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The Role of Political-Industry Nexus in Promoting Illegal Extraction of Mineral Resources and Deforestation: A Case of Iron Ore Mining in Goa

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Abstract

Mining of mineral resources entails significant deforestation in developing countries. The large financial rewards associated with mining create corrupt linkages between the government regulators and mining industry, often resulting in illegal extraction of minerals in environmentally sensitive areas. We develop a model of political-industry corrupted relationship to explore the problem of illegal mining of iron ore and its impact on deforestation in Goa, India. For the regulator, the decision to allow illegal extraction and relaxation from environmental remediation requirement is made with the objective of accumulating illegal wealth while simultaneously mitigating the risks of political ouster and conviction. Results suggest that several factors, such as the relative risks of political survival and conviction, the degree of impatience displayed by the regulator as well as the contribution of the mining sector to the economy, play a role in influencing the extent of illegal mining activity. When the regulator faces a low risk of political ouster, an increase in conviction risk may not provide enough deterrence to illegal mining, resulting in high levels of deforestation.

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1. Introduction

While mining of earth's mineral resources provides economic benefits to the society, it also causes significant environmental degradation, directly as well as indirectly. For instance, while gold mining in Guyana supports more than 10,000 small and medium businesses, it is also the largest driver of deforestation in the country. In 2009, about 9000 ha of forest area loss was directly attributed to mining related activities in Guyana (Lowe, 2014). Similarly, it has been estimated that extracting a year's supply of coal for domestic consumption in the US leads to a degradation in the quality of 2300 km of water streams and destroys ecosystems with enough carbon sequestration potential to offset emissions of 33000 homes (Lutz et al., 2013). The indirect effects of mining manifest through the auxiliary industrial activities, urbanization and land use changes in the vicinity of mineral rich regions. The presence of large deposits of coal reserves in the Singrauli district of Madhya Pradesh in India has resulted in significant forest cover loss and land use changes (Areendran et al., 2013). In Singrauli, during the period 1978-2010, about 365 km² of the original 773 km² of dense forests (i.e. forests with a canopy cover of 40% or more) were degraded into open forests (which have a canopy cover between 10% and 40%), and an additional 165 km² and 16 km² of dense forests got converted in scrublands and farmlands, respectively (Areendran et al., 2013).

Very often, economic forces such as high mineral prices can exacerbate the incentive to mine unsustainably. In Madre de Dios, Peru, the annual rate of gold mining related deforestation in the past decade has increased non-linearly, even with a constant rate of increase in international gold prices (Swenson et al., 2011). Between 2003 and 2009, the price of gold increased at an annual rate of 18%, whereas, the mining driven deforestation in Peru increased from 292 ha/yr between 2003 and 2006 to 1915 ha/yr between 2006 and 2009. There also appears to exist some spatial correlation across biodiversity protected areas and the presence of mineral ore deposits, as about 14% of the world's protected regions hold mines within their

vicinities (Duran et al., 2013). This correlation has been attributed to a policy bias towards creation of protected regions in high altitude topographical areas and away from locations with significant economic activities. Coincidentally, some of the world's main metal deposits are found in similar high altitude and complex topographical regions (Edwards and Atkinson, 1986).

In addition to the mining led destruction of their forests and ecosystems, economies rich in mineral resources (such as Nigeria, Papua New Guinea, Saudi Arabia, etc.) have also faced the 'resource curse' challenge (Auty, 1993; Hilson and Laing, 2016). The resource curse idea is based upon the empirical observation that resource-rich countries (those with a high share of natural resource based exports in their national incomes) have performed substantially worse than their resource-poor counterparts in terms of economic growth. The inability of the resource-rich countries to gainfully utilize the natural resource generated incomes towards promoting economic development has been primarily attributed to their institutional shortcomings. A sudden surge in resource led revenues promotes corruption and rent-seeking behaviour, which, coupled with inefficient bureaucracy hampers economic progress (Sachs and Warner, 1995). Further, an increase in the export of natural resources puts other export oriented domestic industries at a disadvantage through causing an appreciation of the domestic currency.

In the above context of the various challenges generated through mineral resource exploitation, their illegal extraction creates further complications, as it not only exacerbates the environmental degradation problem (through unauthorised deforestation) but also hampers economic development through a leakage of precious revenues (Banchirigah, 2008; Lahiri-Dutt, 2007; Schueler et al., 2011). The large profits generated in the mining industry create a corrupted relationship between the government regulators, who are entrusted with the task of allocating mining rights, and the mining firms. The Western Ghats region in India is one such

example of a biodiversity region that is characterized by large-scale illegal mining, high levels of environmental degradation and the presence of a corrupted relationship between politicians and the mining firms (Ghosh, 2012; Jha et al., 2000; Ministry of Environment and Forests, 2013; Panigrahy et al., 2010; Padma, 2013). Illegal mining has also deprived the local state government of the much-needed revenues. A supreme court appointed Commission reported that illegal mining in Goa, in the period 2007-2012, had led to a loss of 35,000 crore INR (which is roughly 5 Billion USD) to the state government. It also pointed to the presence of a large-scale illegal nexus between several state ministers and the mining firms (Ministry of Mines, 2014). In 2017, a special investigation team in Goa, arrested a local businessman who was charged with illegally extracting iron ores worth 2 lakh tonnes between 2007 and 2012. The businessman was alleged to have the support of the former chief minister of the state, who has been separately charged with mining related fraud (Times of India, 2017b). The presence of a corrupted relationship between regulators and polluting industries is a global phenomenon, which is not confined to the developing world only (Oates and Portney, 2003). For instance, between 2010 and 2015, mining companies were found to have paid more than 2 million dollars to various politicians at local and federal levels in Australia in order to gain approval for mining gas, coal and sand in Queensland (Aulby and Ogge, 2016).

The key reason behind the existence of such an illegal nexus is that preserving the environment requires curtailing the existing patterns of environmentally polluting economic activities, which puts the interests of the environment at loggerheads with those of commerce and trade. In this context, the political economy of environmental decision making, such as those concerning the regulation of polluting industries or allowing oil exploration in biodiversity protected areas, has been a subject of extensive research in the past (Becker, 1983). The key insight from this body of literature is that governments propose and enact policy measures that suit the interests of various industries or lobby groups in order to receive political

or other forms of in-kind support (Ekins and Speck, 1999; Grossman and Helpman, 1994). The objective of the government is to increase its chances of getting elected, or if already in power, to promote its future political interests. Environmentally polluting economic activities, therefore, are sustained through political support. The polluting firms, in return, provide monetary and political contributions to the policy makers and their political parties (Smith et al., 2003a&b; Ross, 2012; Gibson et al., 2005; Oates and Portney, 2003; Grossman and Helpman, 1994). Stratmann (1991) analysed contributions (totalling 177 million USD) made by political action committees representing various agricultural groups (such as dairy, peanut, sugar, etc.) in the US during the 1987-88 elections and found that such contributions had an important role to play in the voting behaviour of the congressmen.

The policy maker returns the favor to the interest groups through enacting rules benefitting them, or imposes lax environmental regulations and allows under-reporting of environmental degradation. Magat et al. (1986) found that while setting industry standards over removal of total suspended solids and biological oxygen demand, the US environmental protection agency (EPA) had different expenditure requirements for different industries. These requirements were not based upon economic efficiency criteria or the impact such standards had on the industry's outputs and employments, but purely on the strength of the trade associations that were representing those industries. However, more recent empirical evidence also suggests that public policies often tend to balance the interests of various industry groups with the larger societal welfare considerations (Hird, 1990). For instance, the superfund program was started in the US in 1980 to allocate funds towards identification and clean-up of hazardous sites. There were allegations that the EPA selected sites influenced by congressmen's needs of catering to their particular constituents. However, Hird (1990) used data associated with the selection of hazardous sites, the speed of clean-up, and measures of congressional influence along with variables that would indicate acting in public interest, to

conclude that the EPA acted fairly independently in the selection of sites and was more influenced by public interest motives than congressional ‘distributive politics’.

In the context of illegal exploitation of mineral resources in developing economies, the crucial challenge is to understand the key drivers of the corrupted relationship between the regulators and the mining industry and to predict the implications that could arise for the environment if the same were to continue into the future. Despite the significance of the problem, the political economy aspect of illegal mining within the biodiversity regions of developing economies is a topic that has remained inadequately addressed in the literature. Keeping this gap in mind, the objective of this paper is to explore the role of political incentives at the regulatory level in promoting the illegal exploitation of mineral resources and allowing deforestation through enforcing lax remediation requirements.

We develop a dynamic optimization model of the regulator’s objective function that has illegal wealth accumulation as its key argument. The regulator optimizes over allowing the extent of illegal extraction keeping in mind the proven reserves of the mineral ore and its economic value. The mining firm bargains with the regulator over profit sharing resulting through the illegal extraction as well as seeks relaxation in environmental remediation requirements. The higher the relaxation granted, the more is the illegal payment received by the regulator. The significance of mining related deforestation in influencing the political survival chances of the regulator, as well as the role of political survival in protecting the regulator from conviction are also incorporated in the model. Key insights are derived using the context of illegal iron ore mining in the state of Goa.

2. Model

This section presents the model background and the equations. It further sets up the dynamic optimization problem and derives optimality conditions.

2.1. Background

The model presented in this paper uses the case of iron ore mining in Goa as an example. In order to keep the model tractable, we abstract away from the real world scenario in a number of ways. First, we pick a single representative regulator and a single representative firm. All legal and illegal transactions are assumed to go through these two representative agents. Second, it is assumed that all illegal mining activities occur with the direct approval and knowledge of the regulator. Third, the level of legal licenses to be granted per year is fixed through a legal framework, which the state regulator has little power to alter. This has indeed been the case, as the ministry of environment and forests (MoEF) as well as the supreme court of India have, on separate occasions in the past, suspended mining licenses in the state citing the presence of environmental or financial irregularities (Banerjee, 2014). Fourth, the regulator can allow any level of illegal extraction. Illegal extraction is allowed in various ways, such as through co-mingling of legal and illegal extraction, allowing extraction beyond the permissible legal licenses, allowing under-reporting by the firm, allowing transporting of minerals illegally, and allowing mining outside of the permitted areas¹.

The regulator is expected to require the mining firm to remediate the environmental damages generated in the process of mining. This remediation process could take various forms such as requiring afforestation, ensuring proper relocation of overburden, seeking compensation for environmental damages, etc. As remediation is costly, the mining firm

¹ The Shah Commission that investigated the case of illegal mining in Goa between the period 2006-2011, found that 90 mines were illegally operating of which 33 were operating in close proximity to the wildlife sanctuaries. Further, it was alleged that the exposure of corruption within the government and bureaucracy forced the government to shut down the investigation process abruptly (The Guardian, 2013).

negotiates with the regulator over the extent of remediation to be done for each unit of extraction that results in deforestation. The regulator, by allowing relaxation from remediation for both legally and illegally mined ores, helps the firm lower its costs. In return, the mining firm pays a monetary amount to the regulator, which is for the illegal mining allowed as well as a reduction in the remediation requirement. The firm and the regulator bargain over the monetary payment in each period, in order to determine the new illegal extraction level and the extent of remediation. Following Binmore et al. (1986), a Nash bargaining framework is used, which maximizes the product of the surpluses (or net profits) of the two parties from this illegal transaction. The surplus to the firm would be the net profits from the sale of the illegally extracted ores minus the costs of environmental remediation and the payments made to the regulator. The regulator's profit would simply be the monetary payments made by the firm.

The regulator, by allowing illegal mining for financial payments, runs the risk of getting convicted in the future. The risk of conviction is lower when the regulator is in political power. This assumption is supported by the observed reality in the state, where the past chief ministers have been indicted in the mining related irregularities, however, no conviction has occurred while they were in power. When the regulator is out of power, the risk of conviction increases as they are not able to influence the judicial process any more. The risk of conviction is assumed a function of the level of illegally amassed wealth. This assumption is consistent with the evidence of past convictions within the state, as mentioned previously. The regulator also reduces their chances of staying in political power if the level of deforestation is high. When deforestation becomes excessive, it is a tell-tale sign of corruption in mining, which results in a public outcry, drawing the attention and involvement of the judicial bodies as well as the central government². We do not model conviction risks faced by the firm even though they

² There is a high correlation found between transparency International's corruption perception index and the level of environmental destruction in countries (Morse 2006).

would be held equally liable for illegal extraction. As we are interested in understanding the regulator's motives for granting extraction, the mining firm is simply assumed to internalize any expected conviction related risks while negotiating with the regulator.

Through allowing the illegal extraction of ores, the regulator accumulates wealth. However, through causing deforestation and amassing illegal wealth, they increase their chances of losing political power and of conviction. When faced with the prospects of financial gains as well as losses resulting from political ouster and conviction, the regulator balances the expected costs and benefits of illegal extraction and remediation relaxation through optimally adjusting them over time. We formalize this idea next.

2.2. Equations

Let $q(t)$ be the total quantity of iron ores mined per period. Variable, $q(t)$, comprises both legal licenses, q_0 , and illegal extractions³, $e(t)$:

$$(1) \quad q(t) = q_0 + e(t),$$

where quantity extracted is measured in million tons (MT). Mining generates revenues for the government, has forward and backward multiplier effects, and provides employment to the local population. The gross domestic product (gdp), $i(t)$, of the local economy, grows at a rate:

$$(2) \quad \dot{i}(t) = \left(\beta + \phi \frac{q^{\phi_0}(t)}{q^{\phi_0}(t) + \phi_1} \right),$$

³ We define illegal extraction as all mining of ores occurring beyond the legal limit, but done with the approval of the regulator. There may be additional illegal extraction that goes on without the knowledge or approval of the regulator, which we do not include in the model. Mining allowed by the regulator in protected biodiversity areas, would also be deemed illegal extraction as the MoEF would not give environmental clearance for such mines.

where β is the exogenous component of the gdp growth rate which is independent of the mining sector's contribution, and ϕ is the maximum possible contribution to the gdp growth rate from mining related activities. Parameters ϕ_0 and ϕ_1 allow for non-linearity in the relationship between the level of mining activity and the gdp growth rate.

Along with promoting economic growth, mining also causes deforestation. The cumulative deforestation level, $d(t)$, which is a direct result of open-surface type iron ore mining, increases through forest acreage destruction:

$$(3) \quad \dot{d}(t) = p_0 \cdot (p_1 + l(t)) \cdot (e(t) + q_0(t)).$$

The variable $l(t)$, ranging between 0 and 1, is the level of relaxation from environmental remediation granted by the regulator to the firm. When $l(t)$ is 1, there is zero remediation requirement and the extent of deforestation associated with one MT of legally or illegally extracted ores becomes $p_0 \cdot (1 + p_1)$. The product of parameters $p_0 \cdot p_1$ is the level of deforestation (say in km^2 units) that occurs even after complete remediation ($l(t) = 0$) of 1 MT of extracted ores. That is, remediation does not lead to a complete restoration of the forests.

The value of the forests comprises the sum total of all the environmental services provided by it. We assume that the cost of an additional unit of deforestation increases non-linearly with respect to the total area already cleared. This cost function, $z(t)$, is specified as:

$$(4) \quad z(t) = \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot \dot{d}(t),$$

where γ_0 is a fixed cost component associated with a unit acre of forests destroyed, and

$\gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2}$ is the variable component that makes the cost of additional unit of forests lost

dependent upon the area that is already lost. In the empirical application section, further justification is presented for assuming a non-linear cost function, however, the simple explanation is that it reflects the non-linearities and threshold effects that are associated with sensitive ecosystems. For instance, once a certain threshold level of forest area is destroyed, the rate of loss of the remaining areas could increase non-linearly due to climate-induced dieback effects (Allen, 2009). Some ecological systems also exhibit hysteresis, whereby they flip from a good state to bad state following the crossing of a threshold in terms of degradation or stress (see Scheffer et al., 2001; Pimm, 1984). Parameters γ_1 and γ_2 incorporate these non-linear effects of deforestation.

The process of illegal arrangement between the regulator and the firm is as follows. The firm is allowed a fixed level of legal extraction, $q_0(t)$, which cannot be altered by the regulator. The firm is also allowed $e(t)$ MT of illegal extraction by the regulator. The regulator further decides on the level of relaxation in the environmental remediation requirement given to the firm on the basis of the financial contribution, $m(t)$, made by the firm. The cost of remediation, $c(t)$, to the firm is given as:

$$(5) \quad c(t) = \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(t)) \cdot (1 - l(t)).$$

For the illegal extraction component, the cost of remediation (as shown in equation (5)) is the part it has to do after getting a relaxation of $l(t)$. Note that the firm can only remediate $p_0 \cdot e(t)$ km² when the actual deforestation is $p_0 \cdot (1 + p_1)$ km², given our assumption that hundred percent remediation is not possible. For the legal component, the firm benefits from not having to remediate, where the benefit $b(q_0(t))$ is given as:

$$(6) \quad b(q_0(t)) = \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) \cdot l(t).$$

The negotiation between the regulator and the firm involves a Nash bargaining game (Binmore et al., 1986), where the two maximize the joint product of their surpluses in each period. The regulator's surplus function, $\pi_r(t)$, is simply given as:

$$(7) \quad \pi_r(t) = m(t),$$

where $m(t)$ is the monetary bribe paid by the firm. The firm's surplus function, $\pi_f(t)$, is given as:

$$(8) \quad \pi_f(t) = (\pi \cdot e(t) + b(q_0(t)) - m(t) - c(t)),$$

where π is the fixed revenue earned per MT of ore mined. The joint product of the surpluses of the two parties is given as:

$$(9) \quad \pi_f(t) \cdot \pi_r(t) = (\pi \cdot e(t) + b(q_0(t)) - m(t) - c(t))^{1-\theta(t)} \cdot m(t)^{\theta(t)},$$

where $\theta(t)$ is the bargaining power of the regulator. The bargaining power of the regulator varies over time, and is endogenous to the state of the local economy. The regulator will have a higher bargaining power (with respect to sharing the surplus with the firm) when economic growth reaches very high levels, as additional demand for illegal extraction would be higher. The bargaining power is modelled as:

$$(10) \quad \theta(t) = \bar{\theta} \cdot \left(1 + \theta_i \cdot \frac{i(t)^{\psi_0}}{i(t)^{\psi_0} + \psi_1} \right),$$

where $\bar{\theta}$ is the minimum bargaining power that the regulator holds which is independent of the state of the economy. However, as the economic growth rate increases, the bargaining power increases non-linearly as governed by the parameters ψ_0 and ψ_1 . In a case where the

regulator's bargaining power is not sensitive to the economic growth rate, a high value of parameter ψ_1 and a low value of parameter ψ_0 would reflect that possibility.

The maximization of the product of their surpluses with respect to $m(t)$ yields:

$$(11) \quad m(t) = (\pi \cdot e(t) + b(q_0(t)) - c(t)) \cdot \theta.$$

The regulator's utility function, $U_{reg}(t)$, has only monetary payment as its argument, as they are assumed to be indifferent to the economic or environmental benefits (or costs) that occur to the society in this transaction:

$$(12) \quad U_{reg}(t) = \log(m(t))^{m_1}.$$

In the above equation, m_1 is the elasticity of utility with respect to the illegal income $m(t)$. The regulator maximizes the discounted sum total of their per-period utilities over time through optimally picking the level of illegal mining to be allowed and the level of remediation relaxation to be granted, subject to constraints posed by the bargaining outcome, economic growth rate, and the forest loss dynamics.

The regulator also faces two key risks through their illegal transactions. The risk of the regulator losing political power in the future is largely exogenously determined, however, deforestation can add to this risk. The risk of losing political power is given as a hazard function, $\dot{\lambda}_p(t)$, which is defined as:

$$(13) \quad \dot{\lambda}_p(t) = \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right),$$

where λ_{p0} is the maximum hazard of losing political power when the extent of deforestation reaches very high levels. λ_0 is the exogenous hazard of losing political power which is independent of the mining related activities.

There also exists a hazard of getting convicted for promoting the illegal exploitation of mineral resources. While we assume here that the two hazards are uncorrelated, once the regulator loses political power, the hazard of getting convicted would increase. This assumption (which is further explained in the empirical section) mimics reality in such mining regions, where political power shields the regulators from being investigated or tried for corruption. The hazard rate of conviction while in power, $\dot{\lambda}_{c_power}(t)$, is modelled as a function of the total illegal wealth acquired, $w(t)$,:

$$(14) \quad \dot{\lambda}_{c_power}(t) = \lambda_{c0} \cdot \log(w(t) + w_0),$$

where λ_{c0} is the exogenous hazard rate of conviction, which is further increased with the level of illegally acquired wealth. Parameter w_0 is a small constant. The wealth, $w(t)$, acquired through granting illegal extraction is defined as:

$$(15) \quad w(t) = \int_0^t m(x) dx.$$

The hazard rate of conviction, $\dot{\lambda}_{c_no_power}(t)$, when the regulator is out of political power, is similarly, given as:

$$(16) \quad \dot{\lambda}_{c_no_power}(t) = \zeta_{c0} \cdot \log(w(t) + w_0),$$

where the parameter ζ_{c0} has similar interpretation as its counterpart in (14), however, with the condition that, $\zeta_{c0} > \lambda_{c0}$.

We further assume that if the regulator loses political power first (before getting convicted), they would face a hazard of future conviction determined by (16), however, if they get convicted first (while in power), they are also immediately out of political power.

The value function, $V_{no_power}(t)$, obtained when they lose power first (but still face the risk of future conviction) is given as:

$$(17) \quad V_{no_power}(t) = \int_t^{\infty} \left(\mathcal{E} \cdot \exp(-\lambda_{c_no_power}(x)) \cdot \exp(-\rho \cdot x) - \zeta_{c0} \cdot \log(w(x) + w_0) \right. \\ \left. \cdot \exp(-\lambda_{c_no_power}(x)) \cdot \exp(-\rho \cdot x) \cdot \log\left(\kappa \cdot \int_0^t m(x) dx\right) \right) dx,$$

where $\mathcal{E}$ is a small constant utility (measured logarithmically) derived per period in the time between losing power and avoiding conviction, and κ is the fraction of amassed wealth that they have to return when convicted. ρ is the discount rate parameter in equation (17). We do not model disutility from physical incarceration, however, increasing the value of κ increases the disutility from conviction. In equation (17), conviction leads to one-time disutility, $U_c(t)$, as given by:

$$(18) \quad U_c(t) = -\log\left(\kappa \cdot \int_0^t m(x) dx\right).$$

The optimization problem for the regulator is given as (see Reed and Heras, 1992 for optimization involving hazard functions):

$$(19) \quad U_{reg}(t) = \int_0^{\infty} \left(\log(m(t))^{m_1} \cdot \exp(-\rho \cdot t) \cdot \exp(-\lambda_p(t) - \lambda_{c_power}(t)) \right. \\ \left. - \lambda_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_power}(t)) \cdot \exp(-\rho \cdot t) \cdot \log\left(\kappa \cdot \int_0^t m(x) dx\right) \right) dt. \\ \left. + \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right) \cdot \exp(-\lambda_{p0}(t)) \cdot \exp(-\rho \cdot t) \cdot V_{no_power} \right)$$

We perform an empirical application of the model to derive some insights next. Further analysis involving the first order conditions and their interpretation is provided in Appendix A.

3. Empirical Example

The empirical application relates to the case of illegal iron ore mining in Goa, India. Section 3.1 presents parameter calibration and section 3.2 derives some key results.

3.1. Parameter Calibration

When averaged over the period 2007-2011, the iron ore mining sector's contribution to the state's gdp has been roughly 16% (Economic Survey, 2014). It also employs over 7500 workers (NCAER, 2002). The known reserves of iron ore deposits in Goa are estimated to be 712 MT (Mukhopadhyay and Kadekodi, 2011). The annual production of ores has varied between 33 MT in 2008 and 52 MT in 2011. In 2001, there were about 90 operating mines spread over an area of 200 to 250 sq. km (Aghor, 2011). Following a ban imposed by the supreme court (in October 2012), citing illegal mining and serious environmental degradation, ore production declined to 11 MT in 2012 and stopped completely in 2013. Mining has resumed since 2014, following another court order. The Shah Commission has recommended an upper limit of 20 MT of ore extraction annually in order to curb illegal mining and reduce damages to the environment (Banerjee, 2014). In 2015-16, the state government renewed 88 mining licences leading to a total extraction of 16 MT. However, the current state government has been arguing for further increasing the limit to 37 MT annually.

Illegal mining goes on under the patronage of the political powers (Ministry of Mines, 2014). A large number of licenses granted by the union ministers during the period 2005-2009 was declared illegal by the Supreme Court. While most mines were located within the forest

areas, 15 of them fell inside the protected Netravali wildlife sanctuary in South Goa (Aghor, 2011). The director of mines and geology has filed several illegal mining complaints against ore traders as well as people who were in political power during the period when most of the illegal extraction occurred (Times of India, 2017a). During the period 2007-2012, roughly 395MT of iron ores mined went unreported (Ministry of Mines 2014). The Shah Commission inquiry reported that illegal mining scam in Goa during the period 2007-2012 resulted in a loss of about 35,000 crore INR (roughly 5 Billion USD).

The total forest area in the state is 2151 km², of which 511 km² is very dense forests, 624 km² is dense forests and 1016 km² is open forests (FSI 2009)⁴. The value of all services provided by these forests has been estimated to be 43 M INR per km² (Mukhopadhyay and Kadekodi, 2011). We pick this as a lower range estimate to calibrate the cost to the environment from mining led deforestation (see table 1 in Appendix B). The cost to the environment is assumed to increase non-linearly with an increase in the forest area lost, as existing estimates only account for positive services provided by the forests and not the preventative services, such as protection against flooding hazard, control of soil erosion, etc.

The initial forest area lost to the existing mining activity is taken at 296 km² based upon Mukhopadhyay and Kadekodi (2011). In the worst case scenario, if all of the known reserves of 712 MT of the ores were to be mined, it would cause a destruction of the very dense and dense forest types, totalling 1135 km², as a majority of current mining activity occurs within the forest areas (Aghor, 2011). This gives the rate of forest loss from mining at 1.59 km²/MT. Between 2001 and 2012, about 378 MT of ores were extracted from mines located within 296 km² of forests. Given that there is still twice the amount of ores left (712 MT), it could cause additional destruction of 592 km² of forests. In the best case scenario, one may assume that

⁴ Very dense forests are defined as all lands with canopy cover with a density of 70% and above, dense forests have a canopy cover density of 40-70%, and open forests have a density of 10-40%.

after allowing for remediation, at least another 296 km² of forests could be destroyed. This gives a lower bound rate of forest loss at 0.415 km² per MT. Whereas, a medium range estimate would be twice that rate at 0.83 km² per MT.

To estimate the positive impact of mining on gdp growth rate, we look at the average growth rate for the period 2007 to 2011, when mining activity (including a large number of illegal operations) was in full swing. The average economic growth rate during this period was 12.57% (Economic Survey 2014, pg. 137). Following a ban in 2012, the economic growth dropped to 4 percent in 2013 and recovered back to about 7 percent in 2014 and 2015. Given that this was an exogenous shock to the economy, the difference in the gdp growth rate before and after can be considered as the net impact of mining on the gdp in the short term. Another way to derive the same estimate is to look at the share of mining in the total gdp of the state, which has been about 16 percent averaged over the period 2007-2011. Goa's GDP was 27,044 B INR in 2011 and increased to only 28,173 B INR in 2012 (which is roughly a 4 percent increase). In 2012, the share of mining in gdp fell to 5 percent, so adding the remaining share of 11 percent would lead to an average gdp growth rate of about 12 percent. Additionally, there is no information over the differential impacts of legal and illegal extractions on the gdp growth rate. In the case of illegal extraction, the government loses revenues between 470 and 750 M INR per MT (at 40 percent of mining revenues). However the multiplier effect of state revenue expenditures is close to 1 in India (Jain and Kumar, 2013). This suggests that forgone revenues may not be holding back the gdp growth rate significantly. For want of a better estimate, we assume that illegally extracted ore contributes only 25 percent to the local economic growth compared to legal extraction. The revenue from a MT of iron ores is taken at 1175 M INR⁵. It is estimated that firms earn about 20 percent profits from mining activities, which gives profits

⁵ When using the price of a ton of ore at 18.1 USD and an exchange rate of 65 INR per USD.

per MT at 235 M INR (Mukhopadhyay and Kadekodi, 2011). These revenue estimates will vary with prices.

Estimation of political ouster and conviction risks is difficult as there have been no significant convictions of politicians thus far. The hazard rate of political exit is calibrated such that (at $\lambda_{p0}=10$) if the current level of forest acres destroyed was 596 km², the probability that the regulator would be out of political power by the next 10 years would be 25 percent, whereas if the forest area destroyed was 894 km² (three times the current level of 298 km²), the same probability would be about 50 percent. At $\lambda_{p0}=100$, if the current level of forest area destroyed was 596 km², the probability that the regulator would still be in power by the end of 10 years would be about 3 percent. Therefore, this scenario models a higher sensitivity of political risk to deforestation. The probability of conviction while out of power is calibrated such that if the regulator were to amass a wealth of 25,000 M INR, the probability that they would get convicted by the next 10 years would be more than 60 percent. Whereas, the probability of conviction while in power and having amassed the same level of illegal wealth, would be only 25 percent.

3.2.Results and Discussion

In section 3.2.1, we first present results for the base case which assumes that the regulator does not face the risks of losing political power or conviction. This assumption allows us to explore illegal extraction decisions that are solely based on unfettered profit maximization. Further scenarios considered within this section help us understand the workings of the model and also, to a certain extent, replicate the outcomes observed in the case study region. Section 3.2.2, then adds the two types of risks and derives illegal extraction levels as well as the implications for deforestation. The model is run using the general algebraic modelling systems (GAMS) software with a time horizon of 25 years.

3.2.1. *No political ouster or conviction risk present*

Figure 1 presents the time path of illegal extraction of the ore for the base case and some alternate scenarios where key parameters are varied. The base case level of illegal extraction is initially 37 MT and declines gradually over time to zero, as the mineral reserves run out. Note that there is also a fixed amount of legal licenses granted per year (equal to 20 MT) for extraction, which influences how long the reserves would last. The regulator does not allow high illegal extraction all at once due to the logarithmic utility function assumption. Figures 2 and 3 depict the payments received by the regulator from the firm and the impact of ore extraction on local economic growth, respectively.

A scenario where the ore reserves are cleared out faster than the base case involves a much impatient regulator (scenario “ $\rho = 0.25$ ”). An impatient regulator, unwilling to wait longer to accumulate wealth, grants a higher level of illegal extraction, receiving a higher payment from the firm (figure 2). This scenario also leads to a very high economic growth. GDP growth is higher when the total ore extraction is higher (figure 3). While the illegal extraction does not contribute to the economy to the same extent as legal extraction, a high level of illegal extraction is still beneficial. Total ore reserves remaining (figure 4) is a function of the sum of legal and illegal extractions over time. Figure 5 depicts the level of deforestation under these scenarios. Deforestation is higher under a more impatient regulator.

Another scenario where the limit on legal extraction is lower (at 10 MT per year), adversely affects economic growth. A low economic growth reduces the bargaining power of the regulator. Therefore, the regulator allows a higher illegal extraction to prevent their profits from going down. When the regulator faces a shorter time horizon and are also highly impatient (scenario “ $\rho = 0.25, T=10$ ”), they allow the highest levels of illegal extraction. In fact, this scenario closely mimics the Goa iron ore mining scenario during the period 2007-

2012, when high levels of illegal ore extraction allegedly occurred. The above scenario leads to a level of illegal extraction (404 MT over a period of 5 years) in our model similar to what occurred in Goa (about 395 MT) during the period 2007-2012.

Another interesting scenario arises when mining is highly damaging to the forests, causing twice the rate of deforestation compared to the base case. One would expect lower illegal extraction under this scenario. However, note that by granting relaxation from remediation requirement the regulator improves their profits. As the remediation required under a higher deforestation rate would be higher, the regulator gets more payments from the firm under this scenario by granting a higher extraction rate. It is worth noting that there is no environmental remediation required by the regulator (despite the option of remediation requirement being included in the model) for all the above scenarios. As there is no risk involved, the regulator has no incentive to preserve the environment while allowing the illegal exploitation of minerals, especially when doing so would lower their payments received from the firm. Next, we incorporate the risks of political ouster and conviction.

3.2.2. *Risk of political ouster and conviction present*

The risk of political ouster increases non-linearly with deforestation. The risk of conviction increases non-linearly with the level of illegal wealth amassed by the regulator. The risk of conviction is assumed higher when the regulator is out of power as compared to when they are in power.

Consider first a scenario where the risks of losing power as well as that of conviction while in power are small, however, conviction risk when out of power is relatively high (scenario “ $\lambda_{p0} = 10, \lambda_{c0} = 0.003, \zeta_{c0} = 0.01$ ”). The level of illegal extraction increases in the early years compared to the base case (which involves no risks), however, it is lower after year 8 onwards (figure 6). A low risk of political ouster leads to a full relaxation from remediation

requirements from year 8 onwards (figure 7). By granting higher licenses in the early years (compared to the no-risk case), the regulator reaps higher profits, however as the risks of political ouster (figure 9) and conviction (figure 10), start to increase, illegal extraction is lowered below the base case levels. The presence of the two risks also exerts a discounting effect, which incentivizes the regulator to extract higher amounts in the early years. Additionally, due to a strict remediation requirement until year 8, the payments received from the firm go down, which prompts higher extraction allowance compared to the base case.

In contrast, if the risk of political ouster were kept the same, but the risk of conviction while in power were higher, whereas that of conviction while out of power were lower (scenario “ $\lambda_{p0} = 10, \lambda_{c0} = 0.01, \zeta_{c0} = 0.003$ ”), it leads to a significant increase in the level of illegal extraction. A higher risk of conviction while in power, leads to a higher discounting effect compared to the previous scenario. This is because in the previous scenario, even though the conviction risk when out of political power is high (and increases as more illegal wealth is amassed), the risk of political ouster is still low (and a higher level of remediation requirement prevents it from increasing further). Therefore, as long as the political ouster risk is kept low, an increase in conviction risk when out of power is of little concern. Whereas, when the risk of conviction while in power is higher and that when out of power is lower, it leads to a perverse incentive to exploit the resources faster and exit. Also remediation requirements are relaxed sooner. As figure 7 depicts, there is no remediation requirement from year 5 onwards. Therefore, this scenario highlights the possibility that when risks of conviction after losing power are lower, it not only leads to a rapid exploitation of mineral resources, but also the process of extraction is environmentally unsustainable.

Consider the next scenario (“ $\lambda_{p0} = 10, \lambda_{c0} = 0.01, \zeta_{c0} = 0.003$, higher deforestation rate”), where the deforestation rate is double the base case scenario. This scenario also highlights the

presence of a high discounting effect and perverse incentives, where conviction when out of power is less likely, whereas conviction when in power is more likely. A high rate of deforestation resulting from mining requires more stringent remediation requirements. However, imposing such requirements does not help with reducing the risk of conviction, as conviction risk is wealth related. Whereas, if the regulator were to increase the risk of losing power, they are better off as the conviction chances after political exit are lower.

So far we have kept the political risk fairly low. Next, we significantly increase the political ouster risk (scenario “ $\lambda_{p0} = 100, \lambda_{c0} = 0.003, \zeta_{c0} = 0.01$ ”). Under this scenario, the regulator grants higher levels of illegal extraction compared to the scenario “ $\lambda_{p0} = 10, \lambda_{c0} = 0.003, \zeta_{c0} = 0.01$ ”, which had a lower political ouster risk. As figure 9 reveals, the probability of ouster by year 10 is close to 75 percent for the scenario “ $\lambda_{p0} = 100, \lambda_{c0} = 0.003, \zeta_{c0} = 0.01$ ”, whereas in the scenario “ $\lambda_{p0} = 10, \lambda_{c0} = 0.003, \zeta_{c0} = 0.01$ ”, it is only about 14 percent. Also, a higher risk of political ouster forces strict remediation requirements for longer (until year 10), as a result of which deforestation is one of the lowest under this scenario. However, note that the necessity to preserve the forests does not arise out of sustainability concerns but the need to sustain political power, as the risks of conviction when out of power are relatively higher as well as the risk of political ouster is also higher. Compare this to another scenario “ $\lambda_{p0} = 100, \lambda_{c0} = 0.01, \zeta_{c0} = 0.003$ ”, where the risk of conviction while in power is high but the risk of conviction when out of power is relatively small. Given that the regulator faces the same higher level of political ouster risk as before, this scenario leads to one of the second highest levels of illegal extraction, as the main concern for the regulator here is to amass wealth quickly and exit from political power. The fact that risk of political ouster is higher as well as the risk of conviction when out of power is lower, adds to this incentive.

Finally, when all the risks are very high, “ $\lambda_{p0} = 100, \lambda_{c0} = 0.02, \zeta_{c0} = 0.02$ ”, it leads to a very different outcome compared to previous scenarios. The level of illegal extraction granted is one of the lowest (much lower than the base case as well). The remediation requirement is relaxed only after year 23, which leads to one of the lowest levels of forest area destruction. The key difference in this scenario as compared to all the previous scenarios is that there is no room for trading off one risk with another, which makes the regulator worse off if they allow illegal extraction.

4. Conclusions

The process of exploitation of mineral resources in developing countries inherently causes significant deforestation. This problem is further exacerbated by the presence of a corrupted relationship between the regulators and the mining firms. The regulators, who are entrusted with the task of ensuring sustainable mining, authorize illegal extraction of minerals and enforce lax environmental remediation requirements in return for financial rewards received from mining firms. Using the case of iron ore mining in Goa, we developed a model of political-mining illegal nexus to derive insights over the various incentives that influence the unlawful exploitation of mineral resources and cause deforestation.

Results derived through the empirical example (as presented in figures 1-10) indicate that a number of factors determine the rate of illegal extraction of mineral resources. Chief among such factors are the degree of impatience exhibited by the regulator towards appropriating illegal wealth and the relative risks of political ouster and conviction. When the regulator exhibits a high level of impatience, they are likely to grant more illegal licences over a short period of time, thereby leading to a rapid exhaustion of the ores as well as a destruction of the forests. The nature and magnitude of the risks faced by the regulator also affect the

scope of illegal activities. When the regulator faces the risks of political ouster and conviction, the level of illegal activity is generally higher compared to a no-risk scenario due to a discounting effect. When the regulator does not face illegal extraction related political ouster risks or conviction possibilities, they do not enforce any environmental remediation requirements. Instead, as was found from our analysis, in certain cases the regulator may even allow higher extraction coupled with no remediation requirement to maximize their profits. Whereas, when faced with the above risks, environmental remediation requirement is used in combination with illegal extraction allowance as a way to balance the two risks resulting from acquiring illegal wealth and causing deforestation.

When the risk of political ouster is low and that of conviction while in power also low, illegal extraction of resources is done with the objective of prolonging the expected time of survival while reaping maximum rewards. However, if the risk of conviction while in power is higher and that when out of power is lower, it leads to a perverse outcome where the incentive shifts from prolonging political survival to making rapid profits and exiting. A higher risk of political ouster has a moderating effect on the extent of illegal extraction only when the risks of conviction while in power as well as that out of power are both high enough. Otherwise, it results in a resource discounting effect where minerals are extracted in highly unsustainable fashion.

From a policy perspective, our results suggest that the perverse incentives related to excessive illegal extraction increase with an imbalance in the various risks faced by the regulator. If the risk of conviction is made high and independent of whether the regulator is in political power or not, it will help reduce the illegal extraction of minerals and also lead to lower levels of deforestation. As the chances of conviction are usually low during the period the regulator holds political power, they can reduce their expected costs from conviction in the post-power scenario through lowering the risk of losing power. This could be accomplished

through either preventing excessive deforestation (as our results indicated) or through other means such as increasing their vote banks using their illegal wealth. Therefore, delinking of the conviction risk with political survival risk is key to preventing corrupted relationships between politicians and mining firms. Through strengthening the judicial institutions and the auxiliary mechanisms associated with indicting and convicting those engaged in illegal extraction, it could become possible to increase conviction chances while keeping them independent of any political influence.

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Appendix A: First order conditions

The current value Hamiltonian (CVH) is given as:

(A1)

$$\begin{aligned}
& m_1 \cdot \log \left(\left(\pi \cdot e(t) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) \cdot l(t) \right) \cdot \theta \right) \cdot \exp(-\lambda_p(t) - \lambda_{c_power}(t)) \\
& - \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(t)) \cdot (1-l(t)) \cdot \exp(-\lambda_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_power}(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta \right) dx \right) + \\
& \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right) \cdot \exp(-\lambda_p(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \left(\int_t^\infty \left(\varepsilon \cdot \exp(-\lambda_{c_no_power}(x)) \cdot \exp(-\rho \cdot x) - \right. \right. \\
& \left. \left. \zeta_{c0} \cdot \log(w(x) + w_0) \cdot \exp(-\lambda_{c_no_power}(x)) \cdot \right. \right. \\
& \left. \left. \exp(-\rho \cdot t) \cdot \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta \right) dx \right) \right) \right) + \\
& \mu_d \cdot (p_0 \cdot (p_1 + l(t)) \cdot (e(t) + q_0(t))) + \mu_i \cdot \left(\beta + \varphi \frac{q^{\varphi_0}(t)}{q^{\varphi_0}(t) + \varphi_1} \right) + \mu_p \cdot \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right) + \\
& \mu_{c_power} \cdot \lambda_{c0} \cdot \log(w(t) + w_0) + \mu_{c_no_power} \cdot \zeta_{c0} \cdot \log(w(t) + w_0)
\end{aligned}$$

where $\mu_d, \mu_p, \mu_{c_power}$, and $\mu_{c_no_power}$ are the shadow prices of the level of cumulative deforestation, the stock of cumulative hazard of losing political power, the stock of cumulative hazard of getting convicted while in power, and the stock of cumulative hazard of getting convicted after losing power, respectively. The regulator optimizes with respect to the level of illegal extraction to be allowed per period, as well as the level of relaxation in environmental

remediation requirement. Note that the monetary payments received by the firm through the bargaining process are already incorporated within the CVH.

The first order condition with respect to the level of illegal extraction gives:

(A2)

$$\begin{aligned}
& m_1 \cdot \frac{\left(\pi - \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot p_0 \cdot (1-l(t)) \right) \cdot \theta}{\left(\pi \cdot e(t) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) \cdot l(t) \right) \cdot \theta} \cdot \exp(-\lambda_p(t) - \lambda_{c_power}(t)) - \\
& \left(- \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(t)) \cdot (1-l(t)) \right) \cdot \theta \\
& - \lambda_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_power}(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \frac{\partial}{\partial e(t)} \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta \right. \right. \\
& \left. \left. - \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(x)) \cdot (1-l(x)) \right) dx \right) \\
& + \\
& \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right) \cdot \exp(-\lambda_p(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \left(\begin{aligned} & \varepsilon \cdot \exp(-\lambda_{c_no_power}(t)) \cdot \exp(-\rho \cdot t) - \\ & \int_t^\infty \zeta_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_no_power}(t)) \cdot \\ & \exp(-\rho \cdot t) \cdot \frac{\partial}{\partial e(t)} \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta \right. \right. \\ & \left. \left. - \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(x)) \cdot (1-l(x)) \right) dx \right) \end{aligned} \right) \\
& = -\mu_d \cdot (p_0 \cdot (p_1 + l(t)))
\end{aligned}$$

The first term on the left hand side of equation (A2) is the expected marginal utility to the regulator from receiving payments through granting illegal extraction until they are either convicted or lose political power. The second term is the change in the expected utility in the event of getting convicted while in power. Note that granting an extra extraction increases the

deforestation level. The third term on the left hand side is the change in expected utility in the event of losing political power. If the regulator loses political power, their risk of future conviction is higher ($\zeta_{c0} > \lambda_{c0}$), and also their conviction risk as well as penalty are a function of the accumulated wealth. The right hand side is the impact on the shadow price of deforestation from a marginal increase in extraction.

The first order condition with respect to the level of relaxation in environmental remediation requirement, is similarly derived as:

(A3)

$$\begin{aligned}
& m_1 \cdot \frac{\left(\left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(t)) \right) \cdot \theta}{\left(\pi \cdot e(t) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) \cdot l(t) \right) \cdot \theta - \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(t)) \cdot (1-l(t))} \cdot \exp(-\lambda_p(t) - \lambda_{c_power}(t)) - \\
& -\lambda_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_power}(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \frac{\partial}{\partial l(t)} \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta - \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(x)) \cdot (1-l(x)) \right) dx \right) \\
& + \\
& \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right) \cdot \exp(-\lambda_p(t)) \cdot \exp(-\rho \cdot t) \cdot \\
& \left(\int_t^\infty \left(\begin{aligned} & \varepsilon \cdot \exp(-\lambda_{c_no_power}(t)) \cdot \exp(-\rho \cdot t) - \\ & \zeta_{c0} \cdot \log(w(t) + w_0) \cdot \exp(-\lambda_{c_no_power}(t)) \cdot \\ & \exp(-\rho \cdot t) \cdot \frac{\partial}{\partial l(t)} \log \left(\kappa \cdot \int_0^t \left(\left(\pi \cdot e(x) + \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(x)) \cdot l(x) \right) \cdot \theta - \left(\gamma_0 + \gamma_0 \cdot \frac{d(x)^{\gamma_1}}{d(x)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot e(x)) \cdot (1-l(x)) \right) dx \right) \end{aligned} \right) \right) \\
& = -\mu_d \cdot p_0 \cdot (q_0 + e(t))
\end{aligned}$$

With respect to marginally increasing the relaxation in remediation requirement, the first term on the left hand side improves the illegal payments received, whereas, the other two terms reduce the expected utility from conviction or from a loss of political power.

Appendix B: Parameter calibration

Table1: Parameters Selected for the Model Equations

Equation	Parameter values	Equation No.
$\dot{i}(t) = \left(\beta + \phi \frac{q^{\phi_0}(t)}{q^{\phi_0}(t) + \phi_1} \right)$	$\beta = 0.042, \phi = 0.084,$ $\phi_0 = 3, \phi_1 = 10000$	2
$\dot{d}(t) = p_0 \cdot (p_1 + l(t)) \cdot (e(t) + q_0(t))$	$p_0 = 0.4157, p_1 = 1, q_0 = 20$	3
$z(t) = \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot \dot{d}(t)$	$\gamma_0 = 43, \gamma_1 = 2, \gamma_2 = 10^5$	4
$b(q_0(t)) = \left(\gamma_0 + \gamma_0 \cdot \frac{d(t)^{\gamma_1}}{d(t)^{\gamma_1} + \gamma_2} \right) \cdot (p_0 \cdot q_0(t)) \cdot l(t)$	$p_0 = 0.4157, q_0 = 20,$ $\gamma_0 = 43, \gamma_1 = 2, \gamma_2 = 10^5$	6
$\theta(t) = \bar{\theta} \cdot \left(1 + \theta_i \cdot \frac{i(t)^{\psi_0}}{i(t)^{\psi_0} + \psi_1} \right)$	$\bar{\theta} = 0.5, \theta_i = 0.4, \psi_0 = 6,$ $\psi_1 = 10^{-7}$	8
$m(t) = (\pi \cdot e(t) + b(q_0(t)) - c(t)) \cdot \theta$	$\pi = 235.15$	11
$\log(m(t))^{m_1}$	$m_1 = 0.9$	12
$\dot{\lambda}_p(t) = \left(\lambda_0 + \lambda_{p0} \cdot \frac{d(t)^{\lambda_{p1}}}{d(t)^{\lambda_{p1}} + \lambda_{p2}} \right)$	$\lambda_{p0} = 10, \lambda_{p1} = 2,$ $\lambda_{p2} = 10^8, \lambda_0 = 0$	13
$\dot{\lambda}_{c_power}(t) = \lambda_{c0} \cdot \log(w(t) + w_0)$	$\lambda_{c0} = .003, w_0 = 1$	14
$\dot{\lambda}_{c_no_power}(t) = \zeta_{c0} \cdot \log(w(t) + w_0)$	$\zeta_{c0} = 0.1, w_0 = 1$	16
$\mathcal{E}$	1	17
$U_c = -\kappa \cdot \int_0^t m(t) \cdot \exp(-\rho \cdot t) dt$	$\kappa = 2, \rho = 0.15$	18
$\dot{l}_0$ (initial level of gdp)	10 B USD	
d_0 (initial level of forest cover loss)	296 km ²	
Initial stock of ores	712 MT	
Total forest area	1135 km ²	
Ore revenue per MT	1175.75 M INR	

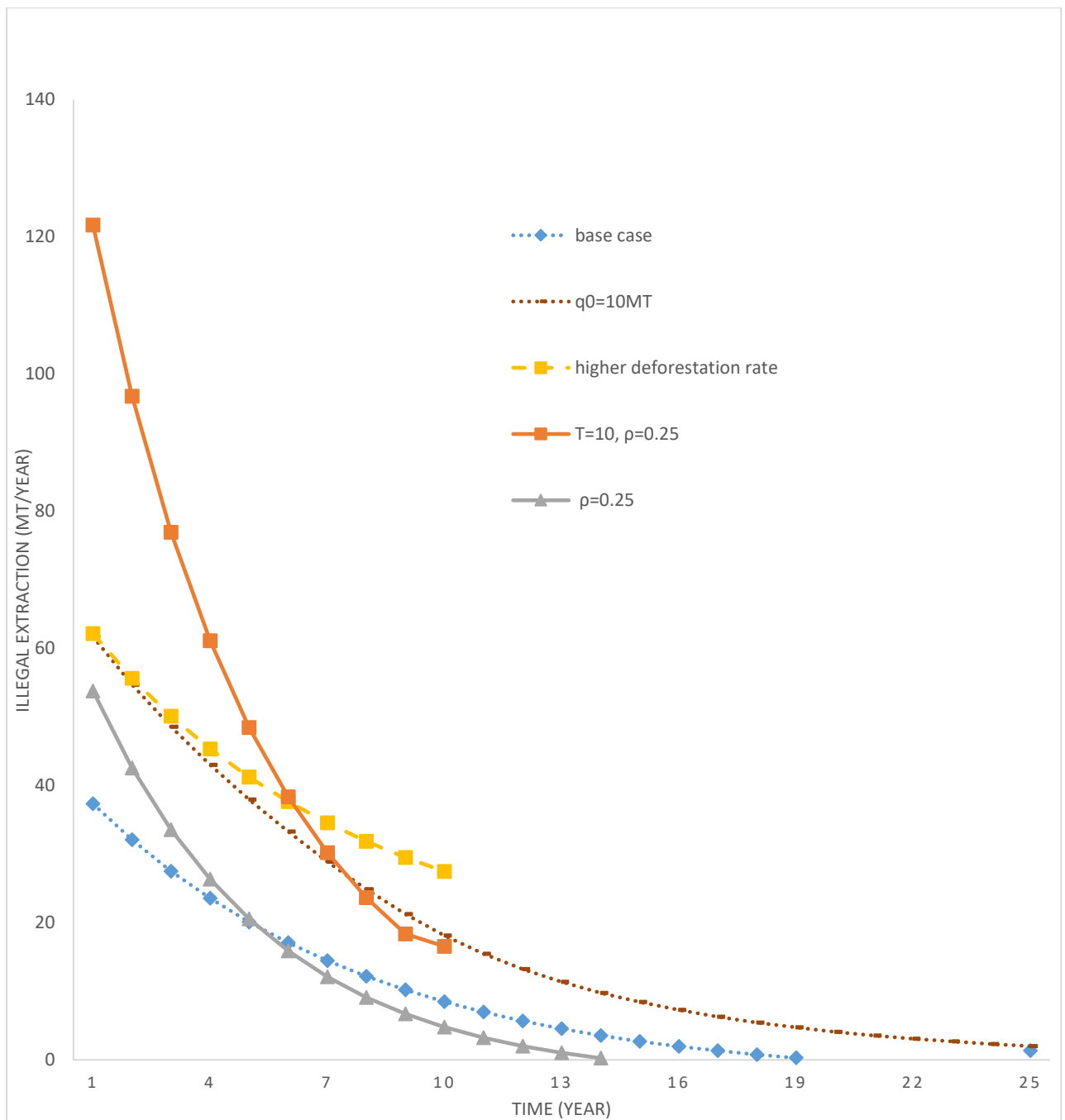


Fig 1. Time path of illegal extraction of iron ores when no risks are present

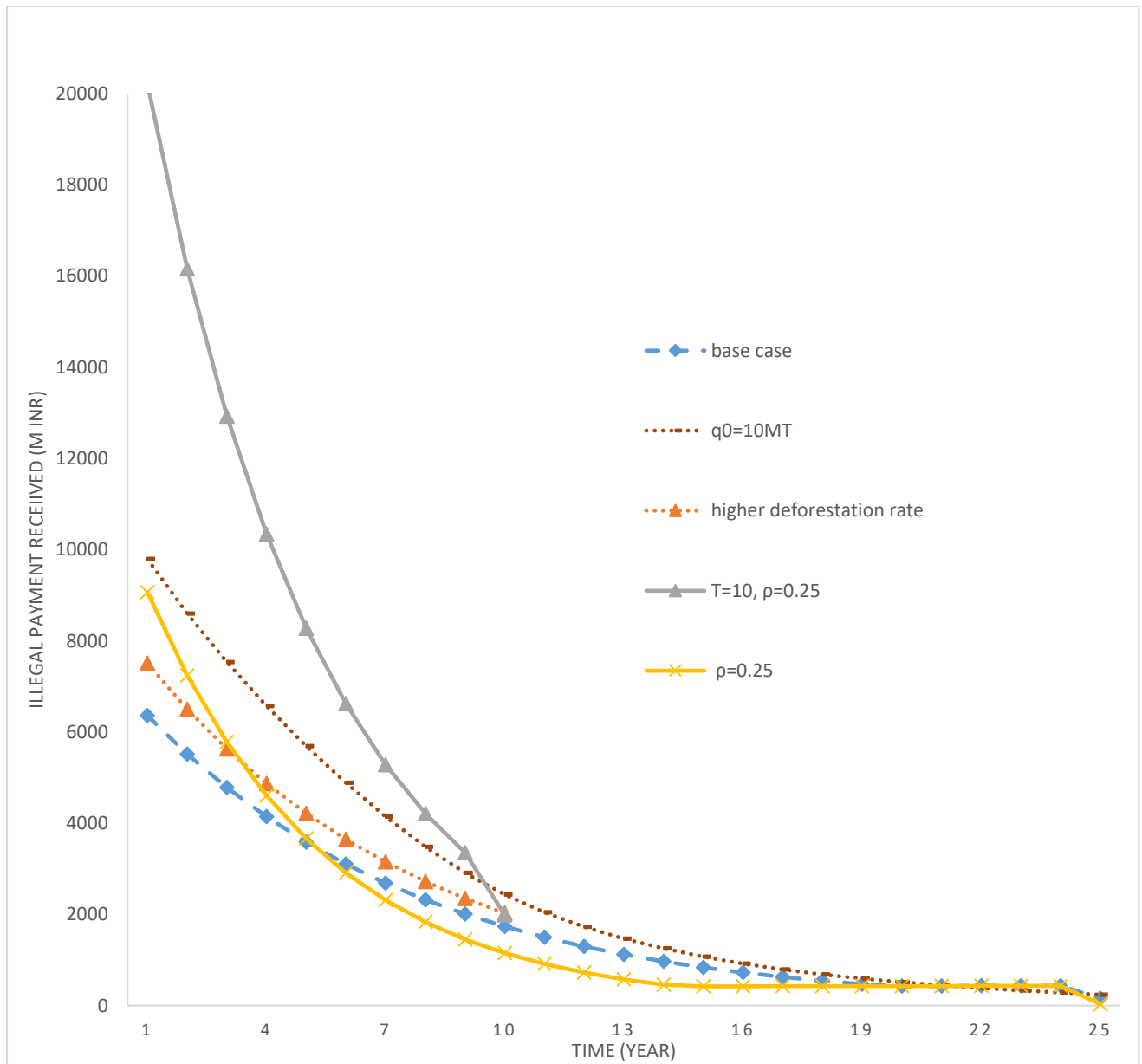


Fig 2. Time paths of illegal payments received by the regulator under the no-risk scenarios

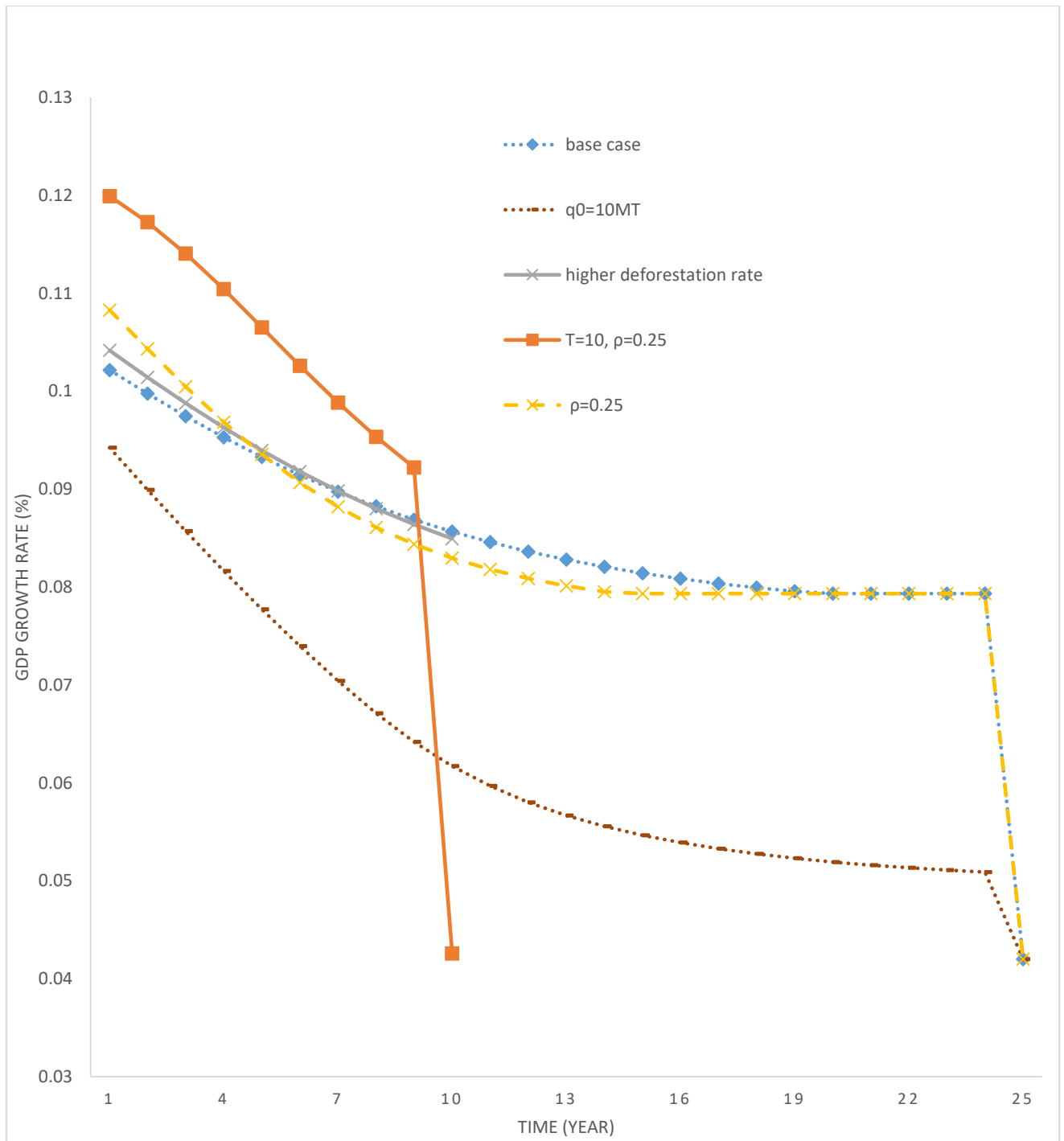


Fig 3. Time paths of local economic growth rates under the no-risk scenarios

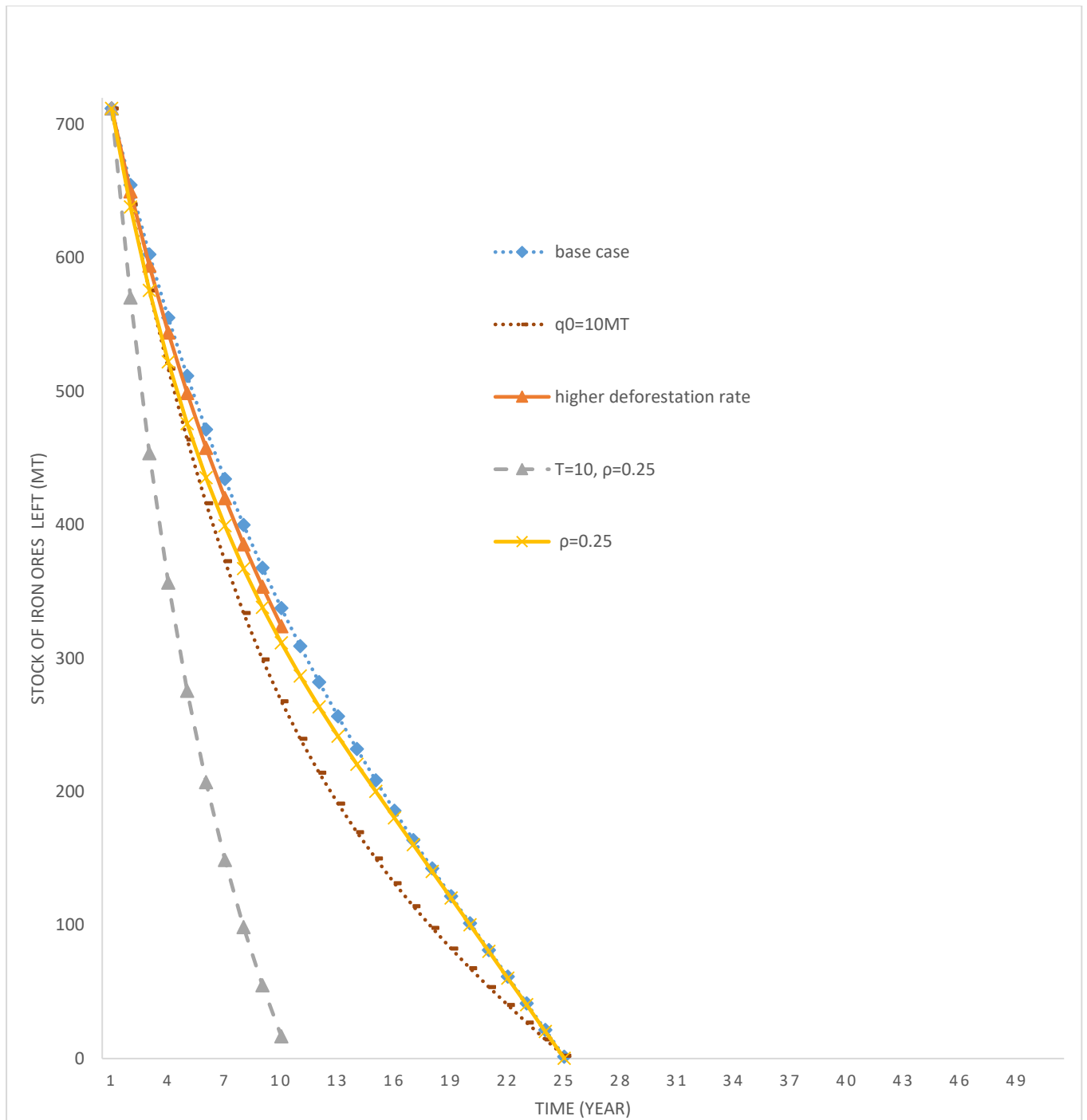


Fig 4. Time paths of total iron ore minerals left underground under the no-risk scenarios

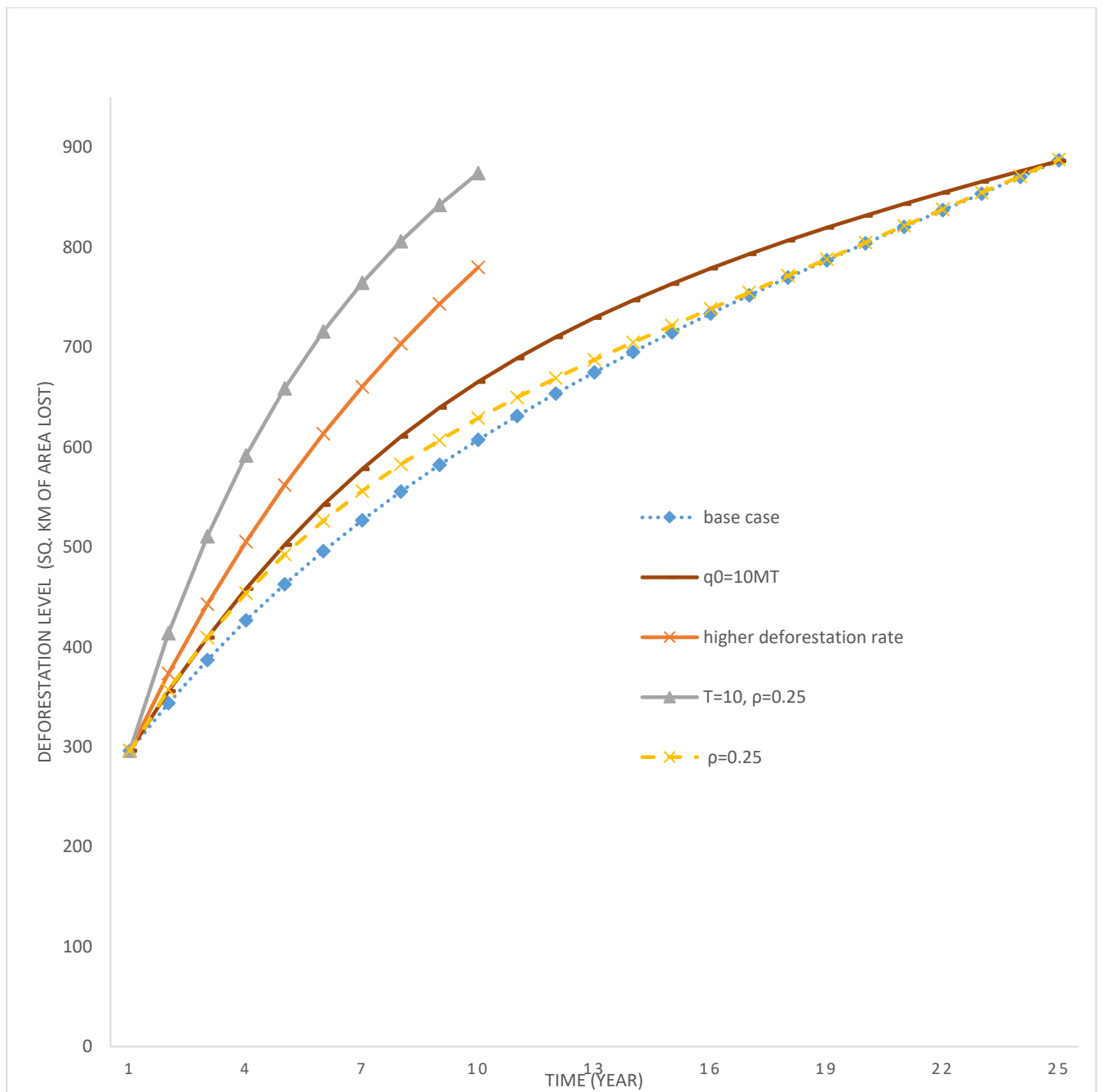


Fig 5. Time paths of total deforestation level for the various no-risk scenarios

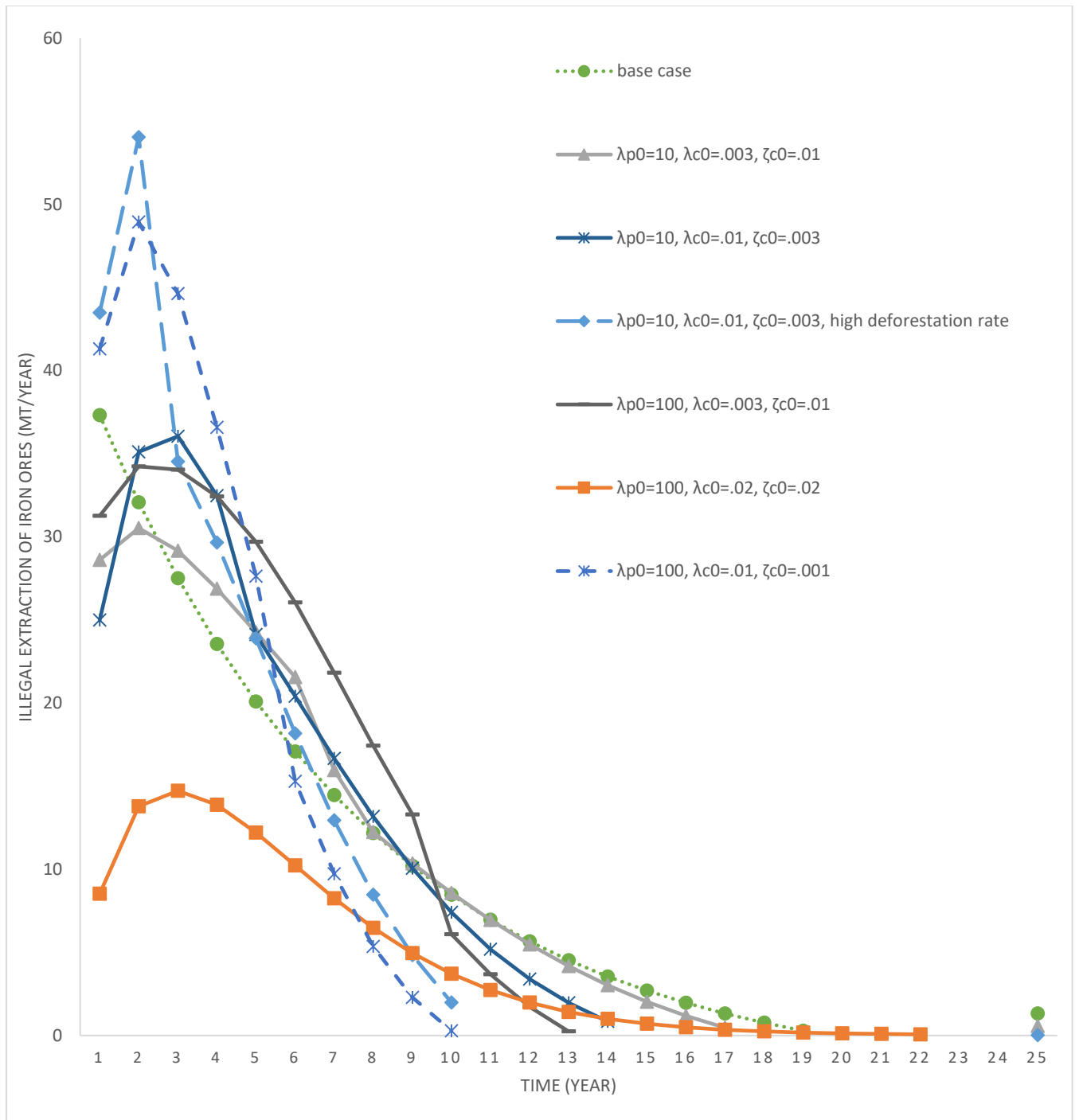


Fig 6. Time paths of illegal extraction levels under the various risk scenarios

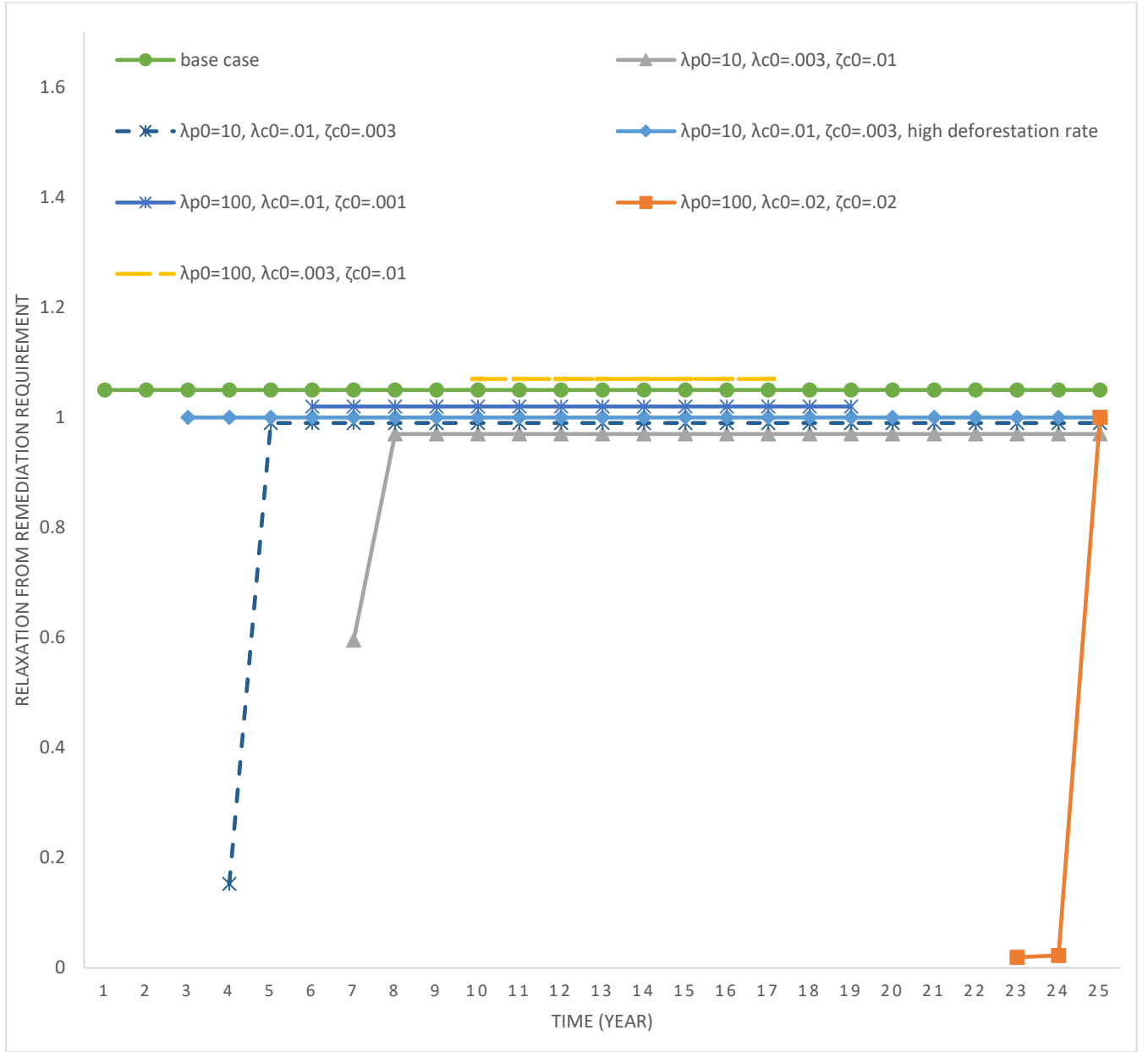


Fig 7. Environmental remediation relaxation granted by the regulator under the risk scenarios

Note: For all the above scenarios, remediation relaxation reaches a value of 1 after a certain time. However, some scenarios are depicted as reaching a value less than 1 for visual clarity. For instance, in the scenario, $\lambda_{p0} = 10, \lambda_{c0} = 0.01, \zeta_{c0} = 0.003$, $l(t)$ reaches a value of 1 from year 8 onwards, however in the figure this value is shown as 0.97.

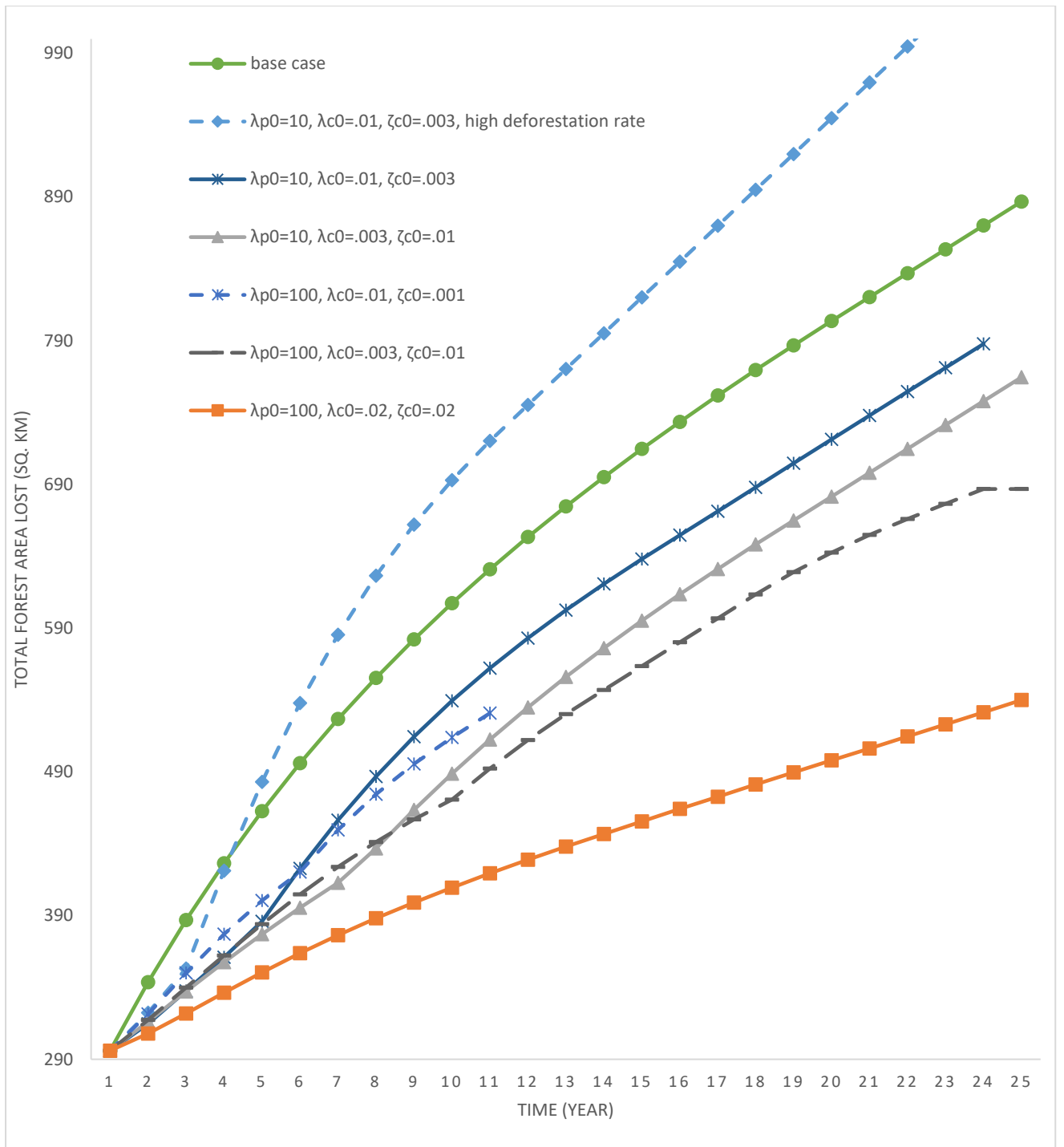


Fig 8. Time paths of cumulative levels of deforestation under the various risk scenarios

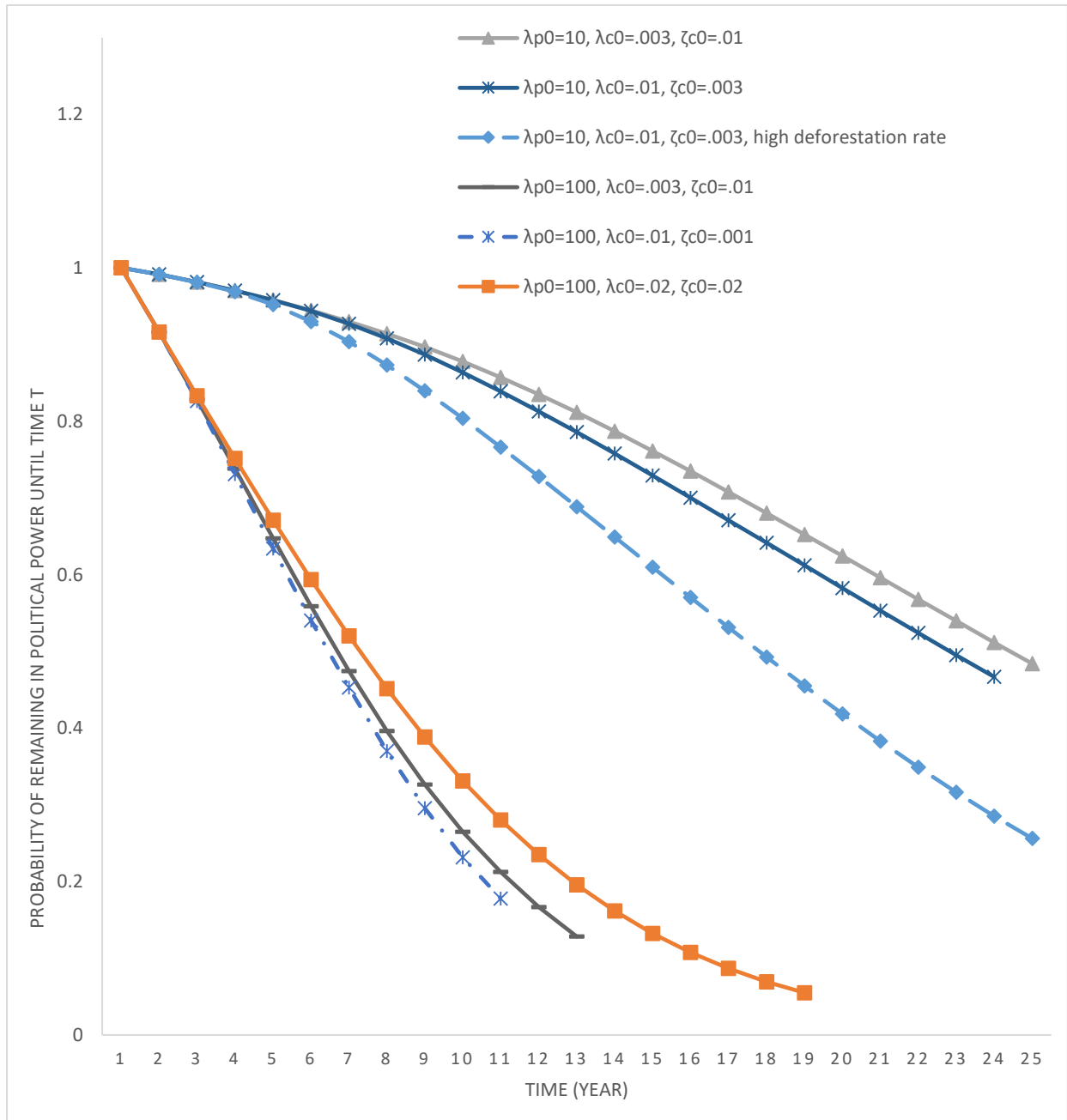


Fig 9. The Probability of remaining in political power until time t for the various risk scenarios

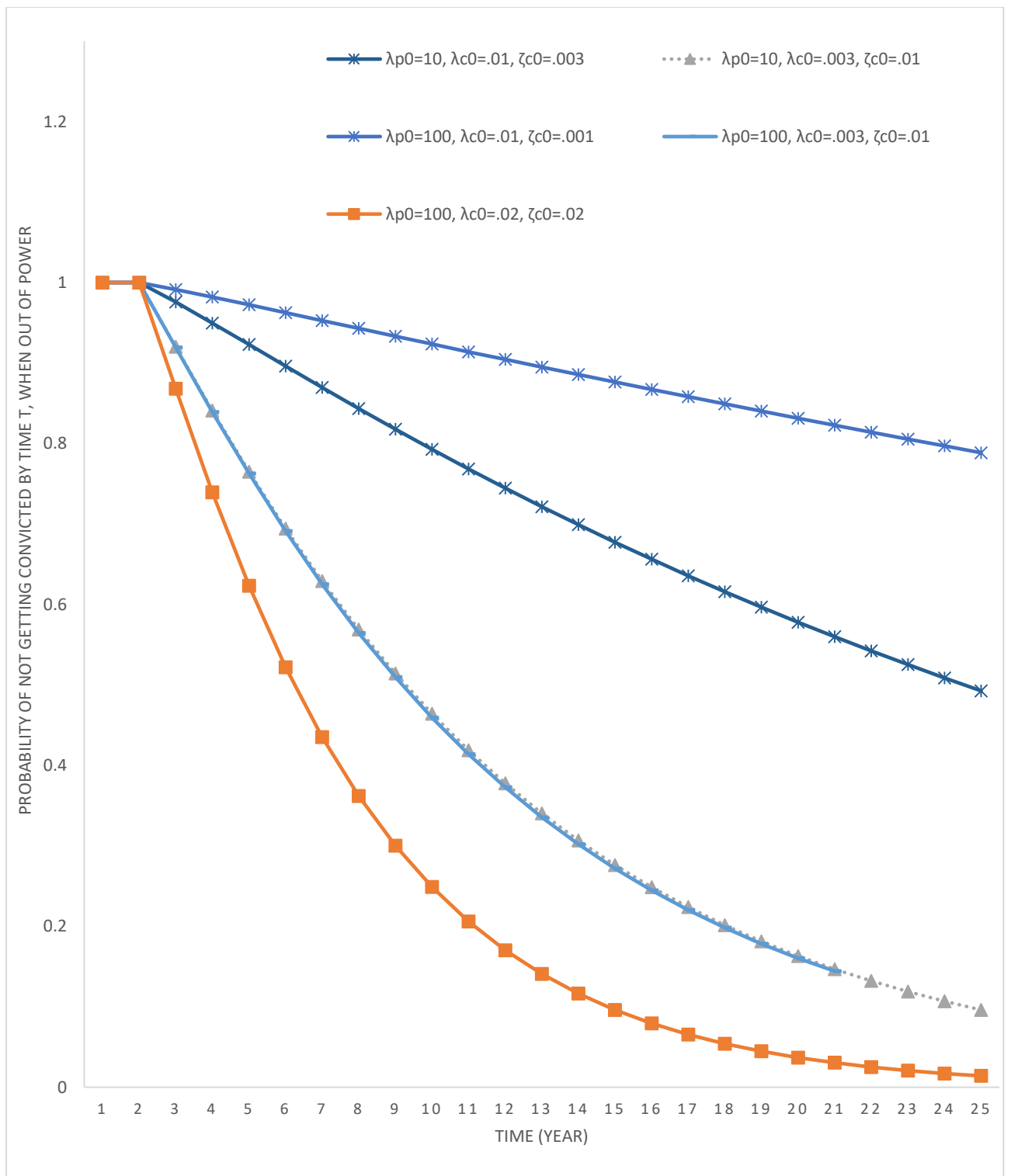


Fig 10. The Probability of not getting convicted until time t after losing power under the various risk scenarios