The impact of conflicts on climate and migration policy*

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Abstract

We develop a theoretical model to study the relationship between climate change, migration and conflicts from the perspective of the recipient countries, which we call collectively the North. The North chooses the number of immigrants it wants to accept together with the amount of climate change mitigation. The potential number of migrants is determined by the extent of climate change in the South. Accepting more migrants allows the North to increase local production but it also exacerbates climate change and gives rise to internal conflicts. Those potential migrants that want to migrate North due to climate change but are not allowed to immigrate may induce external conflicts. We find that a policy maker, subject to the threat of both internal and external conflicts, may either choose a policy that relies more on mitigation with less immigration, or less mitigation and more immigration. Which policy ought to be pursued depends on the relative cost of internal and external conflicts, and the mitigation cost. If either the threat of external or internal conflicts are negligible, then we find that the optimal mitigation and immigration policies are not interdependent any longer. We also discuss when mitigation and immigration policies are substitutes or complements.

Keywords: climate change, immigration policy, conflicts, mitigation policy.
JEL classification: Q54, Q56, F22.

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1 Introduction

It is no longer a question of whether or not climate change may seriously impact humankind. Instead, the important question we now face is how we can reduce the extent of climate change while coping with its economic and social impacts (Parry 2007). There is mounting evidence that climate change is going to have the strongest impact on poor developing countries, with migration often being the last resort (Pachauri et al. 2014). Migrants tend to then target developed countries as their destination. While one may argue that rich countries should allow immigration exclusively for humanitarian reasons (Risse 2008), history instead has shown that immigration policies tend to be framed on both economic as well as social grounds. In particular, migration is well-known for potentially creating (social) conflicts in the recipient country (Hsiang et al. 2013), which must be taken into account when trying to understand the optimal policy responses.[1]

The economic literature on mitigation and climate change is large and researchers have studied a variety of aspects related to the individual or social costs of climate change (Stern 2007, Nordhaus 2014, Golosov et al. 2014, van der Ploeg and Withagen 2014). However, even regional models of climate change (Nordhaus and Yang 1996, Tol 1997, Manne and Richels 2005, Bosetti et al. 2006) have, as of now, avoided to investigate the influence that climate-driven migration may have on climate policy (McLeman 2013), despite the prediction of 150-200 million climate migrants by 2050 (Rigaud et al. 2018, Stern 2007). It is clear that these large streams of immigration need to be managed, and their consequences require a thorough assessment. However, many recipient regions have a significant lack of preparedness to face the massive flow of migrants, and both internal and external conflicts are likely to arise (Stern 2013, Withagen 2014). Internal conflicts are those that arise due to socio-economic impacts of migrants in destination countries, such as xenophobia, crime, violence and fiscal pressures (Dancygier 2010), while external conflicts are those that occur if migrants want to immigrate but are prevented from doing so, such as those that arise through conflicts on the border, political and economic instability or even wars (Hsiang et al. 2013). Policy makers require a unified framework in order to understand which trade-offs are important and which policy decisions are optimal under what kind of circumstances. The answer to this can only come from an investigation that takes a unified look

[1] As United Nations Secretary-General Ban Ki-moon (11/23/11) aptly noted: "Climate change... could well trigger large-scale migration... These and other implications for peace and security have implications for the United Nations itself."

at climate change, migration and conflict.

There exist only few analytical studies within this literature that look at individually-optimal migration decisions (Hoel and Shapiro 2003, Haavio 2005, Eppink and Withagen 2009, Marchiori et al. 2012), and even fewer analyze the decisions from a policy maker's perspective (Marchiori and Schumacher 2011). In this article we develop an analytical model to give first insights into the trade-offs between conflict, climate change and immigration policy. More precisely, we investigate how the recipient countries, which we call collectively the North (e.g. the OECD countries) may want to optimally trade off mitigation and immigration policies when migration impacts socio-economic conditions. Among the questions of interest are: how would an immigration policy interact with a climate policy? When can these policies be studied separately, and under which conditions should they be set jointly? When would the North have an incentive to cut its carbon emissions if faced with the threat of immigration-induced conflict? How should the North evaluate the threat of external conflicts arising from those migrants that are restricted from entering the North? When are immigration and mitigation policies substitutes, when are they complements?

We consider a single receiving region, the North, that is responsible for climate change. Climate change does not directly affect the North,[2] but it negatively impacts the South, which we define as the group of vulnerable developing countries. This induces South-North migration, with the number of potential migrants being endogenously determined by the extent of climate change. Accepting migrants allows the North to increase overall production as they add to the labor force. However, accepting migrants also exacerbates futures climate and migration problems. More production today means more climate change, and subsequently more migrants, tomorrow. Furthermore, it gives rise to internal conflicts today. We view internal conflicts in a broad sense, encompassing negative impacts on social capital (Putnam 2007), welfare spending (Luttmer 2001), civil conflict and trust (Fearon and Laitin 2000), and economic growth as well as institutional quality (Alesina et al. 1999, Alesina et al. 2003). When immigration is not only high-skilled labor, as this should be the case for climate-driven migration, then immigrants also tend to be a burden on the labor market and social security system (Liebig and Mo 2013, Dancygier 2010), resulting in various kinds of native-immigrant conflicts (Dancygier and Laitin 2014). In

[2]This assumption helps us to clearly focus on how migration and the threat of internal and external conflict affects mitigation. Allowing the North to be affected by climate change does not change the basic mechanisms that we investigate here, but unduly complicates the analysis.

addition, those potential migrants that are forced to move due to climate change but that are not allowed to immigrate may induce an external conflict that is costly to the North. By external conflict we mean significant-sized conflicts outside of the country of immigration (Pachauri et al. 2014), but which can potentially spill over into the recipient country. As there is a larger uncertainty associated with external conflicts we assume that there is a probability of conflict that is endogenous to the amount of potential migrants not admitted into the receiving country. In terms of policy, the North chooses both the extent of climate change through the mitigation policy, but also through the number of potential migrants it accepts.

Our analysis of the trade-off between immigration and mitigation policies in the recipient region provides us with the following results. If external conflict is judged to be the only important type of conflict,[3] then the North should take in all potential migrants without undertaking any mitigation policy.[4] This result arises because the North then gets the economic benefits from immigration, while removing any risk of costly external conflict. If the North only perceives internal conflict as being important[5] and it neglects the external conflict that arises on its borders (or in the South), then it simply maximizes its own wealth. We find that, also in this case, no mitigation policy is necessary and the North should admit the level of immigrants that maximizes net income (GDP minus costs of internal conflict). Hence, in these two cases, both climate and migration policies can essentially be studied separately.

Policy making becomes more involved once there is reason to believe that both external and internal conflicts co-exist and are significant. This is where the dynamic dimension of our model shows its importance. In this case, multiple steady states exist and they are all subject to an active mitigation policy. More specifically, depending on the conditions imposed on the fundamentals of the economy, either a corner steady state without immigration but with large mitigation, or an interior steady state with a large number of immigrants but less mitigation will be optimal. We also examine the substitutability versus complementarity between mitigation and immigration policies during the transition to the steady state. When the interior steady state is optimal, we find that mitigation and immigration are complements along the transition

[3]For example, if the North can easily accommodate any inflow of migrants and there is no internal, social conflict.

[4]We remind the reader here again that we abstract from mitigation policy that the North may want to undertake to reduce the direct impact of climate change on its GDP or amenity.

[5]A typical example is Trump's presidency during which the United States blocked most immigration for fear of internal socio-economic costs.

path. If the corner steady state is optimal, then for high levels of climate change these policies are initially substitutes but become complements as we move closer to the steady state.

The article is structured as follows. Section 2 introduces the model. Section 3 first presents the economic trade-offs related to the mitigation and immigration policy, and then discusses the significant yet decisively different roles of external and internal conflicts. It next turns to the analysis of the optimal solution. Section 4 concludes with further lessons and future research perspectives.

2 The model

In this article we focus on the optimal, unilateral decisions of the recipient countries, which we simply call collectively the North. The reason why we only focus on the North is that immigration policy tends to be undertaken unilaterally by the host countries, and, in light of the recent refugees crisis in Europe, it is clear that it is important to understand what ought to determine the optimal immigration policy. Furthermore, we focus on the North simply because most carbon emissions have historically been produced there, and in terms of climate mitigation policy, the North plays a major role. We also assume that the North decides as one single region, which applies well for e.g. the case of the EU or potentially the G20. We now present the essential corner stones of the model.

Production

We assume that the Gross Domestic Production (GDP) in the North, thus total production, is the main driver of climate change, or at least the climate change that it itself can control. We abstract from population growth in the North, and assume that the total number of immigrants, $I(t)$, adds to total production, $G(I(t))$, albeit with decreasing returns.

Assumption 1 *Total production in the North is a function of immigration* $I(t) > 0$ *and given by* $G(I(t))$, *with* $G(0) > 0$, $G'(I) > 0$, $G'(0) \in (0, \infty)$, *and* $G''(I) < 0$.

We abstract from population growth in the North as it is negligibly low (roughly 0.44% on average among OECD countries in 2020). We also do not take into account capital accumulation and changes in technology or international trade as our objective here is to obtain a first, clear picture of how the North should trade off immigration and climate policy when faced with the threat of conflicts.[6] This essentially means that we adopt a steady state perspective according to which GDP can only be further increased by immigration. While these assumptions allow us to clearly focus on the trade-off between climate and migration policy, they also prevent us from taking this model to the data.

Climate change

Production in the North is assumed to be the main source of climate change and carbon emissions come as a fixed proportion $q_1 > 0$ of production. The North can also invest in costly mitigation efforts, $A(t) \geq 0$, to reduce the extent of climate change. The mitigation technology is linear with productivity $q_2 > 0$ that measures how effective mitigation actions are in reducing carbon. In line with empirical evidence we take it that stronger mitigation efforts become more costly (Kuik et al. 2009). We denote the mitigation cost by the non-negative function $c(A)$, with $c'(A) > 0$ for all $A > 0$, $c(0) = c'(0) = 0$, and $c''(A) > 0$. Carbon in the atmosphere is subject to a natural decay at rate $\delta > 0$, which allows us to approximate the carbon cycle by

$$\dot{P}(t) = q_1 G(I(t)) - q_2 A(t) - \delta P(t), \tag{1}$$

with $P_0 \geq 0$ given, the level of carbon in the atmosphere when the North is at its initial condition.

Migration

We assume that the North is itself not directly affected by climate change, which is in line with the results presented in various studies on regional impacts of climate change (Pachauri et al. 2014). This is a sufficiently realistic assumption for climate change levels that are not too extreme and and also excludes thresholds that lead to severe shifts in the earth's climate. The results from the IPCC and various integrated assessment models show that, for smaller

[6]Along this line, other factors of production are assumed to be constant: $G(I) = g(\bar{K}, \bar{L}, I)$, with $\bar{K}$ the capital stock, and $\bar{L}$ the size of the native population. Note also that the functional form comprises more detailed ones where we could distinguish the skills of the local population $\bar{L}$ (constant) from those of the immigrants $I(t)$ by assuming that the locals have a skill premium which could materialize e.g. in the form $G(\bar{L} + \alpha I(t))$ with $\alpha \in (0, 1)$, or that there are complementarities between locals and immigrants, $G(\bar{L}, I)$ with $G_{\bar{L}I} > 0$. These specifications do not affect the main results of our model.

increases in temperature, the direct costs of climate change to the North are small. If one were to allow for significant impacts of climate change on the North then the North would obviously have incentives to curb climate change via mitigation. Note that the model can be changed to accommodate also a climate change impact on the North, which would not alter the channels that we present here. Thus, abstracting from climate change impacts in the North allows us to focus on the role of conflict for mitigation and immigration policy.

In our model, the North then cares about climate change because climate change affects the South, which faces potentially severe environmental damage (droughts, extreme climate events, rise in sea levels etc.), which in turn triggers international migration. The expected number of climate migrants is somewhere around 150-200 million by 2050 (Stern 2007) and this number may significantly increase without adequate climate policy (Parry 2007). The stronger the climatic changes, the more severe will be the strain on the poorer populations and the number of potential migrants will be larger (Marchiori and Schumacher 2011). Assuming that these immigrants add to carbon emissions in a similar way as the local population, this would result in additional emissions.

The number of potential migrants increases with climate change. In particular, we assume that it increases linearly with the stock of carbon at rate $h > 0$, such that the number of potential migrants is given by $hP(t)$.[7] The North can choose the number of immigrants, $I(t)$, from the pool of potential migrations, so that $I(t) \in [0, hP(t)]$. This modelling approach implies that, while the North can directly choose the number of immigrants, it can only indirectly impact the number of potential migrants through emissions and climate policy.

Internal conflict

In 2020, 12% of the population of advanced countries were immigrants, an increase from 7% in 1990. The immediate economic impact of immigrants in advanced countries tends to be a positive one (IMF 2020). Despite that, history has shown us that countries tend to be, for a variety of reasons, unwilling to accept all the potential migrants.[8] Immigration may be costly for

[7] We also investigated a more general functional form, given by $H(P)$, with $H(0) = 0$, $H' > 0$ and $H'' > 0$. The main implications continue to hold, but the increased mathematical complexity does not allow us to present results in a similarly neat way.

[8] For example, the US 'Secure Fence Act' of 2006 led to the construction of a 1,125 km long wall to deter Mexican migrants from freely entering the USA. Also, Europe has several large migration camps in northern

the locals in terms of labor market displacement effects, and it can lead to an internal conflict between immigrants and locals when strains are placed on limited resources (Dancygier 2010). Social conflicts often arise with larger levels of immigration because of internal social tensions. These tensions come directly from the social differences between locals and the new foreign entrants due to language barriers, cultural differences, perceived downward pressure on wages, or sharing of limited resources (Homer-Dixon 1991, Withagen 2014). Dancygier (2010) has shown that countries with higher immigration also tend to have a higher share of votes going to xenophobic or anti-immigration parties. A similar point is made in Mayda (2006) who concludes that attitudes towards immigrants are not only driven by labor market conditions, but also by security and cultural conditions. This problematic, the conflict between the natives and immigrants, has been well-captured in the 'Sons of the Soil' literature (Côté and Mitchell 2015). Fearon and Laitin (2011) finds that around one third of all ethnic civil wars since 1945 took place between natives and immigrants. Similarly, in a case study of 38 cases of larger environmental migration, Reuveny (2007) found that nineteen were followed by a conflict in receiving regions.

One should also expect internal conflicts to arise as both the crime rate and social unrest is expected to increase if migrants are unable to actively contribute to the economic system. In this respect, Angrist and Kugler (2003) show that immigrants to the European Union tend to have higher unemployment rates than locals, and Borjas (1995) shows that these differences often persist over time. In an empirical study covering the period 1951-2001, Salehyan and Gleditsch (2006) find that the arrival of international refugees increases the probability of conflict in the host country. The authors conclude that "[a]lthough the vast majority of refugees never directly engage in violence, refugee flows may facilitate the transnational spread of arms, combatants, and ideologies conducive to conflict; they alter the ethnic composition of the state; and they can exacerbate economic competition."

In our mathematical formulation we capture this internal conflict in a reduced-form way. We assume that these internal conflicts are measurable in monetary terms by a cost function $d(I)$, where $d(I), d'(I) > 0$ for all $I > 0$, $d(0) = d'(0) = 0$, and $d''(I) > 0$. This suggests that the costs associated with various sources of internal conflicts are increasing in the number of immigrants at an increasing rate, and that, absent any immigrants, those costs are zero.

Africa, and it pays Turkey to manage migrant camps for Syrians so that they do not further migrate towards Europe.

External conflict

Since our focus is on the optimal policy from the Northern perspective, we shall not model the conflicts arising in the South itself. We instead focus on the potential external conflict that those migrants who are not allowed to immigrate may indirectly create for the North. We assume that those migrants that are not accepted into the Northern territory may be the cause of an external conflict. We focus on wide-spread external conflicts, such as potential wars, border conflicts or regional instabilities. WBGU (2009) concludes that "[e]xperience has shown that migration can greatly increase the likelihood of conflict in transit and target regions." Migrants play an important role in the dynamics of local conflicts, either through pressures in limited resources, wages (Tumen 2016), ethical tensions (Rüegger 2019) or also the expansion of rebel social networks (Ghobarah et al. 2003). The problem, as Salehyan and Gleditsch (2006) discuss, is that states are not self-contained, but what happens in neighbouring regions very often also bears impacts in adjacent regions. For example, Murdoch and Sandler (2004), using a panel dataset of the world's countries covering the period 1961-95, show that the costs of civil wars spill over to adjacent countries. One important source of this spillover are migrants, as Salehyan and Gleditsch (2006) uncover in their empirical study covering the period 1951-2001. Several case studies covering African countries demonstrate how migrants diffuse conflicts to neighbouring regions (Lischer 2005, Muggah 2013, Onoma 2013, Whitaker 2002). In a case study of 38 cases of larger environmental migration, Reuveny (2007) concluded that "[e]nvironmental migration crosses international borders at times, and plays a role in conflict. Environmental migration does not always lead to conflict, but when it does, the conflict intensity can be very high, including interstate and intrastate wars."

One way to view this external conflict is that those potential migrants that are not allowed to migrate to the North will then go somewhere else, for example to neighbouring regions, or they will have to stay in their respective countries. As we take the regions that we collectively treat as the North as the traditional recipient regions, it is also generally true that these are richer than their neighbouring regions, and are also socially and politically better prepared to host migrants. Hence, if the migrants have to go to the neighbouring regions, then this is likely to lead to an increased internal conflict in those regions that may spill over to the North. Another possibility is that the potential migrants have to stay in their home country, which gives rise to conflict over dwindling resources and local conflicts (Hsiang et al. 2013), which again can spill over to the North.

While we have sufficient information on potential internal costs of immigration due to the world's larger experience with this, a policy maker cannot easily anticipate when an external conflict may arise. We thus treat the arrival of climate-induced external conflicts as stochastic events.

Assumption 2 *Let τ be the random variable representing the date at which an external conflict occurs. This variable is described by a probability distribution function $F(t) = \Pr(\tau < t)$ defined over the support $\mathbb{R}_+$, with endogenous density $f(t)$ defined as follows:*

$$f(t) = \psi(hP(t) - I(t))(1 - F(t)), \tag{2}$$

where $F(0) = 0$ is given and $\psi(.)$ is the hazard rate, with $\psi(0) = \psi'(0) = 0$, $\psi, \psi' > 0$, for $I \in [0, hP)$, and $\psi'' > 0$.

Consequently, the bigger the gap between potential migrants and immigrants, the larger the probability of an external conflict. External conflict is costly, too, and we assume that the North loses a fixed utility cost $\kappa > 0$ in case an external conflict materializes.

In the remainder of the analysis we will make use of the following restriction:

Assumption 3 $G'(0) > \frac{\rho+\delta}{hq_1}$.

As we shall see later, this assumption ensures that, at the optimal solution, abatement can effectively reduce the social cost of pollution. This condition basically requires that the marginal contribution of the first migrant to production is high enough.

Decision problem

In this paper, we adopt the perspective of an infinitely-lived policy maker in the North that chooses at every date the number of immigrants and the mitigation effort. We assume that this policy maker cares about net income, which is a function of GDP, the costs of internal or external conflict, and also of the mitigation expenditure.

Assumption 4 *Felicity function $u(Y(t))$ is a function of net income $Y(t) \geq 0$, which is given by $Y(t) = G(I(t)) - d(I(t)) - c(A(t))$, and satisfies $u(Y(t)) : \mathcal{R}_+ \to \mathcal{R}$, with $u' > 0$, $u'' \leq 0$.*

The policy maker's objective is to maximize the expected present value of utility, taking into account the costs from an uncertain external conflict that arises through the gap between potential migrants and immigrants; the costs from the internal conflicts associated with immigration; the costs of mitigating carbon to reduce climate change (and also to manage the pool of potential migrants); and the benefit of immigration, which yields increased local production. Assuming that the first external conflict occurs at time τ, then the objective functional is given by

$$\mathbb{E}_\tau \left\{ \int_0^\tau u(Y(t)) e^{-\rho t} dt + e^{-\rho \tau} (V(P(\tau)) - \kappa) \right\}, \tag{3}$$

where $\rho > 0$ is the discount rate, $V(P)$ denotes the value function,[9] and $\mathbb{E}_\tau$ is the expectation operator for the random variable. We define the survival probability, $X(t)$, i.e. the probability that no external conflict has taken place up to time t, as $X(t) = 1 - F(t)$. The objective function can be rewritten in terms of its deterministic counterpart by relying on the probability that a conflict arises at time t given that it has not yet occurred. This yields[10]

$$\int_0^\infty \Big(u(Y(t)) + \psi(hP(t) - I(t)) \big(V(P(t)) - \kappa \big) \Big) X(t) e^{-\rho t} dt.$$

This criterion has to be maximized by choosing the sequences $\{A(t), I(t)\}_0^\infty$ subject to the set of constraints:

$$\begin{cases} Y(t) = G(I(t)) - d(I(t)) - c(A(t)), \\ \dot{X}(t) = -\psi(hP(t) - I(t)) X(t), \\ \dot{P}(t) = q_1 G(I(t)) - q_2 A(t) - \delta P(t), \\ I(t) \in [0, hP(t)], A(t) \geq 0 \text{ and } P_0,\ X_0 (= 1) \text{ given}, \end{cases} \tag{4}$$

To quickly summarize, the questions that we want to address with this framework are as follows: when would the North have an incentive to cut its carbon emissions given the threat of conflict? Under which circumstances would the North find it worthwhile to implement an active immigration policy? How would an immigration policy interact with a climate policy? Can we derive conditions under which these policies are substitutes or complements? What will be the impact of the optimal mitigation and immigration policies on the evolution of the climate system?

[9]This is a continuation payoff corresponding to the total value of utility from time τ onwards, thus from the time after the external conflict occurred.

[10]The model follows the approach of optimal control problems with endogenous hazards (Tsur and Zemel 2008, Tsur and Zemel 2009, van der Ploeg 2014).

3 Active mitigation vs. immigration policy

We define the constant-value Lagrangian as follows:

$$\begin{aligned}\mathcal{L} = &\left[u\big(G(I) - c(A) - d(I)\big) + \psi\big(hP - I\big)\big(V(P) - \kappa\big)\right] X + \\ &\lambda\big(q_1 G(I) - q_2 A - \delta P\big) - \mu\psi\big(hP - I\big)X + \phi_1 I + \phi_2(hP - I) + \phi_3 A\end{aligned} \tag{5}$$

with λ, μ the co-state variables respectively associated with the stock of climate change and the survival probability, and ϕ_1, ϕ_2 and ϕ_3 the Lagrange multipliers corresponding to the constraints respectively on I and A. Defining $\Lambda \equiv \lambda/X$ as the risk-adjusted shadow value of climate change, the optimality conditions are given by[11]

$$-q_2\Lambda = c'(A)u'(Y) - \frac{\phi_3}{X}, \tag{6}$$

$$u'(Y)G'(I) + \kappa\psi'(hP - I) = u'(Y)d'(I) - \Lambda q_1 G'(I) + \frac{\phi_2 - \phi_1}{X}. \tag{7}$$

Equation (6) depicts the optimal trade-off for mitigation, with the marginal gain of mitigation, on the left-hand side, and the marginal cost of mitigation, $c'(A)u'(Y)$, which is the change (in utility terms) in GDP when increasing mitigation, on the right-hand side. An interior solution (with $\phi_3 = 0$) in mitigation requires a negative risk-adjusted shadow value of climate change ($\Lambda < 0$) as the policy maker would only want to reduce climate change if she also views climate change as being a cost.[12] The key to understanding the trade-off in this model lies with this risk-adjusted shadow value of climate change. Without external or internal conflict, the policy maker in the North does not view climate change as something which is detrimental for her welfare. In contrast, more climate change will increase the number of migrants which in turn increases the GDP in the North. Any model that studies migration and climate change in a welfare-oriented framework such as this one will be subject to this perverse effect.[13] This result will only be reversed if immigration also induces costs on the North, such as those coming in terms of cultural or social pressures (internal conflict), or potentially external conflicts that may spill over to the North.

[11] We relegate the mathematical derivations into the appendix.

[12] If we were to assume that the North would also be affected by climate change then this would make it more likely that Λ is negative. It would, however, also further blur the subsequent results and not add more to intuition.

[13] In other words, a policy maker who benefits from immigration would not want to reduce climate change as it increases the potential inflow of migrants and thus benefits the local economy.

Equation (7) depicts the optimal trade-off related to a change in the level of immigrants. The marginal benefit of accepting more immigrations, on the left-hand side, has two component. First, it implies a lower risk of external conflict which could cost the economy κ in terms of utility, coming at a marginal probability that changes with the immigration level. Second, increasing immigration helps to increase production. However, more migration also comes with costs (right-hand side). It increases the internal cost of migration and adds to climate change. In case that immigrants add little to GDP but turn out to be very costly in terms of internal conflict, then at least from the immediate perspective of the North there is little incentive to take in more migrants. If external conflicts are potentially important, then this could be a reason for the North to still need to take in immigrants even if this increases the cost of internal conflict by more than the increase in GDP due to a larger workforce. In this case the risk-adjusted shadow value of climate change is negative, and, therefore, the future costs of a larger pool of potential migrants reduce the incentives to increase the number of immigrants.

3.1 External conflict only

We now look separately at the roles that the internal and external conflicts play for the optimal mitigation and immigration policies. We start by assuming that a policy maker does not expect an internal conflict to occur. This would be a reasonable assumption if there are no cultural or educational differences between locals and immigrants or if there is enough space and work for all immigrants. In other words, we assume that immigrants cannot be significantly distinguished from locals and that there are no negative returns from adding to population. Mathematically, this would be equivalent to assuming that $d(I) = 0$, $\forall I$.

In this situation, firstly, there is only a benefit to income. Secondly, it is possible to minimize the risk of the external conflict by allowing all potential migrants to come in. Thus, the North should reap all the benefits and incur no cost by choosing no mitigation ($A = 0$) but accept all potential migrations ($I = hP$). Along the corresponding development trajectory, climate change increases monotonically to reach the maximum level of climate change while its (positive) shadow value decreases.

At first instance it seems unreasonable to accept that climate change may have a positive shadow value, or, in other words, that climate change may be somewhat beneficial.[14] The North

[14]We note that this result should not be surprising as overall humankind, ever since the industrial revolution,

can benefit from climate change since more climate change leads to more potential migrants who help the North to increase its production. The North should thus optimally use the possibility to accept all potential migrants, thereby removing external conflicts, with immigrants subsequently becoming a source of the North's economic growth. The fact that immigrants are, and always have been, a source of economic expansion in the receiving country is generally well-accepted (Borjas 1995). Here we add the point that climate change is likely to increase the number of potential migrants that the North may want to take in.

3.2 Internal conflict only

If there was no external conflict, then a policy maker would be free to constrain the inflow of migrants to the level up to which society benefits directly from these migrants. The reason is that without the external conflict there is no cost from not allowing potential migrants to enter the country. As a result, we can show that the North's valuation of climate change is non-negative, and thus optimal mitigation should be zero.

Our results then show that the policy maker should set immigration at the level that maximizes GDP, i.e. where $G'(I) \geq d'(I)$, $\forall t$. For low levels of climate change the potential pool of migrants is small so that the GDP-maximizing level of immigration cannot be reached. The policy maker should then take in the whole pool of potential immigrants. This policy should be followed up to the point where the number of potential migrants exceeds the level of immigrants that maximizes income minus internal conflict. From this point onwards the policy maker will keep the level of immigration at the GDP maximizing level, essentially only trading off income increases from immigration with internal conflicts.

We have just shown that the North, if it is not driven by ethical considerations, would face the trade-offs as discussed above. Even if the North were not to take the feedback from immigration on climate change into account, the results would still fully hold. The North would still set immigration at the maximum potential level if the number of potential migrants is below the income maximizing one, and would hold it at the income maximizing level otherwise. If the potential pool of migrants is large relative to the GDP-maximizing level of immigration, then the case where the North only considers the internal conflict leads to lower levels of immigration

has benefited immensely from the emission of carbon.

and climate change than the case where only external conflicts matter.

3.3 Optimal policy under both internal and external conflicts

If we allow for both internal and external conflicts, then our system gives rise to multiple potential solutions and transitions between regimes. Based on the combinations between corner and interior solutions we can identify six potential regimes, each being characterized by a particular combination of mitigation, A, and immigration, I. One of these regimes ($A = 0, I = 0$) can be neglected since it cannot satisfy the necessary conditions (see the Appendix B). The remaining five regimes can all be represented in the $\Lambda - P$ space, which describes the relationship between climate change and its the risk-adjusted shadow value. It is possible to define three regime curves, $\Lambda = 0$, $\Lambda = F_1(P)$, and $\Lambda = F_2(P)$, that divide this space into five different regions (see the Appendix A).[15] The analysis in the $\Lambda - P$ plane allows us to present the complete description of the global dynamics. Before that, we identify the possible outcomes in the long run.

3.4 Policies in the long-run

Assume that the economy accepts all of the migrants and does not undertake any abatement so that the system lies in the regime $A = 0$, $I = hP$. In this case, net income, $G(hP) - d(hP)$, and the rate of variation of pollution, $q_1 G(hP) - \delta P$, are inverted U-shaped functions of P, reaching a maximum respectively at $\tilde{P}$ and $\check{P}$. Net income must be non-negative, which requires $P \leq \bar{\bar{P}}$, while the highest level of pollution attainable is denoted by $\bar{P}$.[16] Because of physical and economic constraints, pollution is constrained above by the minimum of $\bar{P}$ and $\bar{\bar{P}}$. Hereafter we take $\bar{P} < \bar{\bar{P}}$ [17] and we assume that $\check{P} < \tilde{P} < \bar{P}$. In addition, we introduce two final pieces

[15] As depicted in Figure 1, the horizontal axis splits the plane into the region with positive mitigation (strictly below the axis) and the one with zero mitigation (above and including the axis). $F_1(P)$ separates the region with full immigration from the one with only partial immigration whereas the location with respect to $F_2(P)$ tells us whether or not the economy accepts migrants. This is enough to locate the different regimes in the $\Lambda - P$ plane. Moreover, the regime curves $F_i(P)$, $i = 1, 2$, start at $\Lambda = -u'(G(0) - c((c')^{-1}(\frac{q_2}{q_1}))/q_1$ for $P = 0$ and satisfy $F_1'(P) > 0$ and $F_2'(P) < 0$.

[16] So, $\tilde{P}$, $\check{P}$, $\bar{\bar{P}}$ and $\bar{P}$ respectively solve: $G'(hP) = d'(hP)$, $hq_1 G'(hP) = \delta$, $G(hP) = d(hP)$ and $q_1 G(hP) = \delta P$.

[17] As we know that the concentration of CO_2 in the atmosphere is quite persistent (δ is low), the emissions-output ratio should be low as well. This is an acceptable assumption if one recognizes that the North has already reached a sufficiently advanced technological level so that the pollution intensity of production is quite low. In

of notation. Let $\hat{P}$ and $\breve{P}$ be respectively defined by $\rho+\delta = hq_1G'(h\hat{P})$ and $\rho+\delta = hq_1d'(h\breve{P})$. By construction we have $\hat{P} < \tilde{P} < \breve{P}$. Note that to each critical level of pollution corresponds a critical level of immigration given by $I = P/h$.

In Proposition 1, we establish which regime may host a steady state and derive the existence conditions (see the Appendix B).

Proposition 1 *The economy can end up in either the corner regime, with $A > 0$ and $I = 0$, or in the interior regime, with $A > 0$ and $I \in (0, hP)$.*

i. The steady state of the corner regime $A > 0, I = 0$ is a saddle point uniquely defined by:

$$\frac{q_1G(0) - q_2A}{\delta} = \frac{1}{h}(\psi')^{-1}\left(\frac{(\rho+\delta)c'(A)u'(G(0)-c(A))}{hq_2\kappa}\right).$$

This steady state exists only if: $G(0) > \max\left\{c((c')^{-1}(\frac{q_2}{q_1})), \frac{q_2}{q_1}(c')^{-1}(\frac{q_2}{q_1})\right\}$. It necessarily satisfies $A > (c')^{-1}(\frac{q_2}{q_1})$.

ii. Suppose that $I \geq \tilde{I}$ and $A \leq (c')^{-1}(\frac{q_2}{q_1})$. A steady state of the interior regime $A > 0, I \in (0, hP)$ solves:

$$(\rho+\delta)c'(A) + hq_2\big(G'(I)(1 - \tfrac{q_1}{q_2}c'(A)) - d'(I)\big) = 0 \Leftrightarrow A = A_1(I)$$
$$q_1G(I) - q_2A - \delta\Phi(I, A) = 0 \Leftrightarrow A = A_2(I),$$

with

$$\Phi(I, A) = \frac{1}{h}\left[I + (\psi')^{-1}\left(-\frac{u'(G(I) - c(A) - d(I))(G'(I)(1 - \frac{q_1}{q_2}c'(A)) - d'(I))}{\kappa}\right)\right].$$

There exists a unique steady state, which is a saddle point, if and only if $A_2(I) < A_1(I)$ at $I = \min\left\{\breve{I}, \bar{I}\right\}$.

This proposition states that the economy has two contrasting steady states in the long run. On the one hand, it can settle in a long-run regime characterized by a high level of mitigation and no immigration at all. This means that, in order to control the threat of external conflict and to avoid any type of internal conflict, the policy maker chooses to keep climate change at a low

addition, the internal conflict function should not be too convex, meaning that serious conflicts may only occur when the number of migrants becomes sizeable.

level. Reducing climate change is costly in terms of mitigation expenditure and thus comes at the expense of GDP. The resulting steady state will be obtained if the policy maker views external or internal conflicts as relatively more expensive than investing in reducing climate change.

On the other hand, the economy can stabilize at an interior regime for a level of mitigation lower than the corner one. In this situation, the North knows that the increase in climate change will lead to a larger pool of potential migrants. On this optimal path the North accepts a significant number of immigrants, which allows for a higher level of GDP. As a byproduct of this policy, the level of climate change is higher than at the corner regime, and the North will see a larger amount of internal conflict. Depending on how many migrants the North allows into the region, the risk of external conflict can either be higher or lower than at the corner solution. This interior regime will occur if the cost of reducing climate change is high, and if both external and internal conflicts are not viewed as too costly. If external conflicts are perceived to be very costly, then the North will both accept a large share of the pool of potential migrants, and, in addition, invest significantly in mitigation.

This steady state analysis emphasizes a substitutability between the two policy instruments, climate and immigration policy. In the next section, we go one step further by examining the global dynamics. The aim is to address a series of questions: what are the development paths that may bring the economy to the possible steady states? Are mitigation and immigration policies substitutes or complements along these paths? What is the optimal policy? To answer these questions, we have studied the dynamical system in each particular regime, and possible combinations of these regimes.

3.5 Dynamic behavior and optimality

For the sake of simplicity, we impose two restrictions henceforth: we assume that the utility function u is linear (so we work directly with net GDP) and that the costs of mitigation, $c(A)$, are quadratic. As shown in Figure 1, we find that the economy may exhibit steady states with transitions between the corner or interior regimes. Given Proposition 1, we know that the optimal path will end up in the steady state of either the corner regime with no immigration (bottom, left), or the interior regime (middle, right). Which steady state then turns out to be the optimal one depends on the parameters of the model.

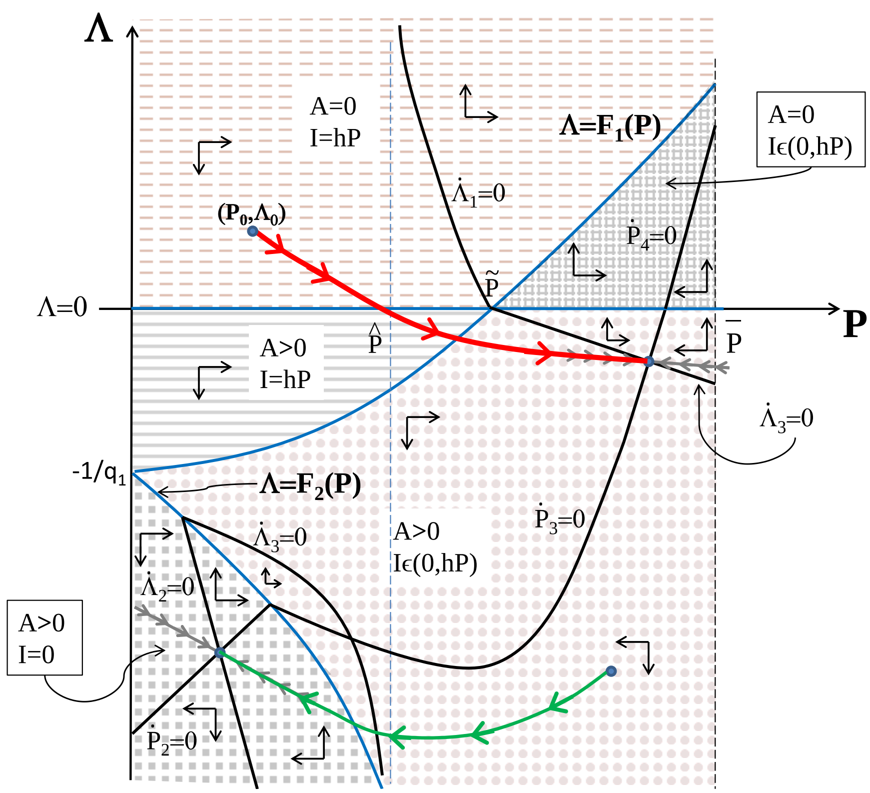
Let us assume that the parameter conditions are such that the high interior steady state is optimal, as depicted in Figure 1, and we are at the initial condition (P_0, Λ_0). This corresponds to the situation where climate change is not (yet) an important driver of migration, and both internal and external conflict are at a low level. In this case the North will choose a development path (depicted by the red curve in the figure) where it first neglects investment in mitigation and accepts as many immigrants as possible for a while. As we discussed above, this can occur because the North may decide to accept migrants in order to reduce the risk of external conflict, or it can occur because the net GDP in the North strongly benefits from immigration. The larger production in the North places the world on a trajectory of increasing climate change, which in turn increases the pool of potential migrants.

After some point, the North finds that the increase in immigrants finally induces some non-negligible levels of internal or external conflict. If that is the case, the policy maker switches to the regime with positive mitigation while she still continues to accept all potential migrants. The reason for undertaking mitigation is that the policy maker wishes to reduce the number of future climate migrant. When the internal conflict starts to outweigh the benefits of immigration to GDP then the North tightens its immigration policy (regime $A > 0$, $I < hP$) and accepts to bear the risk of external conflict in order to keep internal conflict under control. On this optimal path mitigation and immigration tend to be complements.

As a more policy-oriented conclusion and in the light of the Syrian refugee crisis, which some argue has partly been caused by climatic changes, we suggest that Europe is currently in regime $A > 0$, $I = hP$. This means that some mitigation action is undertaken to reduce climate change, and a significant amount of immigration is accepted. The overall value of more climate change now starts to be perceived as being negative since increases to climate change would drive more migrants into Europe. Hence the economy should switch to a regime with more mitigation and somewhat less immigration ($A > 0$, $I \in (0, hP)$). This would imply that in future there will be a somewhat smaller number of Syrian immigrants in Europe, while mitigation efforts are likely to increase in order to reduce the pool of potential migrants. From the results in Section 3.1, the trajectory as described above would be optimal if internal conflicts are not very costly, if there is a high risk of external conflict, and if mitigation is rather expensive.

It is also possible that the North is neither much concerned with a potential external conflict, nor does it feel that migrants add sufficiently to the region's income in order to find that immigration is worthwhile. This, for example, could be the case for the USA, a region that blocks immigration from Mexico for precisely those two reasons. However, let us furthermore assume that, despite the recent European experience, this rich region has sufficient foresight and is able to acknowledge that the current way of producing leads to emissions that would increase the number of potential immigrants. Not willing to accept the increase in the pool of potential migrants, the North decides to undertake substantial mitigation. This would place the system in regime $A > 0$, $I = 0$ where the North does not accept immigration, yet at the same time reduces climate change in order to lower the potential for external conflict. For this trajectory to be optimal, it must be that the mitigation option is actually cheap enough, or sufficiently efficient. If that is not the case, then the solution with positive mitigation but zero immigration is not the best choice and it becomes relatively cheaper to actually allow for some immigration.

Figure 1: Graphical representation of optimal solution



If the internal conflict is of high significance while mitigation is sufficiently cheap such that the optimal solution ends up in the corner regime ($I = 0$, $A > 0$), then the optimal trajectory is similar to the green curve depicted in Figure 1. We find that the North always chooses an interior level of immigration in order to reduce the importance of the external conflict. At the same time it uses mitigation in order to bring climate change down again. Along the optimal path, the mitigation and immigration policy are then substitutes. They are substitutes insofar as the North invests significantly in mitigation in order to be able to reduce the future flow of migrants. Once the North has managed to reduce climate change significantly it will start to slow down both mitigation and immigration and stop accepting migrants eventually. In this case, the North can afford to live with a certain relatively low risk of external conflict, yet benefit from not having the more significant internal conflict.

Another possibility is if the North recognizes the importance of both internal and external conflict and does not have a sufficiently cheap mitigation option. In this case either of the two possible development trajectories, leading to the two different steady states, can be a candidate for optimality and the initial level of climate change determines which one should be optimally approached.

4 Conclusion

In this article we investigated the links between conflict and optimal mitigation and immigration policy. We developed a theoretical model where a receiving region chooses the number of immigrants it wants to accept from a pool of potential migrants that is endogenously determined by the extent of climate change. Accepting these migrants allows increases in local production, but gives rise to internal conflicts. In addition, those potential migrants that are forced to move due to climate change but that are not allowed to immigrate may induce external conflict. We then allow a policy maker, in conjunction with her optimal mitigation policy, to dynamically choose the optimal number of immigrants in this framework. This model is a first step to understand the way a policy maker may wish to trade-off immigration and climate policies.

Our results suggest that immigration policy, unless a policy maker views internal or external conflicts as negligible, can no longer be separately studied from climate policy. The model presented here highlights the particularly important role of conflicts that drive optimal policy. If external conflicts are judged to be the only important conflict, then the North should take in all potential migrants without undertaking any mitigation policy. If a policy maker only perceives internal conflict as being important, then we find that again no mitigation policy is necessary and the North would take in the GDP-maximizing level of immigrants. Instead, policy making becomes more complicated if there is reason to believe that both conflicts co-exist. In this case multiple steady states exist and they are all subject to an active mitigation policy. More specifically, depending on parameters, either a corner steady state without immigration but with larger mitigation will be optimal, or an (high) interior steady state with a larger number of immigrants but less mitigation.

In terms of future research we suggest to work on the following. Firstly, we desperately need more empirical evidence on the precise costs, probabilities and extent of national and international conflicts that are due to migration from climate change. Examples like the Syrian conflict show that even smaller climatic shocks may aid or even trigger destabilization in countries or regions that then induces significant migration waves and humanitarian crises. The situation becomes much more difficult to predict once we are in a high carbon emission scenario with significant increases in global temperature. In terms of theoretical work, one may argue that the shape of the social welfare function matters a lot. Rather than considering a standard utility function defined on aggregate income, one may alternatively choose the average utilitarian criterion. One may want to add capital accumulation and demographic aspects, or one may want to investigate the impact of the cost of border controls. Additionally, one larger uncertainty that policy makers have is when it comes to the precise relationship between climate change and international migration. While evidence is mounting and giving more and more precise numbers on the expected future climate-induced migration flows, it is also clear these numbers are very much scenario-dependent and will vary with further evidence coming in. While we decided, for simplicity reasons, to assume a linear relationship between climate change and the potential pool of migrants, a useful extension would look into a specification that allows for a more complex and uncertain relationship between climate change and migration. Furthermore, the literature suggests that institutions do play an important role for the probability of conflicts between migrants and natives, and thus the development of institutions may be another important focus of future theoretical work.

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Appendix

A Regime curves

Following Zemel (2015), the necessary optimality conditions (NOC) associated with problem (4) can be written as

$$\begin{aligned}
\Lambda &= -\frac{c'u'}{q_2} + \frac{\phi_3}{q_2 X}, && (8)\\
0 &= u'\big(G' - d'\big) + \kappa\psi' + q_1\Lambda G' + \frac{\phi_1 - \phi_2}{X}, && (9)\\
\dot{\Lambda} &= (\rho + \delta)\Lambda + \kappa h\psi' - \frac{h\phi_2}{X}, && (10)\\
\dot{P} &= q_1 G(I) - q_2 A - \delta P, && (11)
\end{aligned}$$

with $\Lambda = \frac{\lambda}{X}$, and where we used $\mu = V(P)$ and $\Lambda = V'(P)$ for all t.

The system may exhibit five different regimes corresponding to all the possible combinations between the controls A and I. In order to get a general representation of the system, we will work (as far as possible) in the $\Lambda - P$ plan. The location of the five regimes is determined by three regime curves (RC). From (8), with $A = \phi_3 = 0$, the first RC is the horizontal axis $\Lambda = 0$. For all $\Lambda \geq (<)0$, we have $A = (>)0$.

The curve delimiting the region where $I = hP$ from the one with $I < hP$ is:

$$u'(G(hP) - d(hP) - c(A))(G'(hP) - d'(hP)) + q_1\Lambda G'(hP) = 0, \qquad (12)$$

which requires $u' + q_1\Lambda > 0$.

First consider the region where $\Lambda \geq 0$. The RC is defined for $P \geq \tilde{P}(\Leftrightarrow d' \geq G')$ by:

$$\Lambda = \frac{u'(G(hP) - d(hP))}{q_1}\big(\frac{d'(hP)}{G'(hP)} - 1\big) \equiv F_1(\underset{+}{hP}; \underset{-}{q_1})$$

Now consider the region where $\Lambda < 0$. For $P < \tilde{P}$, we can use the relation between Λ and A, given by (8), with $\phi_3 = 0$ and $I = hP$,

$$\Lambda = -\frac{c'(A)u'(G(hP) - d(hP) - c(A))}{q_2},$$

to get $A = A(\underset{-}{\Lambda}, \underset{+}{hP}; \underset{+}{q_2})$. Replacing in (12), the second RC is implicitly defined by:

$$u'(G(hP) - d(hP) - c(A(\Lambda, hP; q_2)))(G'(hP) - d'(hP)) + q_1\Lambda G'(hP) = 0.$$

From the implicit function theorem, we obtain:

$$\Lambda = F_1(\underset{+}{hP}; \underset{+}{q_1}, \underset{-}{q_2}).$$

This part of the regime curve joins the second part at $P = \tilde{P}$, where $\Lambda = 0$. We also have $F_1(0) = -\frac{u'(G(0)-c((c')^{-1}(\frac{q_2}{q_1})))}{q_1} < 0$, which requires $G(0) > c((c')^{-1}(\frac{q_2}{q_1}))$.

The curve delimiting the region where $I = 0$ from the one where $I > 0$ is given, from (9) with $\phi_1 = \phi_2 = 0$ and $I = 0$, by

$$\kappa\psi'(hP) = -G'(0)(u'(G(0) - c(A)) + q_1\Lambda). \tag{13}$$

It is defined only in the region where $u' + q_1\Lambda \leq 0$, which implies $\Lambda < 0$. For $\Lambda < 0$, mitigation efforts are positive and given by (8), with $\phi_3 = 0$:

$$\Lambda = -\frac{c'(A)u'(G(0) - c(A))}{q_2}. \tag{14}$$

This expression gives A as a function of Λ, parameterized by q_2: $A = A(\underset{-}{\Lambda}; \underset{+}{q_2})$. Note that imposing $\Lambda \leq -\frac{u'}{q_1}$ is equivalent to $c'(A) \geq \frac{q_2}{q_1} \Leftrightarrow A \geq (c')^{-1}(\frac{q_2}{q_1})$.

Replacing this expression in (13), we obtain the third RC in the $\Lambda - P$ plan:

$$P = \frac{1}{h}(\psi')^{-1}[-\frac{G'(0)}{\kappa}(u'(G(0) - c(A(\Lambda; q_2)) + q_1\Lambda)] \Leftrightarrow \Lambda = F_2(\underset{-}{hP}; \underset{-}{q_1}, \underset{+}{q_2}).$$

Note that the RC, F_1 and F_2, start from the same point, i.e., $F_1(0) = F_2(0)$. For the corner regime with $I = 0$ to be attainable, one must have $G(0) > c((c')^{-1}(\frac{q_2}{q_1}))$.

In sum, for any $\Lambda \geq \max\{0, F_1(P)\}$, the regime is $A = 0$, $I = hP$. For $P \geq \tilde{P}$ and $\Lambda \in [0, F_1(P))$, the regime is $A = 0$, $I \in (0, hP)$. For $P < \tilde{P}$ and $\Lambda \in [F_1(P), 0)$, the regime is $A > 0$, $I = hP$. For $\Lambda \leq F_2(P)$, the regime is $A > 0$ and $I = 0$ and for $\Lambda \in (F_2(P), \min\{F_1(P), 0\})$, the regime is $A > 0$, $I \in (0, hP)$.

B Steady state analysis

First notice that the regime with $A = I = 0$ neither hosts a steady state nor can be optimal along the transition. Suppose that there exists a non-degenerate interval of time M during which the system lies in this regime. Then, from the NOC at any $t \in M$:

$$\begin{aligned}&\Lambda = \tfrac{\phi_3}{q_2 X}\\ &\phi_1 = -X\left[u'(G(0))G'(0) + \kappa\psi'(hP) + q_1 G'(0)\Lambda\right].\end{aligned}$$

Thus, it must hold that $\Lambda \geq 0$, which in turn implies the RHS of the second equation is strictly negative, a contradiction. We can also establish that there is no steady state with $A = 0$ and $I < hP$. Suppose that such a steady state exists. Then, one must have from (8) and (10): $\Lambda = -\frac{\kappa h\psi'}{\rho+\delta} < 0$ because $\psi' > 0$, and $\Lambda = \frac{\phi_3}{q_2 X} \geq 0$ because ϕ_3 is the Lagrange multiplier associated with $A \geq 0$; another contradiction. So 3 regimes only may have a steady state: two corner regimes (with $A > 0$, $I = 0$, and with $A = 0$ and $I = hP$) and the interior regime $A > 0$, $I \in (0, hP)$.

B.1 Corner regime with $A > 0$ & $I = 0$

In this regime, a steady state solves the following system of steady state curves (SC):

$$\begin{aligned}&\Lambda = -\tfrac{\kappa h\psi'(hP)}{\rho+\delta}\\ &\delta P = q_1 G(0) - q_2 A(\Lambda; q_2) \Leftrightarrow \Lambda = \Lambda(\underset{+}{P}; \underset{-}{q_1}, \underset{+}{q_2})\end{aligned} \tag{15}$$

where the expression of A comes from (14). From the properties of the SCs, there always exists a unique intersection between them. We can further identify three necessary conditions for this steady state to be located in the right domain. The first one, mentioned above, requires that: *(i)* $G(0) > c((c')^{-1}(\frac{q_2}{q_1}))$. In addition, the second SC must start from a level below $F_2(0)$, which yields: *(ii)* $G(0) > \frac{q_2}{q_1}(c')^{-1}(\frac{q_2}{q_1})$. Finally, there must be some mitigation levels (or some Λ) for which the first SC is located below the frontier F_2. A necessary condition for this is: *(iii)* $G'(0) > \frac{\rho+\delta}{hq_1}$.

Comparative statics: combining (14) and (15), one obtains that:

$$\begin{aligned}&A^* = A(\rho,\kappa,\delta,q_1,q_2,h) \text{ with } A_\rho, A_\delta < 0;\ A_\kappa, A_{q_1}, A_h > 0;\ A_{q_2} \lesseqgtr 0,\\ &P^* = P(\rho,\kappa,\delta,q_1,q_2,h) \text{ with } P_\rho, A_{q_1} > 0;\ A_\kappa, A_h, A_{q_2} < 0;\ A_\delta \lesseqgtr 0.\end{aligned}$$

Finally, if the steady state exists, it is a saddle point. Moreover, we have $\dot{\Lambda} \geq (<) 0 \Leftrightarrow \Lambda \geq (<) -\frac{\kappa h \psi'(hP)}{\rho+\delta}$ and $\dot{P} \geq (<) 0 \Leftrightarrow \Lambda \geq (<) \Lambda(\underset{+}{P}; \underset{-}{q_1}, \underset{+}{q_2})$. The only transition possible from this regime leads the system to the interior regime with $I > 0$.

B.2 Regime with $A = 0$ & $I = hP$

If a steady state belongs to this corner regime, then it solves:

$$\begin{aligned} & q_1 G(hP) = \delta P, \\ & \Lambda = \frac{hu'(G(hP)-d(hP))(G'(hP)-d'(hP))}{\rho+\delta-hq_1G'(hP)}. \end{aligned} \tag{16}$$

The first equation gives the unique steady state level of climate change, $P^* = \bar{P}$. By construction, it satisfies $hq_1 G'(hP^*) < \delta$, which implies that $hq_1 G'(hP^*) < \delta + \rho$. Now the non-negativity of Λ requires, from the second equation, that $G'(hP^*) - d'(hP^*) \geq 0 \Leftrightarrow \bar{P} \leq \tilde{P}$, which is in contradiction with the ranking considered in the main text. For any pair (P, Λ) located below the second SC, we'll have $\Lambda = 0$ in finite time because $\dot{\Lambda} < 0$. This corresponds to a switch to the regime with $A > 0$, and $I = hP$, that can only be transitory. For any (P, Λ) such that $\dot{\Lambda} > 0$, Λ keeps growing and so does P because $P < \bar{P}$. For the ranking considered, P hits $\check{P}$ then $\tilde{P}$ in finite time. Therefore from the date when $\tilde{P}$ is hit on, we have: $\frac{\dot{\Lambda}}{\Lambda} = \rho + \delta - hq_1 G'(hP) + h\frac{d'(hP)-G'(hP)}{\Lambda} > \rho$. Λ grows at a rate always larger than ρ, thereby violating the transversality condition: $\lim_{t\to\infty} e^{-\rho t}\Lambda(t)P(t) = 0$.

B.3 Interior regime: $A > 0$, $I \in (0, hP)$

Here we have two controls and a state variable and it is simpler to study existence in the $A - P$ plan once we observe that (8) and (9) define a relationship $P = \Phi(I, A)$, with

$$\Phi(I, A) = \frac{1}{h}[I + (\psi')^{-1}(-\frac{u'(G(I) - c(A) - d(I))(G'(I)(1 - \frac{q_1}{q_2}c'(A)) - d'(I))}{\kappa})], \tag{17}$$

provided that the pair (I, A) satisfies $G'(I)(1 - \frac{q_1}{q_2}c'(A)) - d'(I) \leq 0$. We have

$$\begin{aligned} \Phi_I &= -\frac{u''(G'-d')(G'(1-\frac{q_1}{q_2}c')-d') + u'(G''(1-\frac{q_1}{q_2}c')-d'') - \kappa\psi''}{\kappa h \psi''} > 0, \\ \Phi_A &= \frac{u''c'(G'(1-\frac{q_1}{q_2}c')-d') + \frac{q_1}{q_2}G'c''u'}{\kappa h \psi''} > 0, \end{aligned} \tag{18}$$

the sign of $\Phi_I > 0$ resulting from the concavity of the optimization program w.r.t I.

Combining (10), (11) and (17), the SCs in the $A-I$ plan are given by:

$$\begin{aligned}&(\rho+\delta)c'(A)+hq_2\big(G'(I)(1-\tfrac{q_1}{q_2}c'(A))-d'(I)\big)=0\\&q_1G(I)-q_2A-\delta\Phi(I,A)=0.\end{aligned}\tag{19}$$

Note that the first equation in (19) defines the steady state curve $\dot{\Lambda}=0$, or $\dot{A}=0$ whereas the second corresponds to the locus $\dot{P}=0$, as seen from $A-I$ plan. Of course we have that $\dot{A}=0$ together with $\dot{P}=0$ imply $\dot{I}=0$. Note also that we work with the ranking $\check{P}<\tilde{P}<\bar{P}$, which once rewritten in terms of I, gives $\check{I}<\tilde{I}<\bar{I}$.

For all $I\geq\tilde{I}$, $d'(I)\geq G'(I)$. Define $\hat{I}$ such that $G'(\hat{I})=\frac{\rho+\delta}{hq_1}$. For all $I\geq\hat{I}=G'^{-1}(\frac{\rho+\delta}{hq_1})$, $G'(I)\leq\frac{\rho+\delta}{hq_1}$. By construction, we have $\hat{I}<\check{I}$. A necessary and sufficient condition for the existence of a solution $A_1(I)$ to the first SC above is $I\in[0,\hat{I}]\cup[\tilde{I},\bar{I}]$. Then we have:

$$A_1(I)=c'^{-1}\left(\frac{hq_2\big(d'(I)-G'(I)\big)}{\rho+\delta-hq_1G'(I)}\right).\tag{20}$$

with $A_1(0)>c'^{-1}(\frac{q_2}{q_1})$, $A_1(\hat{I})=\infty$, $A_1(\tilde{I})=0$. The derivative of A_1 is:

$$A_1'(I)=-\frac{hq_2(G''(I)(1-\frac{q_1}{q_2}c'(A))-d''(I))}{c''(A)(\rho+\delta-hq_1G'(I))}.$$

Next, define $\check{I}>\tilde{I}$ such that $\rho+\delta=hq_1d'(\check{I})$; then $A_1(\check{I})=c'^{-1}(\frac{q_2}{q_1})$ and $A_1'(I)>0$ on $[\tilde{I},\check{I}]$. For $I\in[0,\hat{I})$, we only know that A_1 should end up being increasing as $A_1(\hat{I})=\infty$.

The second SC can be rewritten as

$$\kappa\psi'\big(\frac{h(q_1G(I)-q_2A)-\delta I}{\delta}\big)+u'(G(I)-c(A)-d(I))(G'(1-\frac{q_1}{q_2}c')-d')=0.$$

It defines a second relationship between A and I, $A_2(I)$, with

$$A_2'(I)=\frac{q_1G'(I)-\delta\Phi_I(I,A)}{q_2+\delta\Phi_A(I,A)}.\tag{21}$$

To avoid discussing multiple cases (which would in any case be easy to handle), we take $\check{I}<\bar{I}$ and first search for a steady state for $I\in[\tilde{I},\check{I}]$. One can check that $A_2(\tilde{I})\in(0,\infty)$. If $A_2(\tilde{I})<c'^{-1}(\frac{q_2}{q_1})$, then from (18) and (21), $A_2'<0$ for $I>\tilde{I}$, which is sufficient to conclude that there exists a unique steady state. Otherwise, the condition $A_2(\check{I})<(c')^{-1}(\frac{q_2}{q_1})$ is necessary and sufficient to reach the same conclusion.

Second there may also exists steady state(s) for $I \in [0, \hat{I})$. But it proves difficult to find the sign of $A_1'(I)$ and $A_2'(I)$ on that interval. Given that $A_2(\hat{I}) < \infty$, a sufficient condition for the existence of an odd number of steady states is: $A_2(0) > A_1(0) = c'^{-1}\left(\frac{hq_2 G'(0)}{hq_1 G'(0)-\rho-\delta}\right)$. Note that the inequality $hq_1 G'(0) > \rho + \delta$, identified as a necessary condition for the existence of a steady state in regime $A > 0$, $I = 0$, is also necessary for the existence of a steady state in the interior regime with $[0, \hat{I})$ because if $hq_1 G'(0) \leq \rho + \delta$, $\hat{I}$ is simply not defined or equal to 0.

The dynamics can be expressed as a two dimensional system the $A - I$ plan. Combining (8)-(10) and the equations obtained by differentiating (8) and (9), we have

$$\dot{I} = \frac{1}{D}\left[\Phi_A((\rho+\delta)c'u' - \kappa h q_2 \psi') - (c''u' - (c')^2 u'')(q_1 G - q_2 A - \delta\Phi(I, A))\right], \quad (22)$$

$$\dot{A} = \frac{1}{D}\left[-\Phi_I((\rho+\delta)c'u' - \kappa h q_2 \psi') + u''c'(G' - d')(q_1 G - q_2 A - \delta\Phi(I, A))\right]. \quad (23)$$

with,

$$\begin{aligned} D &= u''c'(G' - d')\Phi_A - \Phi_I(c''u' - (c')^2 u'') \\ &= \tfrac{1}{k\kappa\psi''}[c''u'u''(G' - d')^2 + (c''u' - (c')^2 u'')(u'(G''(1 - \tfrac{q_1}{q_2}c') - d'') - \kappa\psi'')], \end{aligned}$$

for $I < \tilde{I}$, D is negative; otherwise $D < 0$ if $1 - \frac{q_1}{q_2}c' \geq 0$.

Linearizing the system (22)-(23) around a steady state, we get the Jacobian matrix and the associated characteristic polynomial $P(X) = (J_1 - X)(J_4 - X) - J_2 J_3 = X^2 - (J_1 + J_4)X + J_1 J_4 - J_2 J_3$, with

$$\begin{aligned} J_1 &= -\tfrac{1}{D}\left[c'u''(G' - d')(q_2 + \delta\Phi_A) + \Phi_I c''u'((\rho+\delta) - hq_1 G')\right], \\ J_2 &= \tfrac{1}{D}\left[c'u''(G' - d')(q_1 G' - \delta\Phi_I) - \Phi_I h q_2 u'(G''(1 - \tfrac{q_1}{q_2}c') - d'')\right], \\ J_3 &= \tfrac{1}{D}\left[\Phi_A c''u'((\rho+\delta) - hq_1 G') + (c''u' - (c')^2 u'')(q_2 + \delta\Phi_A)\right], \\ J_4 &= \tfrac{1}{D}\left[\Phi_A h q_2 u'(G''(1 - \tfrac{q_1}{q_2}c') - d'') - (c''u' - (c')^2 u'')(q_1 G' - \delta\Phi_I)\right]. \end{aligned}$$

The determinant of the Jacobian, $J_1 J_4 - J_2 J_3$, is equal to:

$$\det(J) = -\frac{1}{D}c''u'(q_2 + \delta\Phi_A)((\rho+\delta) - hq_1 G')(A_2' - A_1'). \quad (24)$$

From all the analysis above, we can conclude the following. At the "high" interior steady state (with $I > \tilde{I} > \hat{I}$), we have $A_2' < A_1'$, $\det(J)$ is negative and the steady state is a saddle point. As to the low steady state(s), with $I < \hat{I}$, things are more tricky. Assume that such a steady state is unique. Then, the intersection between the two SCs necessarily satisfies $A_2' < A_1'$, which now implies that $\det(J) > 0$.

C Dynamic analysis in the $\Lambda - P$ plan

To go deeper into the dynamic analysis, we take u linear and $c(A) = cA^2/2$. In this case the expression of the 2 RC reduces to:

$$F_1(P) = \frac{1}{q_1}\left(\frac{d'(hP)}{G'(hP)} - 1\right) \text{ and } F_2(P) = -\frac{1}{q_1}\left(\frac{\kappa\psi'(hP)}{G'(0)} + 1\right). \tag{25}$$

For $P \in [0, \bar{P}]$, we have: $F_1' > 0$, $F_1(0) = F_2(0) = -\frac{1}{q_1}$, $F_1(\tilde{P}) = 0$, and $F_2' < 0$.

C.1 Corner regimes with $I = hP$

Assume first that $A > 0$, and $\Lambda < 0$, Then, the SC are given by:

$$\begin{aligned} \dot{\Lambda} = 0 \Leftrightarrow \Lambda = S_1(P) &= \tfrac{h(G'(hP)-d'(hP))}{\rho+\delta-hq_1G'(hP)} \\ \dot{P} = 0 \Leftrightarrow \Lambda = S_2(P) &= -\tfrac{c}{q_2^2}\left(q_1G(hP) - \delta P\right). \end{aligned}$$

Properties of $S_1(P)$: For $P \in [0, \hat{P})$, it's easy to see that $S_1(P) < F_1(P)$. So, the SC is not located in the right domain. This implies that for all $\Lambda \in (F_1(P), 0)$, $\dot{\Lambda} < 0$. For $P \in (\hat{P}, \tilde{P}]$: $S_1(\hat{P}) = +\infty$, $S_1(\tilde{P}) = 0$ and $S_1' < 0$. Again the SC is not located in the right domain; for all $F_1(P) < \Lambda < 0$, $S_1(P) > \Lambda$, which is equivalent to $\dot{\Lambda} < 0$.

Properties of $S_2(P)$: $S_2(0) = -\frac{cq_1G(0)}{q_2^2} < 0$ and $S_2(0) < -\frac{1}{q_1} \Leftrightarrow G(0) > \frac{q_2^2}{cq_1^2}$. This is the necessary existence condition *(i)* (see the Appendix B.1), which is supposed to hold. $S_2(\bar{P}) = 0$ and $S_2(\tilde{P}) < 0$ as $\tilde{P} < \bar{P}$. $S_2' \leq 0$ for all $P \leq \check{P}$, then $S_2' > 0$. It is clear that $S_2(P) < F_1(P)$ for all $P \leq \tilde{P}$, so the second SC is not located in the right domain as well. For all $\Lambda \in (F_1(P), 0)$, we necessarily have $\dot{P} > 0$.

Consider next the regime with $A = 0$, and $\Lambda > 0$, the SCs are:

$$\dot{\Lambda} = 0 \Leftrightarrow \Lambda = S_1(P);\ \dot{P} = 0 \Leftrightarrow q_1G(hP) = \delta P.$$

The first SC is the same as in the previous case. So we have, for $P \in [0, \hat{P})$, $\Lambda > 0 > S_1(P) \Leftrightarrow \dot{\Lambda} < 0$. And for $P \in (\hat{P}, \tilde{P}]$, $\Lambda \lesseqgtr S_1(P) \Leftrightarrow \dot{\Lambda} \lesseqgtr 0$. The second SC is a vertical line at $P = \bar{P}$. Thus, for all $P < \bar{P}$, $\dot{P} > 0$.

C.2 Regime with $A > 0$ $I = 0$, $\Lambda < 0$

The SCs are given by(15), where the second one reduces to:

$$\dot{P} = 0 \Leftrightarrow \Lambda = S_4(P) = -\frac{c}{q_2^2}\left(q_1 G(0) - \delta P\right),$$

for $q_1 G(0) - \delta P \geq 0$. $S_3(P)$ is such that $S_3(0) = 0$, $S_3'(P) < 0$ for all P. $S_4(0) = S_2(0) < -\frac{1}{q_1}$ under the same condition as before, $S_4' > 0$, and $S_4(\frac{q_1 G(0)}{\delta}) = 0$. Moreover, under Assumption 3, there exists a unique positive and finite intersection between S_3 and F_2 at: $P = \frac{1}{h}(\psi')^{-1}(\frac{(\rho+\delta)G'(0)}{\kappa(hq_1 G'(0)-(\rho+\delta))})$. The resulting level of the shadow price follows when replacing P with the expression above in either S_3, or F_2. An intersection between S_4 and F_2 also arises at P implicitly defined by:

$$\frac{c(q_1 G(0) - \delta P)}{q_2^2} = \frac{1}{q_1}\left(\frac{\kappa\psi'(hP)}{G'(0)} + 1\right). \tag{26}$$

Finally, it's easy to check that $\dot{\Lambda} \lesseqgtr 0 \Leftrightarrow \Lambda \lesseqgtr S_3(P)$ and $\dot{P} \lesseqgtr 0 \Leftrightarrow \Lambda \lesseqgtr S_4(P)$.

C.3 $A = 0$ $I \in (0, hP)$, $\Lambda > 0$

In this regime, the NOC (9) holds only if $I > \tilde{I}$ and allows us to define Λ as follows:

$$\Lambda = \frac{d'(I) - G'(I) - \kappa\psi'(hP - I)}{q_1 G'(I)} \equiv \xi(I, P),$$

with $\xi_I > 0$ and $\xi_P < 0$. The dynamical system is given by:

$$\dot{\Lambda} = (\rho + \delta)\xi(I, P) + \kappa h \psi'(hP - I)$$
$$\dot{P} = q_1 G(I) - \delta P$$

As Λ must be positive, we necessarily have $\dot{\Lambda} > 0$. The second equation defines a SC:

$$I = (G)^{-1}(\frac{\delta P}{q_1}) \equiv I(P), \text{ with } I'(P) > 0.$$

In the $\Lambda - P$ plan, this curve is represented by the upward slowing locus obtained through the following substitution: $\Lambda = \xi(I(P), P) \equiv \tilde{\xi}(P)$ with $\tilde{\xi}'(P) = \xi_I I'(P) + \xi_P > 0$. For any pair $(P, \tilde{\xi}(P))$, i.e., located on this locus, consider an increase in Λ such that $\Lambda > \tilde{\xi}(P)$. For P given, this increase necessarily comes from an increase in I (as $\xi_I > 0$), which implies that $I > I(P)$. Then, from the differential equation in P above, it must hold that $\dot{P} > 0$. Conversely, $\Lambda < \tilde{\xi}(P) \Leftrightarrow \dot{P} < 0$.

C.4 $A > 0$ $I \in (0, hP)$, $\Lambda < 0$

The dynamics of Λ and P can be written as (with a slight abuse of notation):

$$\begin{aligned}\dot{\Lambda} &= -(\rho+\delta)\tfrac{cA}{q_2} - h(G'(I)(1 - \tfrac{cq_1A}{q_2}) - d'(I)),\\ \dot{P} &= q_1G(I) - q_2A - \delta\Phi(I,A).\end{aligned} \tag{27}$$

Remind that the SCs can be studied in the $A-I$ and are given by: $A = A_1(I)$ and $A = A_2(I)$. Again we analyze the two cases ($I < \hat{I}$ vs $I > \tilde{I}$) separately.

For $I \in [\tilde{I}, \breve{I}]$: $A_1' > 0$, varying between $A_1(\tilde{I}) = 0$ and $A_1(\breve{I}) = \frac{q_2}{q_1c}$. We can take the inverse of this function, which yields $I = I_1(A)$, with $I_1' = \frac{1}{A_1'} > 0$ and $A \in [0, \frac{q_2}{q_1c}]$. As A varies in this interval, Λ belongs to $[-\frac{1}{q_1}, 0]$ because, from (8), we have $\Lambda = -\frac{cA}{q_2}$. So we ultimately obtain I as a function of Λ. We also have $A_2(\tilde{I}) \in (0,\infty)$ and $A_2(\breve{I}) \in (0, \frac{q_2}{q_1c})$, from the existence condition. Let's further assume that $A_2(\tilde{I}) > \frac{q_2}{q_1c}$ (the analysis extends easily to the opposite case). Then we can define I^ν such that $A_2(I^\nu) = \frac{q_2}{q_1c}$. On the interval $[I^\nu, \breve{I}]$, $A_2' < 0$ and we can take the inverse of A_2 to obtain: $I = I_2(A)$, with $I_2'(A) < 0$ and $A \in [A_2(\breve{I}), \frac{q_2}{q_1c}] \Leftrightarrow \Lambda \in [-\frac{1}{q_1}, -cA_2(\breve{I})/q_2]$.

Next we can use the relationship $P = \Phi(I, A)$ to express the SCs in the $\Lambda - P$ plan:

$$\begin{aligned}P &= \Phi(I_1(A), A) = P_1(\Lambda) \text{ (for } \dot{\Lambda} = 0),\\ P &= \Phi(I_2(A), A) = P_2(\Lambda) \text{ (for } \dot{P} = 0).\end{aligned}$$

As to the behavior of these two curves, we get $P_1'(\Lambda) = (\Phi_A + \Phi_I I_1')A'(\Lambda) < 0$ because $A'(\Lambda) = -\frac{q_2}{c} < 0$ and all the other derivatives are positive. And

$$\begin{aligned}P_1(-\tfrac{1}{q_1}) &= \Phi(\breve{I}, \tfrac{q_2}{q_1c}) = \tfrac{1}{h}[\breve{I} + (\psi')^{-1}(\tfrac{\rho+\delta}{\kappa h q_1})] > \breve{P} = \breve{I}/h\\ P_1(0) &= \Phi(\tilde{I}, 0) = \tilde{P},\end{aligned}$$

and we observe that this SC is connected with the one of the regime $A = 0$, $I = hP$ at $(\Lambda, P) = (0, \tilde{P})$ because $\Lambda = F_1(\tilde{P}) = 0$.

The second SC derivative is: $P_2'(\Lambda) = (\Phi_A + \Phi_I I_2')A'(\Lambda)$. Using the expression of $I_2' = \frac{1}{A_2'} = \frac{q_2+\delta\Phi_A}{q_1G'-\delta\Phi_I}$ and rearranging, we obtain $\Phi_A + \Phi_I I_2' = (\Phi_A q_1 G' + q_2\Phi_I)/(q_1G' - \delta\Phi_I) < 0$, which in turn implies $P_2'(\Lambda) > 0$. Moreover,

$$\begin{aligned}P_2(-\tfrac{1}{q_1}) &= \Phi(I^\nu, \tfrac{q_2}{q_1c}) = \tfrac{1}{h}[I^\nu + (\psi')^{-1}(d'(I^*))] > \tilde{P},\\ P_2(-cA_2(\breve{I})/q_2) &= \Phi(\breve{I}, A_2(\breve{I}))\tfrac{1}{h}[\breve{I} + (\psi')^{-1}(\tfrac{\rho+\delta}{\kappa h q_1} - G'(\breve{I})(1 - \tfrac{cq_1A_2(\breve{I})}{q_2}))] > \breve{P}.\end{aligned}$$

Let us further assess the local dynamics around the unique "high" steady state (see Appendix B.3). "Linearizing" the system (27) around the steady state, we obtain:

$$d\dot{\Lambda} = -\left(\rho+\delta - hq_1G'(I^*)\right)c''(A^*)dA - h\left(G''(I^*)(1-\frac{q_1c'(A^*)}{q_2}) - d''(I^*)\right)dI$$
$$d\dot{P} = \left(q_1G'(I^*) - \delta\Phi_I^*\right)dI - (q_2+\delta\Phi_A^*)dA.$$

Consider a variation around the steady state such that $dP > 0$ and $d\Lambda = 0$. $d\Lambda = 0 \Leftrightarrow dA = 0$, which from $dP = \Phi_I^* dI + \Phi_A^* dA$, implies $dI > 0$. $dI > 0$ with $dA = 0$ in turn implies from the second equation above and $q_1G'(I^*) - \delta\Phi_I^* < 0$ that $d\dot{P} < 0$. This is enough to draw the arrows yielding the direction of changes in P within the four quadrants delimited by the SCs. Now consider a variation such that $dP = 0$ and $d\Lambda > 0$. $d\Lambda > 0 \Leftrightarrow dA < 0$ and from $dP = \Phi_I^* dI + \Phi_A^* dA = 0$, we have $dI = -\frac{\Phi_A^*}{\Phi_I^*}dA > 0$. Replacing dI with this expression in the first equation above, we obtain: $d\dot{\Lambda} = -\left[\left(\rho+\delta-hq_1G'(I^*)\right)c''(A^*)dA - h\frac{\Phi_A^*}{\Phi_I^*}\left(G''(I^*)(1-\frac{q_1c'(A^*)}{q_2}) - d''(I^*)\right)dI\right]dA > 0$, which is again enough to draw the arrows representing changes in Λ.

For $I \in [0, \hat{I})$: A_1 and A_2 are non-monotone in general. In Appendix B.3, we gave a sufficient condition for the existence of a steady state ($A_2(0) > A_1(0)$). What we can check at least is that the SCs of the interior solution, for a low I, are connected to the ones of the corner regime $A > 0$ and $I = 0$, this connection occurring on $F_2(P)$. Let us define $I_i^m = \min\{I/A_i'(I) = 0\}$ for $i = 1, 2$ (of course, I_i^m is not defined when A_i is monotone, but in this case we have no problem). Then, the reasoning developed above works when restricting our attention to the subintervals $[0, I_i^m]$, and we can express the SCs, in this region, as follows: for $\Lambda \in [\min\{\frac{cA_i(0)}{q_2}, \frac{cA_i(I_i^m)}{q_2}\}, \max\{\frac{cA_i(0)}{q_2}, \frac{cA_i(I_i^m)}{q_2}\}]$,

$$P = \Phi(I_1(A), A) = P_1(\Lambda).$$

In particular we have: $P_1(-\frac{cA_1(0)}{q_2}) = \Phi(0, A_1(0)) = \frac{1}{h}(\psi')^{-1}(\frac{(\rho+\delta)G'(0)}{\kappa(hq_1G'(0)-(\rho+\delta))})$. If the SC P_1 hits the RC F_2 at $(\Lambda, P) = (-\frac{cA_1(0)}{q_2}, P_1(-\frac{cA_1(0)}{q_2}))$, then it must hold that $-\frac{cA_1(0)}{q_2} = F_2(P_1(-\frac{cA_1(0)}{q_2})) = -\frac{1}{q_1}[\frac{\kappa}{G'(0)}\psi'(P_1(-\frac{cA_1(0)}{q_2})) + 1]$. After straightforward manipulations, we can check that this is indeed the case. We also have: $P_2(-\frac{cA_2(0)}{q_2}) = \Phi(0, A_2(0))$, and it is easy to verify that P_2 hits the RC F_2 at $(\Lambda, P) = (-\frac{cA_2(0)}{q_2}, P_2(-\frac{cA_2(0)}{q_2}))$. One can also check that $P_2(-\frac{cA_2(0)}{q_2})$ solves eq (26) (see the Appendix C.2), which is enough to conclude.

We can finally check that, for the example, the trace of the Jacobian matrix is equal to $\rho > 0$. So if there exists a unique "low" steady state, it is a source.