{1}{\rho}\left[\ln\left(\frac{Z_0}{\mu}\right) + \left(\frac{\mu - 1}{\mu}\varphi - \rho\right)\frac{\ln z}{\rho}\right]. \tag{26}$$

The degree of markup that maximizes U^w is given by

$$\mu^w = \max\left\{\frac{\varphi \ln z}{\rho}, 1\right\}. \tag{27}$$

The intuition for μ^w can be explained as follows. Monopolistic power provides incentives for innovation, so even workers may prefer monopolistic firms to have some market power. This is the case when innovation productivity is sufficiently high (i.e., $\varphi > \rho/\ln z$). Given

[6] This upper bound on the markup arises from the constraint due to the Bertrand competition. If current industry leaders can consolidate market power with previous industry leaders, then they would choose an even higher markup, which however would still be proportional the quality step size z; see O'Donoghue and Zweimuller (2004) for such an analysis.

that the benefit of monopolistic power for workers comes solely from innovation, a fall in their discount rate or a rise in innovation productivity or a larger quality step size would enable workers to benefit more from economic growth. Therefore, μ^w is increasing in R&D productivity φ and the quality step size z but decreasing in the discount rate ρ. We impose the following parameter restriction:[7]

$$\frac{\varphi \ln z}{\rho} < z, \tag{28}$$

which ensures that $\mu^w < \mu^c$. Workers prefer less powerful monopolistic firms than capitalists because a larger markup reduces the labor share of income given by $w_t l_t / y_t = 1/\mu$.

Proposition 1 *Given (28), workers prefer a lower markup than capitalists, who in turn prefer the maximum markup given by $\mu^c = z$. If $\varphi \leq \rho / \ln z$, then workers prefer a zero markup (i.e., $\mu^w = 1$). If $\rho / \ln z < \varphi < z\rho / \ln z$, then workers prefer a positive markup (i.e., $\mu^w > 1$), which is increasing in R&D productivity φ and the quality step size z but decreasing in the discount rate ρ.*

Proof. Compare (25) and (27). Then, use (27) to show that μ^w is increasing in φ and z but decreasing in ρ. ■

Suppose both workers and capitalists try to influence the markup policy of the government. In this case, we follow Grossman and Helpman (2001) to specify the government's objective function as follows:

$$\widetilde{U} \equiv \theta U^w + (1-\theta) U^c = \frac{1}{\rho} \left[\theta \ln \left(\frac{Z_0}{\mu} \right) + (1-\theta) \ln \left(\frac{\rho Z_0}{\varphi} \right) + \left(\frac{\mu - 1}{\mu} \varphi - \rho \right) \frac{\ln z}{\rho} \right], \tag{29}$$

where $\theta \in (0,1)$ is the weight that the government places on workers relative to capitalists and captures the bargaining power of workers in their class struggle with capitalists. In this case, the policy chosen by the government is

$$\widetilde{\mu} = \min \left\{ \frac{\varphi \ln z}{\theta \rho}, z \right\} \in (\mu^w, \mu^c], \tag{30}$$

which is decreasing in θ. In other words, as the bargaining power of workers increases, the government reduces the markup of monopolistic firms. This in turn stifles economic growth because monopolistic profit serves as the incentive for innovation, which is a core element in R&D-based growth theory. As Jones (2019) nicely summarizes, "imperfect competition provides the profits that incentivize entrepreneurs to innovate."

Proposition 2 *An increase in the bargaining power of workers in the government's objective function leads to a lower market power of monopolistic firms, which in turn reduces innovation and economic growth.*

[7] If this inequality does not hold, then even workers would prefer the maximum level of markup such that $\mu^w = z$, which is neither realistic nor interesting.

Proof. Use (30) to show that $\widetilde{\mu}$ is decreasing in θ. Use (17) and (18) to show that λ^* and g^* are increasing in μ. ■

The government chooses $\widetilde{\mu}$ to try to balance the conflict of interests between workers and capitalists but cannot satisfy both groups unless they prefer the same level of monopolistic power. Therefore, we use the difference between the levels of monopolistic power preferred by workers and capitalists to measure the severity of their conflict of interests. Formally,

$$\sigma \equiv \mu^c - \mu^w = z - \frac{\varphi \ln z}{\rho}, \tag{31}$$

which is increasing in the discount rate ρ and decreasing in R&D productivity φ. Intuitively, a fall in the workers' discount rate or a rise in innovation productivity would enable the workers to benefit more from economic growth and increase their preferred level of monopolistic power towards the capitalists' preferred level. As a result, the tension between workers and capitalists falls.

As for the quality step size z, its effect on σ is U-shaped. Specifically, at a small (large) quality step size, raising the step size z reduces (raises) σ. A larger quality step size z increases the preferred levels of monopolistic power for both workers and capitalists. For workers, a larger quality step size affects their utility via its positive effect on economic growth, captured by the term $\ln z$. For capitalists, a larger quality step size affects their utility via its positive effect on monopolistic profit, captured by the term $\mu = z$. The growth effect is particularly strong at a small quality step size, whereas the profit effect is particularly strong at a large quality step size. Therefore, at a small (large) quality step size, enlarging the size of quality improvement closes (widens) the gap between the different levels of monopolistic power preferred by workers and capitalists.

Proposition 3 *The severity σ of the conflict of interests between workers and capitalists is an increasing function in the discount rate ρ, a decreasing function in R&D productivity φ and a U-shaped function in the quality step size z.*

Proof. Use (31) to show that σ is increasing in ρ, decreasing in φ, and U-shaped in z. ■

3.1 Discussion

In this study, we have explored the determinants of the class struggle between workers and capitalists but not its destructive consequences on the society. However, one can specify a process in which the probability of social unrest is an increasing function in σ. Therefore, reducing σ helps to avoid social unrest. Our above analysis implies that the government can accomplish this by adopting the following policies. First, the government can try to influence the culture of the society by making workers more patient; see for example Doepke and Zilibotti (2008, 2014). In this case, a reduction in the discount rate ρ would reduce σ. Second, the government can enhance the innovation capacity of the economy by investing in education. In this case, a rise in R&D productivity φ would also reduce σ. Finally, the government can also try to influence the innovation process by targeting an intermediate quality step size given by $z = \varphi/\rho$, which minimizes σ. In other words, the government wants to avoid innovation that is insignificant and does not benefit workers much and also innovation that is too drastic and benefits capitalists more than workers.

4 Heterogeneous workers and capitalists

It may seem that our above analysis assumes homogenous workers and homogenous capitalists. In this section, we show that all our results are robust to heterogeneous workers and heterogeneous capitalists. Suppose there is a unit continuum of workers indexed by $h \in [0,1]$. Worker h is exogenously endowed with $l(h)$ units of labor, which follows a general distribution with a mean of unity such that

$$\int_0^1 l(h)dh = 1. \tag{32}$$

Worker h's consumption is given by

$$c_t^w(h) = w_t l(h). \tag{33}$$

Using (8) and (15), we can derive $c_t^w(h)$ as

$$c_t^w(h) = \frac{y_t}{\mu} l(h) = \frac{Z_t}{\mu} l(h). \tag{34}$$

Substituting (34) into the welfare function of worker h yields

$$U^w(h) = \frac{1}{\rho}\left[\ln c_0^w(h) + \frac{g^*}{\rho}\right] = \frac{1}{\rho}\left[\ln l(h) + \ln\left(\frac{Z_0}{\mu}\right) + \frac{g^*}{\rho}\right], \tag{35}$$

in which $\ln l(h)$ affects the utility of worker h but is independent of the markup μ whereas g^* is given by (17) and (18) as before. Therefore, the utility-maximizing level of markup for all workers $h \in [0,1]$ is given by μ^w in (27).

Suppose there is a unit continuum of capitalists indexed by $k \in [0,1]$. At time 0, capitalist k is exogenously endowed with $a_0(k)$ units of assets, where $\int_0^1 a_0(k)dk = a_0 = v_0$. Her asset-accumulation equation is

$$\dot{a}_t(k) = r_t a_t(k) - c_t^c(k). \tag{36}$$

Dynamic optimization yields the consumption path of capitalist k as

$$\frac{\dot{c}_t^c(k)}{c_t^c(k)} = r_t - \rho, \tag{37}$$

which implies that the growth rate of $c_t^c = \int_0^1 c_t^c(k)dk$ is also given by $\dot{c}_t^c/c_t^c = r_t - \rho$. Therefore, the distribution of consumption share $c_t^c(k)/c_t^c$ among capitalists is stationary. Combining (36) and (37) yields

$$\frac{\dot{c}_t^c(k)}{c_t^c(k)} - \frac{\dot{a}_t(k)}{a_t(k)} = \frac{c_t^c(k)}{a_t(k)} - \rho, \tag{38}$$

which shows that the consumption-asset ratio $c_t^c(k)/a_t(k)$ of capitalist k jumps to ρ. In other words, we have

$$c_t^c(k) = \rho a_t(k), \tag{39}$$

which implies $c_t^c = \rho a_t$ and $c_t^c(k)/c_t^c = a_t(k)/a_t$. Therefore, the stationary distribution of consumption share $c_t^c(k)/c_t^c$ implies that the distribution of asset share $a_t(k)/a_t$ is also stationary. Let's denote the initial share as $s(k) \equiv a_0(k)/a_0$, which is exogenously given at time 0 and remains stationary. Then, capitalist k's consumption is given by

$$c_t^c(k) = \rho s(k) a_t = s(k)\frac{\rho Z_t}{\varphi}, \tag{40}$$

where the second equality uses $a_t = v_t$ and (12). Substituting (40) into the welfare function of capitalist k yields

$$U^c(k) = \frac{1}{\rho}\left[\ln c_0^c(k) + \frac{g^*}{\rho}\right] = \frac{1}{\rho}\left[\ln s(k) + \ln\left(\frac{\rho Z_0}{\varphi}\right) + \frac{g^*}{\rho}\right], \tag{41}$$

in which $\ln s(k)$ affects the utility of capitalist k but is independent of the markup μ whereas g^* is given by (17) and (18) as before. Therefore, the utility-maximizing level of markup for all capitalists $k \in [0, 1]$ is given by μ^c in (25).

5 Conclusion

In this study, we have explored the conflict of interests between workers and capitalists in a Schumpeterian economy. We derive and compare the different levels of monopolistic power preferred by workers and capitalists, respectively. Workers may prefer monopolistic firms to have some market power but they prefer less powerful monopolistic firms than capitalists. Therefore, strengthening the bargaining power of workers relative to capitalists reduces the markup of monopolistic firms, which in turn stifles innovation and economic growth. Using the difference in levels preferred by workers and capitalists as a measure of the severity of their conflict of interests, we find that the severity of class struggle is an increasing function in the discount rate, a decreasing function in innovation productivity and a U-shaped function in the quality step size. These findings provide policy implications for what the government could do to mitigate class struggle.

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Appendix

In this appendix, we derive the dynamics of the economy and show that it jumps to a unique and stable balanced growth path. The free-entry condition for R&D in (12) shows that the value of an invention is $v_t = Z_t/\varphi = y_t/\varphi$, where the second equality holds because $y_t = Z_t$ in (15). The aggregate value of assets owned by capitalists is $a_t = v_t = y_t/\varphi$ because of symmetry $v_t(j) = v_t$ and a unit continuum of industries $j \in [0, 1]$. Therefore, we can rewrite the capitalists' asset-accumulation equation in (2) as

$$\frac{\dot{y}_t}{y_t} = \frac{\dot{a}_t}{a_t} = r_t - \frac{c_t^c}{a_t} = r_t - \varphi\frac{c_t^c}{y_t}. \tag{A1}$$

Substituting the Euler equation in (3) into (A1) yields

$$\frac{\dot{c}_t^c}{c_t^c} - \frac{\dot{y}_t}{y_t} = \varphi\frac{c_t^c}{y_t} - \rho, \tag{A2}$$

which implies that c_t^c/y_t must jump to its unique steady-state value $c_t^c/y_t = \rho/\varphi$ such that $g_t \equiv \dot{y}_t/y_t = \dot{c}_t^c/c_t^c = r_t - \rho$ at all t. Substituting (9), $r_t = \rho + g_t$ and $v_t = y_t/\varphi$ into the no-arbitrage condition in (10) yields

$$\rho + g_t = r_t = \varphi\frac{\mu - 1}{\mu} + g_t - \lambda_t, \tag{A3}$$

which also uses $\dot{v}_t/v_t = \dot{y}_t/y_t$ and shows that the arrival rate of innovation is

$$\lambda_t = \lambda^* = \frac{\mu - 1}{\mu}\varphi - \rho. \tag{A4}$$

Therefore, the economy jumps to a unique and stable balanced growth path along which the growth rates of y_t, Z_t, c_t^c, c_t^w, w_t, a_t and v_t jump to the same steady-state value $g^* = \lambda^* \ln z$ and the real interest rate jumps to its steady-state value $r^* = \rho + g^*$.