# Breaking the Resource Curse: A Model of Institutional Dynamics and Economic Transitions in Extractive Communities

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# Breaking the Resource Curse: A Model of Institutional Dynamics and Economic Transitions in Extractive Communities

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**Communities reliant on extractive industries face a paradox: despite the promise of economic growth from lucrative, well-paying industries, they often experience poor socio-economic outcomes. While the so-called "resource curse" has been debated and studied extensively in a variety of disciplines, understanding when and why the resource curse occurs, and whether it is possible to escape it, remains a challenge. This study examines these questions through a dynamical systems model that incorporates theories from the literature about how extractive industries interact with institutions and the communities in which they're based. The model reveals that both the resource curse and a more diversified economy are possible, depending on the initial level of community capital. It also reveals how various factors, such as declining commodity prices, can trigger an abrupt and irreversible transition from the diversified equilibrium to the resource curse. A generalized version of the model further suggests that socio-political dynamics are critical in determining the occurrence of this type of transition. The results illustrate the difficulty of escaping the resource curse, identify potential leverage points or change, and highlight the critical role of institutional dynamics in producing and perpetuating extractive dynamics in these regions.**

Sustainable development | Critical transitions | resource curse | institutions



From the oil wells of Nigeria, Venezuela, and the Congo to the United States' Appalachian coalfields and the Canadian tar sands, the regions and countries from which fossil fuels and other raw materials that fuel modern life are extracted are diverse but tend to share a common dilemma: despite the incredible wealth generated by these enterprises and the promise of economic development often pitched by extractive industries, the purported long-term economic benefits of extractive industries often fail to materialize. Instead, these regions face not only environmental destruction and adverse health impacts, but also higher poverty rates and slower economic growth (1–3). Understanding this contradiction, often referred to as the "resource curse", why it occurs in some contexts and not others, and whether it can be reversed, remains an open challenge (4). This is in large part because extractive industries are deeply intertwined with the development of the regions in which they are based, leading to two-way feedbacks that the disciplines typically studying this phenomena are ill-suited to account for. Understanding the complex interactions between extractive industries and communities gains particular importance as the energy transition is poised to shift the geography of extraction, and the many places economically reliant on fossil-fuel extraction face the prospects of economic decline and depopulation, while the drive for critical minerals opens up new frontiers of extraction. This study offers a new approach to understanding this phenomena through a stylized model formalizing theories about the socio-political feedbacks associated with extractive industries.

The resource curse has long been studied in a variety of disciplines, including economics, political science, sociology, and geography. The main explanations for the resource curse center either on how extractive industries interact with non-extractive sectors of the economy, or on how they interact with institutions. The first class of theories, based mostly in the macroeconomic literature, focuses on the "crowding out" effect of extractive industries, where they divert resources from activities that support long-run growth, especially during resource booms (1, 3–5). Similarly, the over-adaptation hypothesis suggests that resource-extracting regions become excessively adapted to a certain form of extraction, making them unable to adapt to changing circumstances (6). Therefore, when the extractive industry shuts down, the region may be left with specialized infrastructure that is not useful for other types of economic

## Significance Statement

Many places that rely on extractive industries experience long-term economic and social harm, despite the wealth these industries bring. This paradox—known as the "resource curse"—is widespread, but why it occurs in some regions and not others remains unclear. This study presents a theoretical model capturing feedbacks between extractive industries, communities, and institutions. It reveals how communities often become trapped in extraction-dependent economies as industries decline, but also identifies opportunities for escape if action is taken earlier. These findings shed new light on the structural dynamics that entrench the resource curse and highlight the critical role of institutions in enabling more resilient and diversified economic futures for affected communities.

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activity and ancillary businesses that are no longer linked to anything (3, 6). This specialization is exacerbated by the high wages paid by extractive industries, which discourages workers from local entrepreneurship or pursuing further education or training (4, 6).

The other class of theories centers on how resource extraction interacts with institutions (2, 3, 7, 8). While there is a consensus on the need for strong institutions in order to prevent the resource curse (3, 8, 9), whether the presence of extractive industries itself influences the strength of institutions has been a matter of debate, with some arguing that extractive industries undermine the development of strong institutions (3, 4, 7). For example, the point-source nature of natural resources like minerals is hypothesized to make them easily controlled by small groups, leading to inequality and rentier effects in which resource rents allow governments to avoid accountability and silence critics and maintain power through patronage or repression (3, 10). The micro-scale impact of extractive industries on institutions, including informal institutions has also been well documented in rural sociology, with a focus on the social disruption and fragmentation of community relationships and institutions caused by extractive industries. For example, the influx of workers during resource booms can lead to a strain on existing services and infrastructure, and social tensions and conflict with existing residents, altering community dynamics and cultural norms (11–13). The introduction of powerful external actors such as multinational corporations and government agencies, can reshape local power structures (6, 14, 15). Additionally, the economic benefits of resource extraction are often unequally distributed, leading to increased economic inequality and social stratification within a community (16). In the long term, extractive industries can be powerful not only economically, but also in shaping a community's culture and norms. The fact that these industries typically employ a large proportion of workers in the community, and often multiple generations of workers, and the often long hours and harsh conditions characterizing the work, means that these industries can become embedded in the social fabric and identity of a community (17, 18). This tendency is often exploited by extractive industries, which actively amplify the centrality of extraction to the identity of a community or region to maintain power even as their economic importance may be declining (17, 19, 20).

While these theories are supported by decades of empirical research, the heterogeneity of contexts and multi-dimensional nature of the resource curse means that understanding why the resource curse occurs in some contexts and not others, and whether it is possible to escape once caught in the resource curse, remains a challenge. The macroeconomics and and political-economic literature, in relying on regression analyses and meta-analyses, offer generalizable insight, but are limited to measuring uni-directional impacts and thus struggle with complex feedbacks, such as the one between institutions and extraction, that make it difficult to determine cause and effect. Qualitative case studies, which offer insights into complex dynamics in a contextualized manner, but can be challenging to extend to the diverse contexts in which these communities exist throughout the world. Complex systems models can incorporate the complex feedbacks that generate qualitatively different outcomes in different contexts, allowing them to build on existing contextual, qualitative work while contributing to more general theories about when and why the resource curse occurs. Such models exist for understanding numerous other socio-political phenomena, such as the development and maintenance of institutions for managing the commons in small-scale agriculture (21, 22) and escaping the "poverty trap" (23, 24). Yet, the resource curse, despite its ubiquity throughout the world, numerous theories in multiple disciplines, and its importance in determining the development of entire regions and nations, has not received the same attention from modelers. Existing models of communities reliant on extractive industries address aspects of them, such as the migratory and boom-bust dynamics of these communities (25) and the co-existence of extractive industries with other resource-based livelihoods (26). However, the mechanisms leading to the resource curse have yet to be formalized in a mathematical model. By incorporating existing theories about the underlying dynamics of how extractive industries interact with institutions into a complex systems model, this study allows for systematically exploring prospects for extraction-dependent places to break the resource curse and transition towards more diversified, equitable, and sustainable forms of development.

This study proceeds in two main parts: 1) Developing and analyzing a dynamical systems model linking extractive industries, community capital, institutional strength, and economic diversity to understand the possible long-term outcomes, or equilibria, generated by these dynamics, and the conditions under which the system can transition between these equilibria, and 2) Analyzing a more general version of the model from the first section to verify that results are robust to different model structures, and identify the processes that are most influential in determining whether the resource curse occurs.

## Methods

Dynamical systems modeling allows for modeling complex feedbacks by mathematically operationalizing how key variables in a system evolve over time through interaction with each other. These variables that track the state of the system over time are called state variables, and their interdependencies are often visualized through causal loop diagrams like in Figure 1 and mathematically operationalized through a system of ordinary differential equations.

This study focuses on the feedback at the heart of explanations of the resource curse: extractive industries shape communities' natural, human, and social capital, in both positive and negative ways, which in turn shapes the prospects for non-extractive sectors and livelihoods to prosper (crowding out and overadaptation hypotheses). The ways and extent in which extractive industries impact communities are mediated by institutions, but the quality or strength of these institutions is itself influenced by how dominant the extractive industry is (institutional quality hypotheses). Thus, a positive feedback loop, or lock-in effect, can occur with the extractive industry becoming more economically dominant, weakening the institutions that would regulate them, allowing them to become or remain profitable and further entrenching their dominance.

This dynamic is operationalized in a model with three state variables: extractive industry capital ($K$), community capital ($C$), and the population working in non-extractive industries ($L_n$). These variables interact with each other through intermediary variables, such as economic diversity and institutional quality. Each of the state variables and the processes associated with them is described in more detail below and depicted in Figure 1.

**Extractive Industry Capital and Production.** The dynamics of extractive industry capital are modeled similarly to the formulation in Lopez 2010, with investment increasing proportional to the profit and depreciating at a fixed rate, with the added dynamic of institutions imposing a cost on extractive industries and thus reducing their profit. Thus, the extractive industry capital $K$, in dollars, is modeled by

$$\dot{K} = \phi \frac{\partial Q}{\partial K}\left[1 - I\left(\frac{L_n}{L_n + L_m}\right)\right] - \mu K, \qquad [1a]$$

where $\phi$ is the rate of capital reallocation (\$/time), $Q$ is the profit before the costs imposed by taxes and regulations, $L_m$ is the extractive industry labor (in number of workers), $L_n$ is the labor in a non-extractive industry (in number of workers), and $\mu$ is the depreciation rate. In another departure from Lopez 2010, we use the derivative of the profit with respect to $K$ to represent firms acting on the expected profit rather than the current profit.

The feedback between extractive industries and institutions is captured abstractly through $I$ (dimensionless), representing the fraction of extractive industry profits captured by the community through taxes and regulations. Rather than modeling a specific mechanism through which extractive industries undermine institutional strength (i.e. rentier effects, social disruption), $I$, is directly a function of economic diversity, or the fraction of the workforce in a non-extractive industry $\left(f_n = \dfrac{L_n}{L_n + L_m}\right)$. Lower economic diversity, corresponding with the extractive industry being more dominant economically and politically and fewer interests to contest it, leads to weaker institutions. Thus, a lower cost is imposed on the industry, leading to increased mining activity, creating a positive feedback loop.

In the specific model, $I$ is modeled as a linear function of the economic diversity:

$$I = b f_n,$$

where $b \leq 1$ is a constant factor. Production is modeled using a Leontief production function, $P = a \cdot \min\left(K, \frac{L_m}{\psi}\right)$, where $L_m$ is mining labor, and $\psi$ is the ratio of labor to capital. Because extractive industries pay high wages compared to other rural livelihoods and rely on a fairly mobile workforce, we assume that $K$ will be the limiting factor to production, and that the dynamics of the mining labor move more quickly than the dynamics in the model so that mining always has the necessary labor. Hence, $L_m = \psi K$ and $P = aK$. The pre-tax profit, $Q$, then simplifies to

$$Q = paK - wL_m,$$

where $a$ is the factor productivity of input capital, $p$ is the price of the extracted resource, $w$ is the wage. Assuming the mining industry is not anticipating the institutional dynamics modeled here, changes in mining investment are based on the marginal gain in profit (pre-tax) of additional investment $\left(\dfrac{\partial Q}{\partial K}\right)$, which makes

$$\dot{K} = \phi\left((pa - w\psi)\left(1 - bf_n\right)\right) - \mu K. \qquad [1b]$$

**Community Capital.** The extractive industry is linked to the rest of the local economy in part through its impact on community capital. Community capital encompasses the natural, social, human, financial, and built capital that is critical for successful communities (27, 28). Natural capital encompasses the environmental assets and ecosystem services present in a community, such as land, water, biodiversity, and scenic beauty, whereas cultural capital reflects the shared values, traditions, and identities that shape how community members interact and make decisions. Human capital refers to the skills, knowledge, health, and leadership capacity of individuals. Social capital denotes the networks, trust, and norms that facilitate cooperation and collective action. Financial capital comprises the monetary resources available for investment and development. Built capital includes the physical infrastructure that supports community activities, such as transportation, utilities, and buildings. Especially in the remote places where natural resources extraction typically takes place, extractive industries have enormous influence on each of these dimensions of community capital. The environmental damage they cause has long-term impacts on soil and water quality and dramatic effects on the landscape and scenic beauty of a region. As noted earlier, they also have a significant influence on human and social capital, such as by disrupting existing social networks with an influx of workers during a resource boom (15), and due to their high wages with little educational requirements, dis-incentivizing developing education and other forms of human capital (6). However, with strong institutions in place, they can also benefit community capital. Tax revenue from extractive industries is often used to fund education, and they often build roads and other infrastructure necessary for the development of other industries (29). Thus the ability to capture the benefits of extractive industries while mitigating their impacts on community capital is critical in shaping prospects for alternative development pathways in the future. These different dimensions of how mining impacts community capital (in \$) are modeled by

$$\dot{C} = -F(P) + G\left(I(f_n) \cdot (pP - w\psi K)\right) + H(L_n) - \delta C, \qquad [2a]$$

where $F$ represents the damage from extraction as a function of production, $P$, $G$ represents the contribution of extractive industries to community capital, based on the proportion of profit transferred to the community through $I$, $H$ represents the contribution of non-extractive industries to $C$, and $\delta$ represents a decay/depreciation rate. The net effect of the extractive industry on community capital thus results from the balance between the inevitable destructive impacts of the industry and the benefits that are able to be captured from the industry based on the strength of institutions. Thus, in the case of weak institutions, this captures the "crowding out" and over-adaptation effects of extractive industries.

Each of the functions in Equation 2a is currently modeled as a linear function, making

$$\dot{C} = -\eta aK + \tau b f_n (apK - w\psi K) + \alpha L_n - \delta C, \qquad [2b]$$

where $\eta$, $b$, and $\alpha$ represent scalings on the loss due to extractive industries, gain from transferring wealth from extractive industries, and gain from non-extractive industries, respectively.

**Non-Extractive Industry Labor and Population Dynamics.** The extractive industry is also linked to the rest of the local economy through the distribution of workers. Workers in the community move between working in the extractive industry, in non-extractive industries, and leaving the region altogether based on the opportunities or payoff associated with each of the options at the time, in line with assumptions in prior models of migration (30, 31). The flows of workers between these options is modeled based on evolutionary game theory approaches for modeling how agents switch between options based on pairwise comparisons of their fitness (32).

Since community capital is important in shaping the types of non-extractive sectors that emerge – higher levels of human and social capital, for example, may lead to more white collar jobs – the individual payoff from working in it is assumed to be a function of $C$ (denoted by $E(C)$). As noted earlier, the extractive industry always satisfies its labor needs, so the extractive industry labor is determined by the mining capital. The non-extractive labor dynamics is modeled as

$$\dot{L}_n = L_n \left[c_1 L_m \left[E(C) - w\right] + c_2 \left[E(C) - \pi\right] - c_3 L_n\right], \quad [3a]$$

where $\pi$ is the payoff that can be expected outside of the community and $c_1$, $c_2$, and $c_3$ are constants associated with the rates of flows between the non-extractive industry and extractive industry, external opportunities, and unemployment, respectively. The individual payoff from working in a non-extractive industry, $E(C)$, is assumed to be a linear function of $C$, making

$$\dot{L}_n = L_n \left(c_1 \psi K(\lambda C - w) + c_2(\lambda C - \pi) - c_3 L_n\right). \quad [3b]$$

**System Summary.** This makes the overall system

$$\begin{aligned}
\dot{K} &= \phi\left((pa - w\psi)\left(1 - b\left(\frac{L_n}{L_n + \psi K}\right)\right)\right) - \mu K,\\
\dot{C} &= -\eta a K + \tau b \frac{L_n}{L_n + \psi K}(apK - w\psi K) + \alpha L_n - \delta C,\\
\dot{L}_n &= L_n \left(c_1 \psi K(\lambda C - w) + c_2(\lambda C - \pi) - c_3 L_n\right).
\end{aligned}$$

and the corresponding partially generalized model

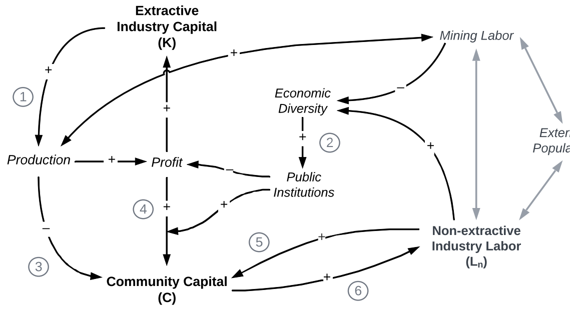
$$\begin{aligned}
\dot{K} &= \phi \frac{\partial}{\partial K}\left[\rho P(K, L_m(K)) - w L_m(K)\right]\left[1 - I(f_n)\right] - \mu K,\\
\dot{C} &= -F(P) + G\left(I(f_n) \cdot (pP - w\psi K)\right) + H(L_n) - \delta C\\
\dot{L}_n &= L_n \left[c_1 L_m(K)\left[E(C) - w\right] + c_2\left[E(C) - \pi\right] - c_3 L_n\right].
\end{aligned}$$

| Symbol | Definition | Unit |
|---|---|---|
| | **State Variables** | |
| $K$ | Extractive industry capital | $[\$]$ |
| $C$ | Community physical and natural infrastructure | $[\$]$ |
| $L_n$ | Population working in non-extractive industry | $[N]$ |
| | **Parameters** | |
| $\phi$ | Rate of extractive industry capital investment with profit | $\left[\frac{\$}{T}\right]$ |
| $p$ | Price of extracted resource | $\left[\frac{\$}{M}\right]$ |
| $a$ | Scaling of extractive industry production with capital | $\left[\frac{M}{\$}\right]$ |
| $w$ | Extractive industry wage | $\left[\frac{\$}{NT}\right]$ |
| $\psi$ | Labor-capital ratio | $\left[\frac{NT}{\$}\right]$ |
| $\tau$ | Timescale of extractive industry investments in community capital | $\left[\frac{1}{T}\right]$ |
| $b$ | Scaling of institutional strength with economic diversity | $[-]$ |
| $\mu$ | Rate of extractive capital depreciation | $\left[\frac{1}{T}\right]$ |
| $\eta$ | Scaling of damage to $C$ with extraction | $\left[\frac{\$}{MT}\right]$ |
| $\alpha$ | Scaling of benefit to $C$ with non-extractive industry | $\left[\frac{\$}{NT}\right]$ |
| $\delta$ | Rate of community infrastructure depreciation | $\left[\frac{1}{T}\right]$ |
| $\lambda$ | Scaling of per-capita payoff from non-extractive industry to $C$ | $\left[\frac{1}{N}\right]$ |
| $\pi$ | Payoff of leaving community | $\left[\frac{\$}{N}\right]$ |
| $c_1$ | Responsiveness of workers to payoff difference between working in extractive and non-extractive industry | $\left[\frac{1}{T\$}\right]$ |
| $c_2$ | Responsiveness of workers to payoff difference between leaving the community and non-extractive industry | $\left[\frac{1}{T\$}\right]$ |
| $c_3$ | Rate of workers being unable to find employment in non-extractive industry (due to saturation) | $\left[\frac{1}{TN}\right]$ |

**Table 1. Definitions and dimensions of the variables and parameters for the specific model.**

## Results

For feasible parameterizations, the system exhibits up to two possible stable equilibria: one in which the extractive industry dominates with weak institutions and no community physical/natural infrastructure or non-extractive industries, and one in which the extractive industry exists at lower levels alongside non-extractive industries, stronger institutions and community physical/natural infrastructure (Figure 2). The first equilibrium demonstrates all of the qualities of the resource curse: the initial rise in community natural and physical capital from gain from the extractive industry is quickly reversed as institutions are weakened and the community bears most of the damage rather than the benefits from the extractive industry. While the total absence of non-




$$\dot{K} = \phi \frac{\partial}{\partial K}\left[\rho P(K, L_m(K)) - wL_m(K)\right][1 - I(f_n)] - \mu K,$$

$$\dot{C} = -F(P) + G(I \cdot Q) + H(L_n) - \delta C$$

$$\dot{L}_n = L_n\left[c_1 L_m(K)\left[E(C) - w\right] + c_2\left[E(C) - \pi\right] - c_3 L_n\right].$$

**Fig. 1.** Graphical representation of the system. The variables in bold are the state variables, and the italicized variables represent intermediary variables. Each link represents a process in the model, and is marked by whether it is a positive or negative interaction. The numbered links represent those that are analyzed in their generalized form in the second part of the study.

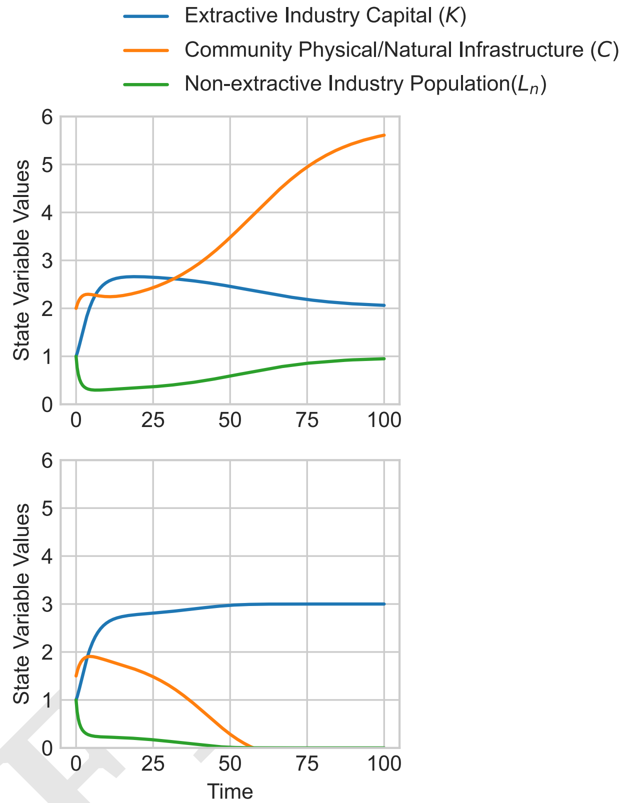



**Fig. 2.** Time series of trajectories for the state variables.

extractive industries is unlikely since extractive industries are usually accompanied by auxiliary industries, this equilibrium represents the crowding out effect of the extractive industry on industries that can independently sustain themselves and communities after the decline of the extractive industry. The second equilibrium, on the other hand, represents an alternative to the resource curse in which the maintenance of strong institutions throughout the expansion of the extractive industries ensures that the benefits of the extractive industry are used to develop non-extractive industries, fulfilling the promise of economic development that extractive industries often make. Crucially, extraction takes place at lower levels in this scenario because of the higher costs imposed on it. As revealed by the phase portraits (Figure 3b) and visualization of the basin of attractions for the two equilibria (Figure 4), once there is a sufficiently high level of economic activity, whether extractive or non-extractive, the initial community capital is the main important determinant of whether a community will reach the diversified equilibrium. Unsurprisingly, communities with initially high community capital reach the diversified equilibrium, suggesting that the communities most in need of the economic development promised by extractive industries are least likely to have that promise fulfilled (6).

Crucially, this bistability is only possible when taking into account the feedback between the economic dominance of the extractive industry and the institutional strength. Making the transfer of wealth between the mining industry and community capital based on a fixed parameter scaling rather than a function of economic diversity, for example, leads to a single equilibrium (see Supplementary Information). This reinforces the necessity of taking into account the underlying institutional dynamics of extractive industries to understand how they entrench themselves in the resource curse, as well as how alternative outcomes can arise.

Bifurcation diagrams show how the stability landscape changes as parameters change, allowing understanding how the system responds to exogenous perturbations or shocks. The bifurcation diagrams reveal that at certain parameter values the diversified equilibrium loses stability through a fold or saddle-node bifurcation (see Supplementary Information for calculation of the system equilibria). For example, as the price of the extracted resource declines – as may be expected if the demand declines – the diversified equilibrium loses stability (Figure 5). This leads the system to experience a sudden transition to the resource curse equilibrium. The resource curse equilibrium, on the other hand, remains stable even as the parameter returns to its original value, leading the transition to be irreversible. While it may seem unintuitive that lower commodity prices would lead to the extractive industry becoming more dominant, reduced profits by the extractive industry also means reduced contributions to community physical and natural infrastructure, reducing prospects for non-extractive industry as well and leading to low economic diversity and weak institutions. In practice, this manifests as industries extracting concessions in the form of tax breaks or loosening of regulations from communities that are desperate to avoid mine or plant closures and mass layoffs (6). Freudenberg's 1992 landmark paper on the addictive tendencies of communities reliant on extractive industries gives such an example of a community in remote northwestern Colorado that successfully ensured that the shale oil, and later coal, industries in the area would bear the costs of development and minimize environmental impact. This approach – an illustration of the diversified equilibrium

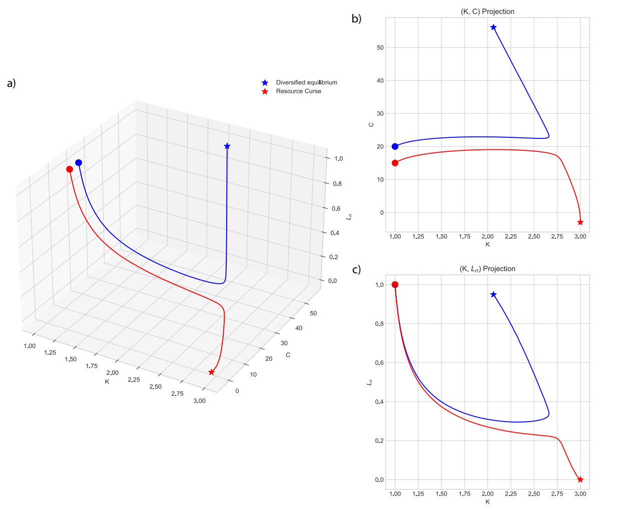



**Fig. 3.** Trajectories in the a) the 3-d phase space, b) the 2-d projection in the $K$-$C$ plane (i.e. a top-down view) and c) a 2-d projection in the $K$-$L_n$ plane (i.e. front view).

- allowed the community to withstand the commodity price shocks of the late 1980s that ravaged many other rural communities. However, just a decade later as the industry was overall becoming less profitable in the region, this same community agreed to cover a significant portion of the developer's costs in the hopes of turning a marginal investment into a profitable one (6). Thus, it is precisely when extractive industries are in decline and it is most important for communities to develop diversified livelihoods that they are least able to. Looking at how the basins of attraction for the two equilibria (Figure 5) paints a more hopeful picture, however. The basin of attraction indicates the resilience of different stable equilibria to perturbations. For higher values of the price, the basin of attraction for the resource curse equilibrium is much narrower than that of the diversified equilibrium, meaning that there is a smaller range of initial conditions leading to the resource curse equilibrium and small stochastic perturbations can push the system to the diversified equilibrium. The basin of attraction for the diversified equilibrium does narrow as the system approaches the bifurcation point, as is common close to a critical transition. Overall though, under the conditions in which the diversified equilibrium is stable, there is a high chance of reaching that equilibrium or perturbing the system from the resource curse equilibrium to the diversified equilibrium.

As shown in Figure 6, a critical transition occurs within the range of feasible parameter values for most of the parameters in the model. In addition to when the price drops, this transition occurs when the scaling of the damage to community capital with extraction increases (6a), suggesting, unsurprisingly, that more damaging forms of extraction contribute to the resource curse, through, for example, undermining other land-based industries like farming. The transition is also triggered when wages increase (6c), making working in the extractive industry more attractive than alternatives. This paradoxical effect of well-paying jobs in extractive industries holds up in the empirical literature, where the ability to make high wages with no higher education

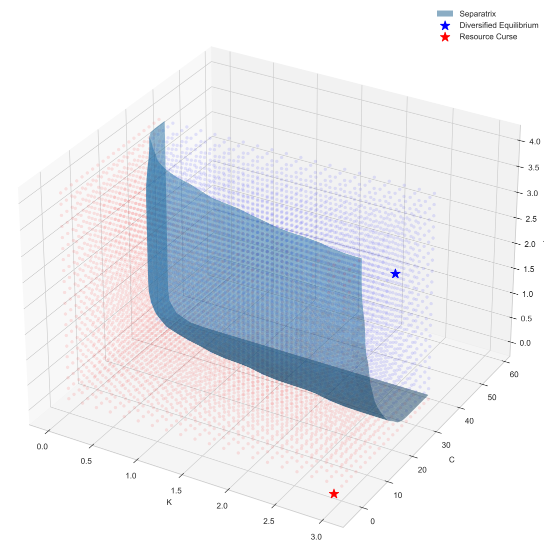



**Fig. 4.** Visualization of the basins of attraction for the two equilibria, with points color-coded by which equilibrium they lead to. The red points indicate points that lead to the resource curse equilibrium (denoted by a red star) while blue points indicate points that lead to the diversified equilibrium (denoted by the blue star).

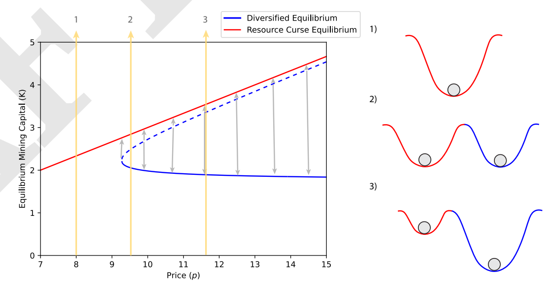



**Fig. 5.** Illustrative bifurcation diagram with respect to the commodity price ($p$). The dashed line indicates an unstable equilibrium while the solid lines represent stable equilibria. The arrows denote which equilibrium the system would reach.

and little training disincentivizes young people from gaining education or developing skills that could develop other industries (6). This is in contrast to farming, for example, which pays significantly lower wages and as a result, relatively few children of farmers go into farming. A similar effect exists for when the labor-capital ratio increases (6d), making more jobs available in the extractive industry. It also occurs when the rate at which the industry invests capital based on profit decreases (6f), leading to lower rates of extractive industry growth, and when the rate of depreciation of community capital increases (6g).

Reduced mobility of workers between the extractive industry and non-extractive industry (6h), and between non-extractive industry and leaving the community altogether (6i) also increases the likelihood of transition. This is likely because the model assumes the mining industry is always able to fulfill its labor requirements, while the non-extractive sector relies on workers switching to it from mining or migrating in, so reduced mobility mostly reflects inertia in willingness to take non-extractive industry jobs. This is realistic in cases where the extractive industry is culturally embedded or

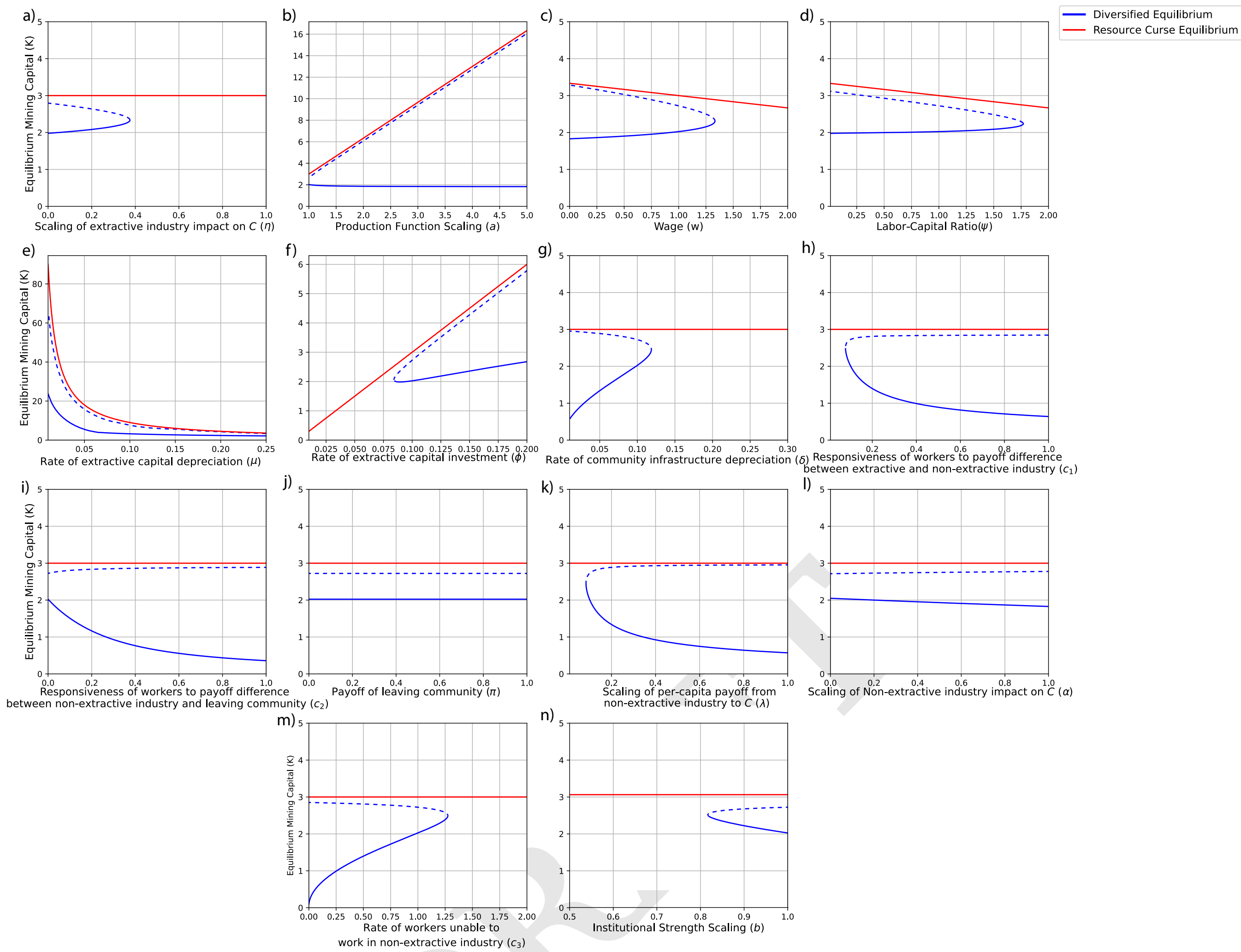



**Fig. 6.** Bifurcation diagrams illustrating how equilibrium K values vary with respect to each parameter in the model. The curves are computed analytically (see Supplementary Information). Dashed lines indicate unstable equilibria, and solid lines indicate stable equilibria. The red line indicates the resource curse equilibrium, while the blue line indicates the diversified equilibrium.

where there's a greater barrier to switching between extractive and non-extractive jobs. Finally, and unsurprisingly, it also occurs when the rate at which community capital translates to per-capita benefits from working in non-extractive sectors decreases (6k), the rate at which workers are unable to find work in non-extractive industry increases (6m), and when the scaling of institutional strength with economic diversity decreases (6n). While for many of these, the fact that they lead to a transition to the resource curse equilibrium is unsurprising, some of the mechanisms leading to a transition are less intuitive. It's not immediately obvious, for example, why declining commodity prices or decreasing rate of capital investment by the industry would make a transition to the resource curse occur without accounting for how it is the wealth generated by the extractive industry that enables diversification.

While the bifurcation diagrams reveals that many factors can trigger a sudden and irreversible transition to the resource curse equilibrium, we want to know whether a similar transition in the other direction is possible. In order for a transition from the resource curse equilibrium to the diversified equilibrium, the resource curse equilibrium must lose stability. The resource curse equilibrium is as follows:

$$K^* = \frac{\phi\,(pa - w\psi)}{\mu}$$

$$L_n^* = 0$$

$$C^* = -\frac{\eta a K}{\delta} = -\frac{\eta a}{\delta}\frac{\phi\,(pa - w\psi)}{\mu}$$

We can check whether this equilibrium is stable by computing the eigenvalues of the Jacobian at this equilibrium (see Supplementary Information for the full Jacobian). When $L_n^* = 0$, the Jacobian (with variables ordered as $K$, $L_n$, and $C$) reduces to

$$J = \begin{bmatrix} -\mu & 0 & 0 \\ 0 & c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi) & 0 \\ -\eta a & \alpha & -\delta \end{bmatrix}$$

Since the Jacobian is lower-triangular, the eigenvalues are simply the diagonal entries ( $-\mu$, $-\delta$, and $c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi)$). Since all coefficients in the model are positive, we just need to check that $c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi) < 0$. Since $C = -\frac{\eta a}{\delta}\frac{\phi(pa - w\psi)}{\mu}$ and is thus negative itself at this equilibrium, $c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi)$ is always negative and the system is always stable. This means that the resource curse equilibrium is extremely self-reinforcing and resistant to perturbations in control parameters, which is perhaps unsurprising given how common an outcome it is empirically. Thus, in the absence of either an external perturbation to the state of the system to push the system out of the basin of attraction for the resource curse, or some change in the structure of the dynamics, the system cannot transition from the resource curse equilibrium to the diversified equilibrium.

**Generalized Modeling Analysis.** Analyzing the generalized model allows us to explore what factors influence transitions to the resource curse in a more general manner. In particular, we can explore which processes in the model are most important in determining when a transition happens and how different functional forms influence the results of the previous section. These different functional forms can represent different technologies (changing the relationship between capital and production), different resources (changing, for example, how damage to community capital varies with resource extraction), or different socio-political contexts (changing the relationship between economic diversity and institutional quality, or between institutional quality and how communities benefit from extractive industries).

Generalized modeling allows for exploring the implications of different functional forms because the functional forms of the ODEs themselves become parameters. In particular, the Jacobian can be written in terms of exponent parameters, which represent the elasticity of a process to a particular variable. For example, $\dfrac{\partial p}{\partial k} = \dfrac{K^*}{P^*}\dfrac{\partial P}{\partial K}$ represents the elasticity of extractive industry production to capital, which conveniently corresponds to the output elasticity parameter in Cobbs-Douglas production functions. This parameter is called an exponent parameter because its value is an indication of the non-linearity of the process (e.g. a value of 1 represents a linear relationship between labor and production, while a value of 2 represents a quadratic, or more generally, a super-linear relationship).

| Parameter | Definition (Elasticity of...) | Value in specific model |
|---|---|---|
| $\dfrac{\partial p}{\partial k}$ | Production to capital (link 1 in Fig. 1) | 1 |
| $\dfrac{di}{df_n}$ | Institutional strength to economic diversity (link 2) | 1 |
| $\dfrac{\partial f}{\partial p}$ | Community capital damage to production (link 3) | $-1$ |
| $\dfrac{\partial g}{\partial\,[i \cdot q]}$ | Community capital benefit from extractive industry to transfer from extraction (link 4) | 1 |
| $\dfrac{\partial h}{\partial l_n}$ | Community capital benefit from non-extractive industry to non-extractive industry (link 5) | 1 |
| $\dfrac{\partial e}{\partial c}$ | Gain in non-extractive industry to community capital (link 6) | 1 |

In order to explore how different exponent parameters shape the stability landscape, we analyze the bifurcations with respect to these parameters. Instead of plotting how the steady state – which cannot be computed without specifying functional forms – changes with respect to model, this analysis focuses on determining when the abrupt transition from the diversified to resource curse equilibrium depicted in Figures 5 and 6 occurs. We analyze when this transition occurs by using the Routh-Hurwitz conditions for a 3x3 matrix to determine when the diversified equilibrium changes stability. By plotting its stability with respect to the exponent parameters, we can see which dynamics are most important in determining when the transition to the resource curse occurs. For ease of interpretation, we show selected bifurcations with respect to varying two exponent parameters at a time (see Supplementary Information for comprehensive 3D bifurcations). In practice, a particular specification of the functional forms, such as the one presented earlier, does not occupy a single point on the diagram because other parameters in the generalized model change when the functional forms change. Thus, rather than being used to determine whether the diversified equilibrium will be stable for a given set of functional forms, these diagrams reveal which functional forms are important in determining when the transition to the resource curse occurs and for which functional forms this transitions occurs earlier or later.

As shown by Figure 7(a), the elasticity of production to capital ($\dfrac{\partial p}{\partial k}$, or link 1 in Fig. 1) is relatively less influential over stability, and interestingly has a non-monotonic relationship with stability. Since $\dfrac{\partial p}{\partial k} + \dfrac{\partial p}{\partial l_m} = 1$ for constant elasticity of substitution production functions, this indicates that a balance between capital and labor in production is best for stability of the diversified equilibrium. The elasticity of institutional strength to economic diversity (link 2) is more influential, and lower values of that elasticity – i.e. institutional strength that scales sub-linearly with economic diversity – are better for diversified equilibrium stability. In short, the diversified equilibrium is more stable when the strength of institutions is less responsive to economic diversity. This would achieved by, for example, safeguards that make public institutions less susceptible to influence by extractive industries.

Additionally, a lower elasticity of the community capital benefit from extractive industry to the proportion of profits transferred to the community, such as through taxes, ($\dfrac{\partial g}{\partial\,[i \cdot q]}$ or link 4) is better for diversified equilibrium stability. In practice, this would be achieved by relying less on the taxes collected from extractive industries, which is often unlikely in the remote and rural communities where extractive industries are often based. Similarly, the elasticity of non-extractive industry to community capital ($\dfrac{\partial e}{\partial c}$ or link 6) is influential, with lower elasticities being better for the diversified equilibrium. However, non-extractive industries that don't rely heavily on community capital are likely less desirable as livelihoods (e.g. involving low-wage or dangerous jobs). Thus, while non-extractive industry being less sensitive to community capital might be better for the stability of the diversified equilibrium, that equilibrium may be less desirable. Finally, the elasticity of damage to community capital from extractive industry production (link 3), and the elasticity of benefit to community capital from non-extractive industry

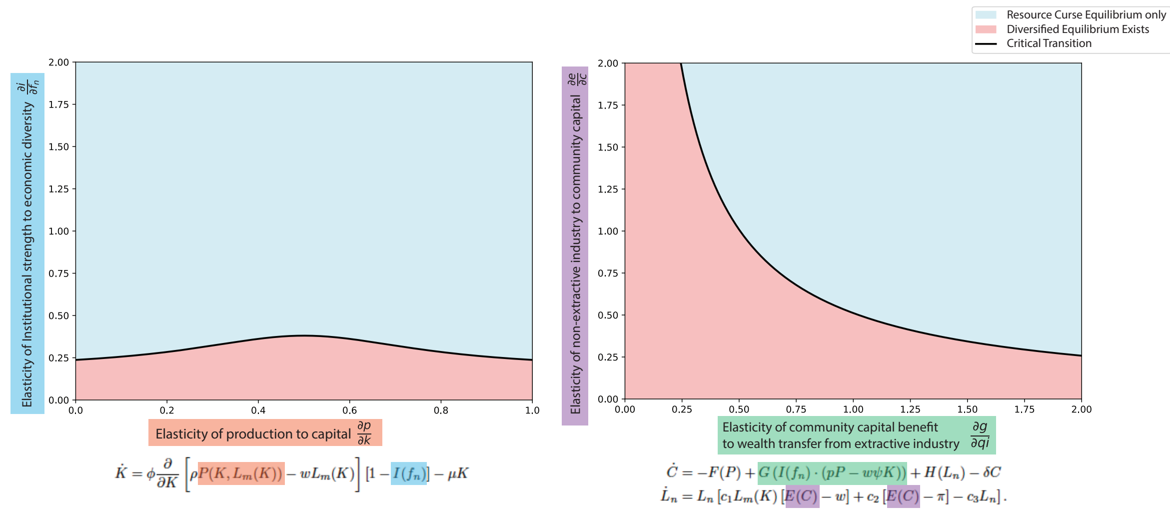



**Fig. 7.** 2-D bifurcation diagrams with respect to exponent parameters of the generalized model. The region in light blue indicates where the diversified equilibrium exists alongside the resource curse equilibrium, and the region in red indicates where only the resource curse equilibrium exists.

have little effect on stability (link 5) (see Supplementary Figure 1 for full results).

This analysis reveals that the results of the model analyzed earlier are not contingent on the specific assumptions of functional forms and that there's a wide range of functional forms for which the transition from the diversified equilibrium to resource curse occurs. Additionally, the dynamics that are most important in determining when this transition occurs are largely those that have to do with the specific relationship between economic diversity, institutional strength, and how extractive industries contribute to community capital. It's clear, then, that the question of when the resource curse occurs cannot be determined purely in terms of economic dynamics, but rather these institutional and sociological dynamics that are more difficult to quantify.

## Conclusion

The dynamics of communities that are the site of extractive industries and their tendency to experience poor outcomes and economic reliance on these industries have long been the subject of study in economics and rural sociology, but determining when or why the so-called resource curse occurs has remained a challenge. This study develops a theoretical model incorporating how extractive industries entrench themselves by undermining the public institutions that regulate their impact on community capital, and thus the possibilities for non-extractive industries to develop. This feedback between extractive industries and institutional strength produces a resource curse equilibrium and a diversified equilibrium. However, as the bifurcation analysis reveals, the diversified equilibrium can lose stability in response to exogenous changes, such as drops in commodity prices or increases in extractive industry wages relative to non-extractive wages, leading to an abrupt and irreversible transition to the resource curse equilibrium. In particular, this transition is likely to occur when the extractive industry is declining in a region, at the precise moment when diversification is most critical. Additionally, the mathematical stability analysis shows that the resource curse equilibrium *never* loses stability. On the other hand, far from the critical transition, the basin of attraction for the resource curse is narrow, so stochasticity induced transitions are likely in practice, offering some hope for escape from the resource curse. This analysis helps explains why the resource curse can be so difficult to break out of, and reveals the importance of avoiding the transition to the resource curse in the first place (6, 29).

Analysis of the generalized version of the model reveals that these results largely generalize to a range of functional forms, representing different technologies, types of resources, or socio-political contexts. It also reveals that the dynamics that are most important in determining when the transition occurs are those associated with how economic diversity influences institutional strength, how institutional strength determines the impact of extractive industries on community capital, and how community capital shapes the growth of non-extractive industries. In particular, weakening the link between economic diversity and institutional quality - such as through democratic safeguards that ensure that institutional quality is not overly susceptible to influence from whatever industry is dominant economically - is critical in preventing the transition to the resource curse.

Ultimately, this study suggests transitioning away from the resource curse is challenging in the absence of a large exogenous intervention or a transformation in the structure of the system itself. However, there remain numerous leverage points at which to help predict or prevent the resource curse in the first place. This work thus complements existing work on these communities by providing additional support for hypotheses from the empirical literature for why the resource curse occurs and suggesting new dynamics and variables on which to focus future empirical research. Better understanding these underlying mechanisms of the resource curse will be crucial for helping places impacted by extractive industries navigate the inherent challenges and inequities associated with them to more just and sustainable forms of development.

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# Supplementary Information for "Breaking the Resource Curse: A Model of Institutional Dynamics and Economic Transitions in Extractive Communities"

## Contents



# 1 Supplementary Methods

## 1.1 System Equilibria

$$
\begin{aligned}
&(1) \quad 0 = \phi(pa - w\psi)\left(1 - b\left(\frac{L_n}{L_n + \psi K}\right)\right) - \mu K \\
&(2) \quad 0 = -\eta a K + b\left(\frac{L_n}{\psi K + L_n}\right)(pa - w\psi)K + \alpha L_n - \delta C \\
&(3) \quad 0 = c_1 \psi K(\lambda C - w) + c_2(\lambda C - \pi) - c_3 L_n
\end{aligned}
$$

Computing the steady state for the case where $L_n = 0$ (the resource curse equilibrium):
Taking Equation (1):

$$0 = \phi(pa - w\psi) - \mu K$$

$$K = \frac{\phi(pa - w\psi)}{\mu}$$

Taking Equation (2):

$$C = -\frac{\eta a K}{\delta} = -\frac{\eta a}{\delta}\frac{\phi(pa - w\psi)}{\mu}$$

Computing the steady state for the case where $L_n \neq 0$ (the diversified equilibrium):
We use equations (1) and (3) to put (2) in terms of $K$.
From (1), we get

$$\frac{L_n}{L_n + \psi K} = \frac{1}{b}\left(1 - \frac{\mu K}{\phi(pa - w\psi)}\right)$$

and

$$L_n = \frac{\psi K}{\dfrac{b}{1 - \dfrac{\mu K}{\phi(pa - w\psi)}} - 1}$$

From Equation (3):

$$C = \frac{c_1 w\psi K + c_2\pi + c_3 L_n}{(c_1\psi K + c_2)\lambda}$$

Substituting into (2), starting with $C$ and $\dfrac{L_n}{\psi K + L_n}$:

$$\begin{aligned}
0 &= -\eta a K + b\left(\frac{L_n}{\psi K + L_n}\right)(ap - w\psi)K + \alpha L_n - \delta C \\
0 &= -\eta a K + b\frac{1}{b}\left(1 - \frac{\mu K}{\phi(ap - w\psi)}\right)(ap - w\psi)K + \alpha L_n - \delta\frac{c_1 w\psi K + c_2\pi + c_3 L_n}{(c_1\psi K + c_2)\lambda} \\
0 &= -\eta a K + \left((ap - w\psi) - \frac{\mu}{\phi}K\right)K - \delta\frac{c_1 w\psi K + c_2\pi}{(c_1\psi K + c_2)\lambda} + \left(\alpha - \frac{\delta c_3}{(c_1\psi K + c_2)\lambda}\right)L_n
\end{aligned}$$

Now substituting in our $L_n$:

$$0 = -\eta a K + \left((ap - w\psi) - \frac{\mu}{\phi}K\right)K - \delta\frac{c_1 w\psi K + c_2\pi}{(c_1\psi K + c_2)\lambda} + \left(\alpha - \frac{\delta c_3}{(c_1\psi K + c_2)\lambda}\right)\frac{\psi K}{\dfrac{b}{1 - \dfrac{\mu K}{\phi(pa - w\psi)}} - 1}$$

It is not possible to solve this expression for $K$, so we plot this expression implicitly for the bifurcation analysis.

## 1.2 Jacobian

Let $\mathbf{x} = (K, L_n, C)$. Then the Jacobian matrix of $f(\mathbf{x})$ with respect to $\mathbf{x}$ is given by $\dfrac{\partial f}{\partial \mathbf{x}}$ where row i, column j contains $\dfrac{\partial f_i}{\partial x_j}$ .

$$J = \begin{bmatrix}
\phi(pa - w\psi)b\dfrac{\psi L_n}{(L_n + \psi K)^2} - \mu & -\phi(pa - w\psi)b\dfrac{\psi K}{(L_n + \psi K)^2} & 0 \\
c_1\psi(\lambda C - w)L_n & c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi) - 2c_3 L_n & L_n(c_1\psi K\lambda + c_2\lambda) \\
-\eta a + 2K(\tau b(ap - w\psi))^2\left(\dfrac{L_n}{L_n + \psi K}\right)^3 & 2(\tau b(ap - w\psi))^2\psi K^3\left(\dfrac{L_n}{L_n + \psi K}\right)\dfrac{1}{(L_n + \psi K)^2} + \alpha & -\delta
\end{bmatrix}$$

## 1.3 Removing Economic Diversity-Institutional Strength feedback

$$\begin{aligned}
\dot{K} &= \phi(pa - w\psi)(1 - b) - \mu K \\
\dot{C} &= -\eta a K + (b(pa - w\psi)K) + \alpha L_n - \delta C \\
\dot{L}_n &= L_n(c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi) - c_3 L_n)
\end{aligned}$$

The resource curse equilibrium remains the same as in the original system. Solving for steady state if $L_n \neq 0$ (diversified equilibrium):

$$\begin{aligned}
&(1) \quad 0 = \phi(pa - w\psi)(1 - b) - \mu K \\
&(2) \quad 0 = -\eta a K + (b(pa - w\psi)K) + \alpha L_n - \delta C \\
&(3) \quad 0 = L_n(c_1\psi K(\lambda C - w) + c_2(\lambda C - \pi) - c_3 L_n)
\end{aligned}$$

Taking (1):

$$\begin{aligned}
\mu K &= \phi(pa - w\psi)(1 - b) \\
K &= \frac{\phi(pa - w\psi)(1 - b)}{\mu}
\end{aligned}$$

This is the same as the mining-dominated equilibrium when $b = 0$.

## 1.4 Generalized Model Analysis

The generalized model equations are as follows:

$$\dot{K} = \phi \frac{\partial}{\partial K}\left[\rho P(K, L_m(K)) - wL_m(K)\right][1 - I(f_n)] - \mu K, \tag{1}$$

$$\dot{C} = -F(P) + G(I(f_n) \cdot (pP - w\psi K)) + H(L_n) - \delta C \tag{2}$$

$$\dot{L}_n = L_n[c_1 L_m(K)[E(C) - w] + c_2[E(C) - \pi] - c_3 L_n]. \tag{3}$$

Generalized modeling allows for determining stability and identifying bifurcations without specifying functional forms. Unlike traditional dynamical systems analysis, it is not possible to compute the location and number of equilibria. The generalized modeling process involves 1) normalization of the variables and functions in terms of the unknown steady state, 2) defining unknown quantities from the normalization process as scale parameters, 3) computing the Jacobian in terms of these parameters, 4) in the case that the Jacobian is not tractable analytically for calculating the Routh-Hurwitz conditions, parameterizing and numerically computing the Routh-Hurwitz conditions.

### Normalization

We define normalized state variables as

$$k = \frac{K}{K^*}$$

$$c = \frac{C}{C^*}$$

$$l_n = \frac{L_n}{L_n^*}$$

the normalized functions for equation (1) as

$$\mathbf{l_m}(r, k) := \frac{1}{L_m^*}\mathbf{L_m}(R^* r, K^* k)$$

$$\mathbf{p}(r, k, \mathbf{l_m}) := \frac{1}{P^*}\mathbf{P}(R^* r, K^* k, L_m^* \mathbf{l_m})$$

$$\mathbf{f_n} := \frac{1}{F_n^*}\frac{L_n}{L_n + \mathbf{L_m}} = \frac{1}{F_n^*}\frac{L_n^* l_n}{L_n^* l_n + L_m^* \mathbf{l_m}} = \frac{1}{F_n^*}\frac{\frac{L_n^*}{L_m^*} l_n}{\frac{L_n^*}{L_m^*} l_n + \mathbf{l_m}}$$

$$\mathbf{i}(\mathbf{f_n}) := \frac{1}{I^*}\mathbf{I}(F_n^* \mathbf{f_n})$$

$$\mathbf{q} := \frac{1}{Q^*}\mathbf{Q} = \frac{1}{Q^*}[\rho \mathbf{P} - w\mathbf{L_m} - \mathbf{H}] = \frac{1}{Q^*}P^*\left(\rho \mathbf{p} - w\frac{L_m^*}{P^*}\mathbf{l_m} - \frac{H^*}{P^*}\mathbf{h}\right)$$

the normalized functions for equation (2)

$$\mathbf{d}(\mathbf{p}) := \frac{1}{D^*}\mathbf{D}(P^* \mathbf{p})$$

$$\mathbf{b}(\mathbf{qi}) := \frac{1}{B^*}\mathbf{B}(Q^* I^* \cdot \mathbf{qi})$$

$$\mathbf{h}(l_n) := \frac{1}{\mathbf{H}^*}\mathbf{H}(L_n{}^* l_n)$$

and finally, the normalized functions for equation (3)

$$\mathbf{e}(\mathbf{c}) := \frac{1}{\mathbf{E}^*}\mathbf{E}(C^* c)$$

This makes the normalized equations

$$\begin{aligned}
\dot{k} &= \phi \frac{1}{K^*} \frac{\partial \mathbf{Q}}{\partial K}(1 - I^* \mathbf{i}) - \frac{\mu K^*}{K^*} k \\
&= \phi \left[ \frac{P^*}{K^*} \left( \rho \left[ \frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}} \frac{\partial \mathbf{l_m}}{\partial k} \right] - \frac{L_m^*}{P^*} \left[ w \frac{\partial \mathbf{l_m}}{\partial k} \right] \right) \left( \frac{1}{K^*} - \frac{I^*}{K^*} \mathbf{i} \right) \right] - \mu k
\end{aligned} \tag{4}$$

$$\dot{c} = \frac{-D^*}{C^*} \mathbf{d} + \frac{B^*}{C^*} \mathbf{b} + \frac{F^*}{C^*} \mathbf{f} - \delta c \tag{5}$$

$$\dot{l}_n = E^* L_m^* c_1 l_n \mathbf{l_m} \mathbf{e} + E^* c_2 l_n \mathbf{e} - L_m^* c_1 w l_n \mathbf{l_m} - c_2 l_n \pi - c_3 {L_n}^* {l_n}^2 \tag{6}$$

**Define Parameters**

Since we are considering the system at steady state, we can then define scale parameters based on these normalized quantities. Scale parameters typically indicate time scales or the relative importance of different processes. For Equation (4), we get the following scale parameter:

$$\alpha_k = \phi \frac{\frac{\partial \mathbf{Q}}{\partial K}^*}{K^*} [1 - I^*] = \mu$$

For Equation (5), we get scale parameters

$$\alpha_c = \frac{D^*}{C^*} + \delta = \frac{B^*}{C^*} + \frac{F^*}{C^*}$$

$$\beta_c = \frac{1}{\alpha_c} \frac{D^*}{C^*}$$

$$\overline{\beta}_c = \frac{\delta}{\alpha_c} = 1 - \beta_c$$

$$\eta_c = \frac{1}{\alpha_c} \frac{B^*}{C^*}$$

$$\overline{\eta}_c = \frac{1}{\alpha_c} \frac{F^*}{C^*} = 1 - \eta_c$$

making the equation

$$\dot{c} = \alpha_c(-\beta_c \mathbf{d} + \eta_c \mathbf{b} + (1 - \eta_c) \mathbf{f} - (1 - \beta_c) c).$$

Finally, for Equation (6), we get

$$0 = E^* L_m^* c_1 + E^* c_2 - L_m^* c_1 w - c_2 \pi - c_3 {L_n}^*$$

$$\alpha_{Ln} = E^* L_m^* c_1 + E^* c_2 = L_m^* c_1 w + c_2 \pi + c_3 {L_n}^*$$

$$\beta_{Ln} = \frac{1}{\alpha_{Ln}} L_m^* c_1 w$$

$$\overline{\beta}_{Ln} = \frac{1}{\alpha_{Ln}} c_2 \pi$$

$$\widetilde{\beta}_{Ln} = \frac{1}{\alpha_{Ln}} c_3 L_n^*$$

$$\eta_{Ln} = \frac{1}{\alpha_{Ln}} E^* L_m^* c_1$$

$$\overline{\eta}_{Ln} = \frac{1}{\alpha_{Ln}} E^* c_2 = 1 - \eta_{Ln}$$

making the equation

$$\dot{l}_n = \alpha_{Ln} \Big( \eta_{Ln} l_n \mathbf{l_m} \mathbf{e} + \overline{\eta}_{Ln} l_n \mathbf{e} - \beta_{Ln} l_n \mathbf{l_m} - \overline{\beta}_{Ln} l_n - \widetilde{\beta}_{Ln} {l_n}^2 \Big).$$

**Computing the Jacobian**

Using the normalized equation, we can now compute the Jacobian.

$$\frac{\partial \dot{k}}{\partial k} = \phi \frac{P^*}{K^*}\frac{1}{K^*}\left[\left(\rho\left[\frac{\partial^2 \mathbf{p}}{\partial k^2} + \frac{\partial^2 \mathbf{p}}{\partial \mathbf{l_m}\partial k}\frac{\partial \mathbf{l_m}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial^2 \mathbf{l_m}}{\partial k^2}\right] - \frac{L_m^*}{P^*}\left[w\frac{\partial^2 \mathbf{l_m}}{\partial k^2}\right]\right.\right.$$
$$\left. - \frac{H^*}{P^*}\left(\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial^2 \mathbf{p}}{\partial k^2} + \frac{\partial^2 \mathbf{p}}{\partial \mathbf{l_m}\partial k}\frac{\partial \mathbf{l_m}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial^2 \mathbf{l_m}}{\partial k^2}\right]\right)\right)(1 - I^*)$$
$$\left. + \left(\rho\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right] - w\frac{L_m^*}{P^*}\frac{\partial \mathbf{l_m}}{\partial k} - \frac{H^*}{P^*}\cdot\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right]\right) I^* \frac{L_m^*}{L_n^* + L_m^*}\frac{d\mathbf{i}}{d\mathbf{f_n}}\frac{d\mathbf{l_m}}{dk}\right] - \mu$$

$$\frac{\partial \dot{k}}{\partial c} = 0$$

$$\frac{\partial \dot{k}}{\partial l_n} = \phi\left[\frac{P^*}{K^*}\frac{1}{K^*}\left(\rho\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right] - \frac{L_m^*}{P^*}\left[w\frac{\partial \mathbf{l_m}}{\partial k}\right] - \frac{H^*}{P^*}\cdot\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right]\right)\left(-I^*\frac{L_m^*}{L_n^* + L_m^*}\frac{d\mathbf{i}}{d\mathbf{f_n}}\right)\right.$$
$$= -\phi I^*\frac{1}{K^*}\frac{P^*}{K^*}\left(\rho\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right] - \frac{L_m^*}{P^*}\left[w\frac{\partial \mathbf{l_m}}{\partial k}\right] - \frac{H^*}{P^*}\cdot\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right]\right)\frac{L_m^*}{L_n^* + L_m^*}\frac{d\mathbf{i}}{d\mathbf{f_n}}$$

$$\frac{\partial \dot{c}}{\partial k} = \alpha_c\left(-\beta_c\frac{\partial \mathbf{d}}{\partial k} + \eta_c\frac{\partial \mathbf{b}}{\partial k}\right)$$
$$= \alpha_c\left(-\beta_c\frac{\partial \mathbf{d}}{\partial \mathbf{p}}\left(\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right) + \eta_c\frac{\partial \mathbf{b}}{\partial[\mathbf{qi}]}\frac{P^*}{Q^*}\left(\left(\rho\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right] - w\frac{L_m^*}{P^*}\frac{\partial \mathbf{l_m}}{\partial k} - \frac{H^*}{P^*}\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right]\right)(\mathbf{i})\right.\right.$$
$$\left.\left. - \left(\mathbf{p} - w\frac{L_m^*}{P^*}\mathbf{l_m} - \frac{H^*}{P^*}\mathbf{h}\right)\left(\frac{d\mathbf{i}}{d\mathbf{f_n}}\frac{1}{F_n^*}\frac{\frac{L_n^*}{L_m^*}l_n}{\left(\frac{L_n^*}{L_m^*}l_n + \mathbf{l_m}\right)^2}\cdot\frac{\partial \mathbf{l_m}}{\partial k}\right)\right)\right)$$
$$= \alpha_c\left(-\beta_c\frac{\partial \mathbf{d}}{\partial \mathbf{p}}\left(\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right) + \eta_c\frac{\partial \mathbf{b}}{\partial[\mathbf{qi}]}\left(\frac{P^*}{Q^*}\left(\rho\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right] - w\frac{L_m^*}{P^*}\frac{\partial \mathbf{l_m}}{\partial k} - \frac{H^*}{P^*}\frac{\partial \mathbf{h}}{\partial \mathbf{p}}\left[\frac{\partial \mathbf{p}}{\partial k} + \frac{\partial \mathbf{p}}{\partial \mathbf{l_m}}\frac{\partial \mathbf{l_m}}{\partial k}\right]\right)\right.\right.$$
$$\left.\left. - \left(\frac{d\mathbf{i}}{d\mathbf{f_n}}\frac{1}{\frac{L_n^*}{L_m^*} + 1}\cdot\frac{\partial \mathbf{l_m}}{\partial k}\right)\right)\right)$$

$$\frac{\partial \dot{c}}{\partial c} = -\alpha_c(1 - \beta_c)$$

$$\frac{\partial \dot{c}}{\partial l_n} = \alpha_c\left(\eta_c\frac{\partial \mathbf{b}}{\partial l_n} + (1 - \eta_c)\frac{\partial \mathbf{f}}{\partial l_n}\right)$$
$$= \alpha_c\left(\eta_c\frac{\partial \mathbf{b}}{\partial[\mathbf{qi}]}\frac{P^*}{Q^*}\left[\left(\rho\mathbf{p} - w\frac{L_m^*}{P^*}\mathbf{l_m} - \frac{H^*}{P^*}\mathbf{h}\right)\frac{d\mathbf{i}}{d\mathbf{f_n}}\frac{1}{F_n^*}\frac{\frac{L_n^*}{L_m^*}\mathbf{l_m}}{\left(\frac{L_n^*}{L_m^*}l_n + \mathbf{l_m}\right)^2}\right] + (1 - \eta_c)\frac{\partial \mathbf{f}}{\partial l_n}\right)$$
$$= \alpha_c\left(\eta_c\frac{\partial \mathbf{b}}{\partial[\mathbf{qi}]}\frac{d\mathbf{i}}{d\mathbf{f_n}}\frac{1}{\frac{L_n^*}{L_m^*} + 1} + (1 - \eta_c)\frac{\partial \mathbf{f}}{\partial l_n}\right)$$

$$\frac{\partial \dot{l}_n}{\partial k} = \alpha_{Ln}(\eta_{Ln} l_n \mathbf{e} - \beta_{Ln} l_n)\frac{\partial \mathbf{l_m}}{\partial k} = \alpha_{Ln}(\eta_{Ln} - \beta_{Ln})\frac{\partial \mathbf{l_m}}{\partial k}$$

$$\frac{\partial \dot{l}_n}{\partial c} = \alpha_{Ln}(\eta_{Ln} l_n \mathbf{l_m} + \overline{\eta}_{Ln} l_n)\frac{\partial \mathbf{e}}{\partial c} = \alpha_{Ln}(\eta_{Ln} + \overline{\eta}_{Ln})\frac{\partial \mathbf{e}}{\partial c} = \alpha_{Ln}\frac{\partial \mathbf{e}}{\partial c}$$

$$\frac{\partial \dot{l}_n}{\partial l_n} = \alpha_{Ln}\Big(\eta_{Ln}\mathbf{l_m}\mathbf{e} + \overline{\eta}_{Ln}\mathbf{e} - \beta_{Ln}\mathbf{l_m} - \overline{\beta}_{Ln} - 2\widetilde{\beta}_{Ln} l_n\Big) = \alpha_{Ln}\Big(\eta_{Ln} + \overline{\eta}_{Ln} - \beta_{Ln} - \overline{\beta}_{Ln} - 2\widetilde{\beta}_{Ln}\Big) = -\alpha_{Ln}\widetilde{\beta}_{Ln}$$

Once the Jacobian is defined, we can conduct stability and bifurcation analysis as usual by parameterizing the Jacobian for a particular equilibrium.

**Generalized Modeling Parameterization**

| Symbol | Meaning | Value in specific model | Range in bifurcation analysis |
|---|---|---|---|
| Scale Parameters | | | |
| $\alpha_k$ | Turnover rate in extractive capital | $\mu$ | – |
| $\frac{L_n^*}{L_m^*}$ | Proportion of non-mining to mining labor | $\frac{b}{1-\frac{rK}{\phi(pa-w\psi)}}-1$ | – |
| $\frac{L_m^*}{P^*}$ | Extractive labor to production ratio | $\frac{\psi}{a}$ | – |
| $\frac{K^*}{L_m^*}$ | Extractive capital to labor ratio | $1/\psi$ | – |
| $w$ | Wage | $w$ | |
| $\alpha_c$ | Turnover rate in community capital | $\frac{-\eta aK}{C}+\delta$ | – |
| $\beta_c$ | Proportion of community capital loss to damage from extraction | $\frac{1}{\alpha_c}\frac{-\eta aK}{C}$ | – |
| $\eta_c$ | Proportion of community capital gain from extraction (i.e. through taxes) | $\frac{\left(b\frac{L_n}{\psi K+L_n}(apK-w\psi K)\right)}{C}$ | – |
| $\frac{I^*}{K^*}$ | institutional strength to extractive capital | $\frac{\frac{1}{b}\left(1-\frac{rK}{\phi(pa-w\psi)}\right)}{K}$ | – |
| $\frac{P^*}{K^*}$ | Production to extractive capital | $a$ | – |
| $\frac{Q^*}{P*}$ | Pre-tax profit to production | | |
| $\alpha_{Ln}$ | Turnover rate in non-extractive labor | $L_m^*c_1w+c_2\pi+c_3L_n$ | |
| $\beta_{Ln}$ | Proportion of loss in non-extractive labor to extractive industry | $\frac{1}{\alpha_{Ln}}L_m^*c_1w$ | |
| $\overline{\beta}_{Ln}$ | Proportion of loss in non-extractive labor to outside the region | $\frac{1}{\alpha_{Ln}}c_2\pi$ | |
| $\widetilde{\beta}_{Ln}$ | Proportion of loss to unemployment (excess labor) | $\frac{1}{\alpha_{Ln}}c_3$ | |
| $\eta_{Ln}$ | Proportion of gain from extractive industry | $\frac{1}{\alpha_{Ln}}c_1\lambda C^*\psi K^*$ | |
| Exponent Parameters | | | |
| $\frac{\partial p}{\partial l_m}$ | resource extraction/production to labor | 0 | $0-1, \frac{\partial p}{\partial l_m}+\frac{\partial p}{\partial k}=1$ |
| $\frac{\partial p}{\partial k}$ | extraction to capital | 1 | $0-1, \frac{\partial p}{\partial l_m}+\frac{\partial p}{\partial k}=1$ |
| $\frac{\partial l_m}{\partial k}$ | labor to capital | 1 | 0 to 2 |
| $\frac{\partial d}{\partial p}$ | damage to extraction | $-1$ | $-2$ to 0 |
| $\frac{\partial b}{\partial qi}$ | infrastructure benefit to transfer from extraction | 1 | 0 to 2 |
| $\frac{\partial f}{\partial l_n}$ | infrastructure benefit to non-extractive activities | 1 | 0 to 2 |
| $\frac{di}{df_n}$ | institutional strength to economic diversity | 1 | 0 to 2 |
| $\frac{\partial e}{\partial c}$ | gain in non-extractive employment to natural/physical infrastructure | 1 | 0 to 2 |

## 2 Supplementary Figures

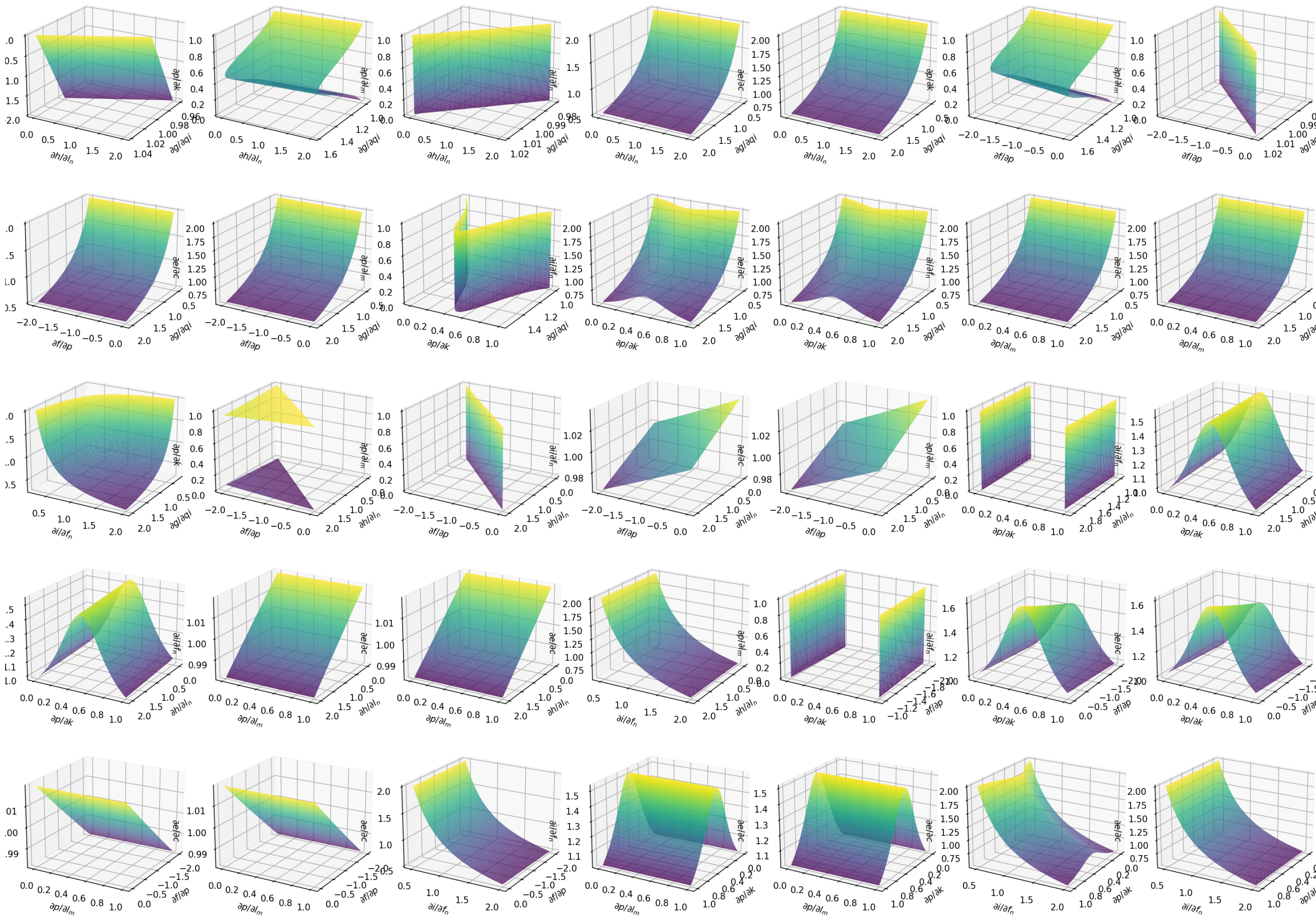

Figure S1: Bifurcation plots with respect to all combinations of three parameters. The surface represents the surface at which the determinant is equal to 0 and thus indicates where the diversified equilibrium changes stability.