A General Model of Bilateral Migration Agreements*

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Abstract

Unilateral migration policies impose externalities on other countries. In order to try to internalize these externalities, countries sign bilateral migration agreements. One element of these agreements is the emphasis on enforcing migration policies: immigrant-receiving countries agree to allow more immigrants from their emigrant-sending partner if they cooperate in enforcing their migration policy at the border. I present a simple theoretical model that justifies this behavior in a two-country setting with welfare maximizing governments. These governments establish migration quotas that need to be enforced at a cost. I prove that uncoordinated migration policies are inefficient. Both countries can improve welfare by exchanging a more "generous" migration quota for expenditure on enforcement policy. Contrary to what could be expected, this result does not depend on the enforcement technology that both countries employ.

Keywords: international migration, cooperation, migration policy

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1 Introduction

Why do countries cooperate in establishing migration policies? In particular, why do immigrant-receiving and emigrant-sending countries sign migration agreements?[1] Clearly, these countries could have opposing interests: immigrant-receiving countries could want to restrict immigration, while emigrant-sending countries could want to relieve their excess labor supply as much as possible. In this paper, we show that cooperation among countries with conflicting interests can be Pareto-improving since unilateral migration policies impose externalities on other countries which can be partly internalized by migration agreements despite a priori conflicting interests. This migration externality takes place because the immigrant-receiving country does not take into account the welfare of its emigrant-sending counterpart when deciding about its optimal migration policy. The result is that this optimal migration policy tends to be inefficiently over-restrictive, thus harming the emigrant-sending country's welfare. There is also an externality on the other side: since restricting migration is costly, the emigrant-sending country has no incentives to do so and therefore imposes inefficiently high enforcement costs on the immigrant-receiving country.

Bilateral migration agreements allow to internalize this externality. One element of these agreements is the emphasis on enforcing migration policies by which immigrant-receiving countries agree to allow more immigrants from their emigrant-sending partner if they cooperate in enforcing their migration policy at the border and thereby share the costs. I present a simple theoretical model that justifies this behavior in a two-country setting with welfare maximizing governments. These governments establish migration quotas that need to be enforced at a cost. The costly enforcement technology is modeled following Ethier (1986b) original paper. I prove that unilateral migration policies are inefficient whereas both countries can improve welfare by exchanging a more "generous" migration quota for expenditure on enforcement policy. Contrary to what could be expected, this result does not depend on the enforcement technology that both countries employ.

The World Trade Organization (WTO) is an institution where countries can get together and negotiate mutually beneficial trade agreements. When countries set their tariffs uni-

[1] The case for cooperation between immigrant-receiving countries who would unilaterally like to divert undesired immigrant inflows to their neighbors has been studied elsewhere. For example, see Barbou des Places and Deffains (2004) for an application of the Sandler and Hartley (2001) joint product theory to the case of refugee distribution.

laterally, they hurt other countries because they improve their own terms of trade at the expense of others' terms of trade. This creates a Prisoner's Dilemma where countries would be better off if they all lowered their tariffs but in fact they do not have the incentive to do so unilaterally. In order to remove this inefficiency, international cooperation is required and this is obtained through the WTO.[2] A key element that explains why international cooperation enhances efficiency is the assumption that freer trade increases world output. This paper shows that a similar reasoning can be applied to migration policy. However, an important difference must also be highlighted: whereas the theory of trade agreements is based on the assumption that all participating countries benefit from higher volumes of trade, this paper shows that migration agreements can be signed even when the immigrant-receiving country welfare is decreasing in the magnitude of the migration flow at the same time that the emigrant-sending country welfare is increasing in the magnitude of the migration flow.

Most theoretical models of migration coincide in concluding that the free movement of factors contributes to a better allocation of resources at the world level, even when one abstracts from fairness considerations (Findlay (1982)). In most cases, the upper estimate of these efficiency gains is notably superior to the efficiency gains that can be expected from, for example, free trade. For example, Hamilton and Whalley (1984) crudely estimated (using data from 1977) that the efficiency gains from totally removing immigration controls could get to double world GNP. In a more recent paper, Rodrik (2002) argues that "...liberalizing cross-border labor movements can be expected to yield benefits that are roughly 25 times larger than those that would accrue from the traditional agenda focusing on goods and capital flows[3]!" Why are these immense efficiency gains not obtained through international cooperation? The typical explanation (Hatton (2007)) is that the movement of people has opposing effects on immigrant-receiving and emigrant-sending countries. Immigrant-receiving countries tend to ask for lower migration whereas emigrant-sending countries tend to ask for freer migration, at least in terms of low-skill migrants.

As a result, the economics literature has typically studied migration policies as a unilateral phenomenon. For example, Ethier (1986b) and Ethier (1986a) use the crime-theoretic analysis of Becker (1968) to analyze the effects of different policies aimed at reducing illegal

[2]Bagwell and Staiger (2003) provide a detailed discussion.

[3]A more modest estimate by the World Bank (2006) finds that "a rise in migration from developing countries sufficient to raise the labor force of high-income countries by 3 percent" would yield gains 13 per cent higher than the gains to be obtained from global trade reforms as proposed in the Doha round.

immigration. Bond and Chen (1987) extend Ethier's analysis to a two-country model with capital mobility but they do not allow a policy response of the emigrant-sending country to the migration policy of the immigrant-receiving country[4]. The same can be said about Woodland and Yoshida (2006) contribution, who add emigrants risk preferences to the model. Guzman, Haslag, and Orrenius (2008) allow a response to the migration policy (on border enforcement) of the immigrant-receiving country. However, the response does not come from the emigrant-sending country but from the smugglers, who can partly nullify the intended effects of border enforcement. Finally, Schiff (2007) analyzes the relative merits of common migration policy options and proposals, such as permanent migration programs, guest-worker programs and Mode IV in the GATS (General Agreement on Tariffs and Services).

On the contrary, Bandyopadhyay and Bandyopadhyay (1998) extension of Bond and Chen (1987) model is more similar to the one in this paper since they consider a policy response of the emigrant sending country. In their case, this policy consists of imposing restrictions on capital inflows and it can render the border enforcement policy of the immigrant-receiving country partly ineffective. Dula, Kahana, and Lecker (2006) also take the policy options of emigrant-sending countries into account. They advance an original proposal to address the migration externality. They claim that immigrant-receiving countries could save in border enforcement by financing relatively more those emigrant-sending governments who would make a bigger effort in avoiding the exit of illegal emigrants from their country, thereby creating competition among emigrant-sending countries for the funds of the immigrant-receiving country. This kind of auction for development aid has not been formally established yet. A third framework that also considers both the emigrant-sending and the immigrant-receiving country policies is proposed by Stark, Casarico, Devillanova, and Uebelmesser (2007). In the presence of a human capital externality in the emigrant-sending country that makes a certain level of emigration welfare improving by generating a brain gain but additional levels welfare inferior by creating a brain drain, they show that there is scope for migration agreements. There is an important difference with my paper since these migration

[4]The issue of the relationship between labor and capital mobility and optimal policies to maximize welfare under different scenarios has a longer tradition in the literature. The classical reference in this area is Ramaswami (1968). He used MacDougall (1960) framework to show how allowing for migration and taxing migrants is preferred to exporting and taxing capital in a neoclassical model with two factors of production. Calvo and Wellisz (1983) showed how the institutional restrictions (inability to discriminate labor) were key in Ramaswami (1968) result so that there was no need to import labor in order to obtain the same outcome.

agreements are only beneficial when both countries' welfare levels are decreasing in the magnitude of the migration flow, that is, when the preferences of both countries are aligned, as Hatton (2007) suggests. In this paper, it will be shown that the scope for migration agreements remains in the absence of human capital externalities and even when one of the countries would favor larger migration flows whereas the other benefits from smaller migration flows.

The public finance literature has also addressed the issue of cooperation in migration policies in the context of regional migration. From this literature, the most relevant result for the purposes of this paper is that of Myers (1990), who shows that, under free migration, decentralized policies are enough to achieve efficiency because countries (regions in his case) internalize the consequences of their policies on their neighbors through their effect on migration flows. The immediate consequence is that the establishment of migration controls may preclude an efficient solution since decentralized policies will then create externalities on other countries (regions). For example, Casella (2005) shows how there are situations in which countries (regions) can individually choose to set migration barriers optimally, thus preventing externalities from being internalized through the effect of other policies (redistribution policies in her model) on migration flows. In those situations, both migratory policies and internal policies must be coordinated in order to achieve efficiency. The difference with my approach is that the source of the externality in Casella (2005) is not the migratory policy itself but the existence of technological spillovers.

As of 2004, there were at least 176 bilateral agreements on migration issues.[5] What is the economic justification behind all of these? One useful starting point to address this question is to incorporate the arguments that are actually given for signing bilateral migration agreements. According to the background paper for the joint IOM/World Bank/WTO Trade and Migration Seminar, IOM/World Bank/WTO (2004), the reasons why migrant-receiving countries sign these agreements are:

- Combatting irregular migration.
- Responding to labor market needs of temporary or permanent nature.
- Promoting economic links with sending countries.

[5]The number refers only to agreements in which at least one OECD member is involved (OECD (2004)).

On the other hand, the reasons why sending states agree to sign these bilateral agreements are:

- Relieving labor surpluses.
- Protecting the rights of their nationals abroad.
- Limiting the effects of brain drain by ensuring the return of their nationals.

The model presented in this paper concentrates on the first point of both set of objectives, that is, the reason for immigrant-receiving countries to sign an agreement will be the will to combat irregular migration. For some reason, they will consider that additional immigration is welfare-reducing. On the contrary, emigrant sending countries will want to relieve their labor market surplus, that is, they will consider that additional emigration is welfare-improving for them.

The following sections develop a general model of bilateral migration agreements.

2 Basic Assumptions

Suppose that there is a world with two countries A and B with original populations normalized to 1 for each country. The initial conditions are such that the nationals of country B have an incentive to migrate to country A, where they can attain higher utility levels than in their home country. For example, in the context of a Ricardian model[6], the reason could be that country A has favorable terms of trade in an environment of free trade. One can also think of a typical specific factors model where country A is relatively labor scarce so that the wage workers can obtain there is higher than in country B.

Governments of both countries maximize a welfare function $W^h\left(t^h, l, i\right)$ $(h = A, B)$. This welfare function depends on three arguments: the tax level required to finance the migratory policy of the government (t^h) and the number of migrants that the country receives or sends: both legal (l) and illegal (i), with $0 \leq i + l \leq 1$. The welfare function can stem from a benevolent government trying to maximize the utility of their inhabitants in the context of a Ricardian or specific factors model or it could just be the result of a political process, as in Benhabib (1996).

Some conditions are imposed on this welfare function:

[6] A Ricardian example of the model is available from the author upon request.

- $\frac{\partial W^h}{\partial t^h} < 0$. A higher tax level in the country directly reduces welfare by itself. Remember that the tax indicated in the function is exclusively used to finance the migratory policy of the government. Further effects of the migratory policy induced by this tax level are not reflected in this partial derivative.

- $\frac{\partial W^h}{\partial t^j} = 0$. The tax level imposed by one country has no direct effect on the welfare of the other country. The only effect of the migratory policy of one country over the other country is channeled through the number of migrants.

- $\frac{\partial W^A}{\partial i} = \frac{\partial W^A}{\partial l} < 0, \frac{\partial W^B}{\partial l} = \frac{\partial W^B}{\partial i} > 0$. An additional immigrant reduces the welfare of the receiving country whereas an additional emigrant increases the welfare (relief of the labor surplus) of the sending country. It is assumed, perhaps counterfactually, that illegal immigration and legal immigration have the same marginal effect on the welfare of immigrant-receiving and emigrant-sending countries[7]. Still, the receiving country government has an incentive to deter immigrants, both legal and illegal, from entering its country. However, forbidding the entry of new immigrants into the richer country (A) can only be done at a cost. The migratory policy must be enforced and the enforcement technology is modeled following Ethier (1986b).

To simplify notation, it is assumed that the welfare functions of both countries also denote the utility level attained by representative individuals who do not migrate in both countries.

3 Migration Policies and Timing

The most extended form of migration policy that we observe in the world is a system of migration quotas. On the other hand, emigrant-sending countries tend to have passive migration policies (at least towards their unskilled labor force) unless they are asked to cooperate by immigrant-receiving countries. A very simple model can capture this incentive for cooperation. Suppose that the only migration policy tool available for countries is to set a migration quota and suppose that this quota cannot be negative. If the migration quota can be costlessly enforced, country A will choose a zero quota and there will be no migration. However, assume that illegal migrants will try to come into the rich country as

[7]This assumption is not inocuous. Whether illegal or legal immigration are more or less harmful affects the nature of the efficient equilibrium.

long as there is a welfare level differential and that the entrance of immigrants can only be stopped by spending resources in policing the border. These resources are collected by imposing a uniform per capita tax on country A's residents. Country B will also be allowed to set a tax that could help enforce country A's migration quota so as to analyze later the possibility of migration agreements.

Clarifying the timing of the model becomes relevant again at this point. First, governments collect a non-negative uniform per capita tax ($t^h \geq 0$) on their residents and, in the case of country A, set a legal non-negative migration quota ($l \geq 0$). Then, individuals move so as their maximize their welfare level. Since $W^A > W^B$ by assumption, all the inhabitants of country B try to move to country A. l inhabitants of B can move legally and costlessly attaining the utility level $W^l = W^A$ whereas the rest will try to emigrate illegally, attaining the expected utility W^i, which will be defined below.

It is assumed that governments choose migration policies in the first step so as to maximize nationals' (original residents') welfare. This formulation might seem artificial but different assumptions about timing do not have any effect on the basic intuition of the model.

4 Costly Enforcement

Following Ethier (1986b), define $g(e)$ as the probability of an illegal immigrant being denied entry, where $e = e^A + e^B$ is the joint enforcement effort of the two countries. Notice that no assumption is made about whether the enforcement effort is more or less effective depending on the country that makes the expenditure. The enforcement effort of the emigrant sending country does not need to refer to policing the border but it could reflect the willingness to accept deported illegal immigrants.

As in Ethier (1986b), it is assumed that $g(0) = 0$, $g' > 0$ and $g < 1$. Hanson and Spilimbergo (1999) implicitly test whether $g' > 0$ by regressing the number of apprehensions of illegal immigrants at the Mexico-US border on the enforcement effort of the US Border Patrol. They find that an increase in the number of hours patrolling the border in the period 1968-1996 results in an increase in the number of apprehensions, controlling for other variables that affect attempts of entry and also instrumenting for the endogeneity of the enforcement effort. This would translate into $g' > 0$ as long as the the elasticity of migrant attempts with respect to enforcement is negative and the elasticity of the probability of detection with respect to the number of attempts is less than one in absolute value.[8]

Let k be the penalty (welfare equivalent) imposed on an illegal immigrant who is denied entry. Following Ethier (1986b), the penalty k is assumed to be exogenous[9]. Assuming that individuals are risk neutral, the inhabitants of the poor country that cannot migrate legally will equalize the expected return from illegal migration (W^i) to the welfare they obtain when staying at home (W^B). In this case, whenever $W^A - W^B > 0$, this will mean:

$$W^i = W^B \tag{1a}$$

$$W^i = \left(W^B - k\right) g\left(e\right) + W^A \left(1 - g\left(e\right)\right) = W^B \tag{1b}$$

As a result, the level of illegal migration will depend on the enforcement level together with the difference in welfare:

$$W^A - W^B = k\frac{g\left(e\right)}{1 - g\left(e\right)} \equiv \kappa\left(e\right) \tag{1c}$$

The interpretation of this equation is straightforward. A differential of welfare levels between the two countries can only be sustained as long as there is expenditure on enforcement.

Together with the government budget constraints: $e^h = t^h$ $(h = A, B)$, the migration equilibrium equation (1a) implicitly defines the function $i\left(l, t^A, t^B\right)$. This migration function gathers the impact of both countries' policies on the number of illegal migrants.

Without loss of generality, the case where fiscal policy can overturn migration from the rich to the poor country will be disregarded by assuming that there is an infinite fixed cost for migrating into the poor country.

5 The Optimal Solution

Suppose that a supranational authority existed and could decide on the optimal migration policies: which would those be under the stated assumptions? Optimal migration policies

[8]Under the same conditions and given the size of some of their estimates, they claim, contrary to Ethier's assumption that $g'' < 0$, that it could be the case that the elasticity of the probability of detection with respect to border enforcement is increasing in the enforcement effort.

[9]The qualitative conclusions of the model do not change if k is endogenous as long as it is not costless.

are defined as those maximizing total welfare in this two-country world. The problem that the central planner has to solve is thus:

$$\begin{aligned}\max_{\{0\leq l\leq 1;t^A\geq 0;t^B\geq 0\}} W &= W^A+(1-l-i)\,W^B+lW^l+iW^i \\ \text{subject to} &: W^A-W^B=\kappa\,(e) \text{ if } W^A\geq W^B\end{aligned} \tag{2a}$$

In equilibrium, migrants end up getting either $W^l = W^A$ or (in expectation) $W^i = W^B$, depending on whether they are legal or illegal. Thus, the objective function can be rewritten as:

$$W=(1+l)\,W^A+(1-l)\,W^B \tag{2b}$$

It can be shown (see appendix) that, under the stated conditions, the central planner solution is:

$$\begin{aligned} l^* &= \min\{1,l'\} \\ t^{A*} &= 0 \\ t^{B*} &= 0 \end{aligned} \tag{3}$$

where l' is the level of legal migration that equates the welfare level in both countries, that is, the level of legal migration that solves:

$$W^A\,(l',0,0)-W^B\,(l',0,0)=0 \tag{4}$$

Intuitively, legal migration is preferred to illegal migration because it has been assumed that its marginal effect on the welfare of both the emigrant-sending and the immigrant-receiving country is exactly the same. This "tie" is broken by the migrants themselves, whose welfare is higher when they are legal rather than illegal so that legal migration is more efficient from a global welfare point of view. If the assumption of analogous marginal impact of legal and illegal migration were to be relaxed, it would be possible to obtain solutions in which illegal migration is optimal.

6 Nash Equilibrium

In the absence of a supranational authority that forces the central planner solution, countries would decide unilaterally on their migration policies. In that case, the Nash equilibrium resulting from applying uncoordinated policies is not efficient.

Proposition 1 *The uncoordinated Nash solutions do not generally coincide with the optimal solution.*

The proof is shown in the appendix. The intuition is the classical one in an externality problem. Country A's migration policy is too restrictive from the point of view of country B whereas country B's unilateral decision not to spend on enforcement hurts country A. When countries set their migration policies unilaterally, they do not take into account the effect of their policies on other countries and so there is scope for efficiency gains through cooperation.

The proof of proposition 1 allows a characterization of the unilateral migration policies in situations in which there is scope for cooperation. In the case of country A, the Lagrangian resulting from its maximization problem is the following:

$$\mathcal{L}^A = W^A + \lambda_1^A t^A + \lambda_2^A l + \lambda_3^A (1 - l) \tag{5}$$

For country B, the Lagrangian of the unilateral problem is:

$$\mathcal{L}^B = W^B + \lambda_1^B t^B \tag{6}$$

Both countries are subject to non-negative constraints and to the satisfaction of the migration equilibrium equation (1a) as long as $W^A - W^B > 0$.

In general, it could be expected that the best policy country B government can undertake in order to maximize its residents' welfare would be one in which it would not spend any resources on making it difficult for its own inhabitants to leave the country. This would imply a 0 tax on B residents. To see when this is the case, suppose that the equilibrium is of the form $\left(l_N = 0, t_N^A > 0, t_N^B = 0\right)$ (where the subscript N will denote Nash policies). Also, suppose that this equilibrium entails a positive illegal migration level $i_N > 0$ defined by:

$$W_N^A - W_N^B = \kappa (e_N) \tag{7}$$

The conditions associated with this equilibrium are:

$$
\begin{aligned}
\frac{dW^A}{dt^A}\left(0, t_N^A, 0\right) &= 0 \\
\frac{dW^A}{dl}\left(0, t_N^A, 0\right) + \lambda_{2N}^A &= 0 \\
\frac{dW^B}{dt^B}\left(0, t_N^A, 0\right) + \lambda_{1N}^B &= 0 \\
\lambda_{2N}^A &\geq 0 \\
\lambda_{1N}^B &\geq 0 \\
k &> \frac{\partial W^A}{\partial t^A}(0,0,0)\frac{\frac{\partial W^B}{\partial i}(0,0,0)}{\frac{\partial W^A}{\partial i}(0,0,0)}\frac{1}{g'(0)}
\end{aligned}
\tag{8}
$$

The need for the last condition is also established in the appendix. The intuition is that the poor country has no incentive to unilaterally help to enforce the migration policy of the rich country whereas the rich country has an incentive to limit the entry of immigrants as long as the enforcement technology is effective enough (high k). The interpretation of the inequality is straightforward. The higher the marginal negative effect of taxation on the immigrant-receiving country ($\frac{\partial W^A}{\partial t^A}(0,0,0)$), the more effective the punishment k must be so that it is welfare improving to tax residents. Also the higher the marginal welfare gain from emigration in the emigrant-sending country ($\frac{\partial W^B}{\partial i}(0,0,0)$), the higher the punishment k needs to be because that reduces the incentive to further emigration and so the need for a stringent migration policy. In the same way, the higher the marginal welfare loss from immigration country A experiences ($\frac{\partial W^A}{\partial i}(0,0,0)$), the lower the punishment k needs to be to create the need for a positive enforcement level. Finally, the higher the marginal efficiency of the enforcement technology ($g'(0)$), the lower the need for a tougher punishment k that makes enforcement welfare improving for the immigrant-receiving country.

7 Scope for cooperation

Since the Nash equilibrium is not efficient, there is a possibility for welfare improving cooperation between the emigrant-sending and the immigrant-receiving country. The rich country can offer more access to its own labor market so that the poor country cooperates in enforcing its migration policy. Both countries can benefit from cooperation as it is established in the following proposition.

Proposition 2 *If the unilateral solution is of the form* $\left(l_N = 0, t_N^A > 0, t_N^B = 0\right)$ *and* $k > -\frac{\partial W^B}{\partial t^B}\left(0, t_N^A, 0\right)\frac{\left(1-g\left(t_N^A\right)\right)^2}{g'\left(t_N^A\right)}$, *then* $\exists\left(l_0, t_0^A, t_0^B\right)$ *close enough to* $\left(0, t_N^A, 0\right)$ *with either* $l_0 > 0$ *or* $t_0^A < t_N^A$ *and* $t_0^B > 0$ *such that* $W^A\left(l_0, t_0^A, t_0^B\right) > W^A\left(0, t_N^A, 0\right)$ *and* $W^B\left(l_0, t_0^A, t_0^B\right) > W^B\left(0, t_N^A, 0\right)$

The proof is also shown in the appendix. The additional condition on k is necessary to make the number of migrants decreasing in the tax level of the poor country in a neighborhood of the Nash equilibrium. Increasing the tax level has two effects on the number of migrants. The tax decreases welfare in the emigrant sending country ($\frac{\partial W^B}{\partial t^B} < 0$) and it thus induces more individuals to migrate. The higher the marginal negative effect of the tax, the higher the punishment k would need to be to make enforcement a preferred option. The second effect is the opposite: the tax is used to finance a tighter enforcement ($g\left(e\right)$) of the migratory policy and that reduces migration. If k is big enough, the latter effect will dominate the former in a neighborhood of the equilibrium and there will be incentives for cooperation. The higher the marginal effect of the enforcement effort ($g'\left(e\right)$), the lower k needs to be to support cooperation.

8 Enforcing the Agreement

Even though both countries could win by cooperating on their migration policy, they have no incentive to do so in the current framework. In the absence of a supranational authority with the ability of punishing the country that deviates from the agreement, the coordinated solution would never be reached since both countries have an incentive to revert to their Nash policies. Country A has an incentive to increase its enforcement effort whereas country B has an incentive to decrease it. How can cooperation be sustained in this case?

The answer is the classical in a Prisoner's Dilemma. A way to sustain cooperation is through repeated interactions. As long as the threat of long-term losses is substantial enough, both countries will be willing to renounce to the short-term profit that can be obtained when deviating from a cooperative solution. This cooperative solution may not be as efficient as the one obtained from a central planner setting but it will still be more efficient than the Nash equilibrium.

The theory of repeated games can be directly applied to study self-enforcing migration agreements in the same way in which Bagwell and Staiger (2003) explain the enforcement of trade agreements. Following their discussion of enforcement, consider the model presented in the previous sections as the stage game of an infinitely repeated migration agreements game. Every period t, governments must simultaneously decide on their migration policies: the duple $\left(l_t, t_t^A\right)$ for country A and $\left(t_t^B\right)$ for country B. Governments take this decision by considering all their previous history of choices of migration policy.

For simplicity, and without loss of generality, assume that the size of the countries is not affected by migration. Another way to rationalize the argument is to think of temporary migration schemes in which workers go back and forth every year. An example of this would be the German-Polish agreement (OECD (2004)) before the entry of Poland into the European Union. It is clear that the long-term relationship introduces new elements that one should consider in the welfare function that governments maximize. For example, some of the past immigrants might become residents of the host country and then begin to influence its policy, that is, the welfare function that the government maximizes (see, for example, Ortega (2005)). Although relevant, the formulation here is simpler and concentrates on the possibility of enforcing agreements even in situations in which the welfare function does not change and immigrants do not integrate in the host country.

Let the discount factor between periods be common to both countries and denote it by $\delta \in (0,1)$. Define also $L_t \equiv \sum_{\tau=0}^{t} l_\tau$ and $I_t \equiv \sum_{\tau=0}^{t} i_\tau$ as the cumulative legal and illegal migration occurred up to time t. The welfare function of each country in the infinitely-repeated game will be:

$$\mathcal{W}^h \equiv \sum_{\tau=0}^{\infty} \delta W^h\left(t_\tau^h, L_\tau, I_\tau\right); h = A, B \tag{9}$$

This welfare function will be subject to the government budget constraint $t_\tau^h = e_\tau^h$ and to the migration equilibrium equation (1a) every period.

Assume now that the agreement that can be enforced is defined as $\left(L_C, t_C^A, t_C^B\right)$ with $L_C > 0$, $t_C^A < t_N^A$ and $t_C^B > 0$. It is also assumed that this agreement is worse than a politically optimal one (in the sense that it would be best for both countries in the one-stage game but not the best in a central planner sense), denoted by $\left(L_{PO}, t_{PO}^A, t_{PO}^B\right)$.

Concentrating on the incentive that country B has to deviate from the agreement, this is given by:

$$\begin{aligned}\Omega^B\left(L_C,t_C^A,t_C^B\right) &\equiv \int_0^{t_C^B}\frac{dW^B}{dt^B}dt^B = \\ &= \int_0^{t_C^B}\frac{\partial W^B}{\partial t^B}dt^B + \int_0^{t_C^B}\frac{\partial W^B}{\partial I}\frac{dI}{dt^B}dt^B > 0 \end{aligned} \tag{10}$$

Country B deviates to $t_N^B = 0$ because $\frac{dW^B}{dt^B} < 0$ as shown in appendix C. There are two immediate benefits from this short-term deviation: a lower fiscal effort ($\frac{\partial W^B}{\partial t^B}$) to promote enforcement of the agreement and also an increase in illegal immigration coming from the lower enforcement effort ($\frac{\partial W^B}{\partial I}\frac{dI}{dt^B}$).

The problem from deviating is that it can trigger a retaliatory move by country A, which could decide to revert to the Nash equilibrium in subsequent periods. For simplicity, suppose that this retaliatory move only changes the enforcement effort of country A and not the legal migration level. The one-period gain for country B of avoiding this behavior is the following:

$$\begin{aligned}\varpi^B\left(L_C,t_C^A,t_C^B\right) &\equiv -\int_{t_C^A}^{t_N^A}\frac{dW^B}{dt^A}dt^A = \\ &= -\int_{t_C^A}^{t_N^A}\frac{\partial W^B}{\partial I}\frac{dI}{dt^A}dt^A > 0\end{aligned}$$

A reversion to the Nash enforcement effort $t_N^A > t_C^A$ would imply a lower level of illegal immigration, which reduces the welfare to be attained by country B. Summing over the infinite horizon, the total discounted value from cooperation that country B would lose if it cheated would be:

$$V^B\left(L_C,t_C^A,t_C^B\right) \equiv \frac{\delta}{1-\delta}\varpi^B\left(L_C,t_C^A,t_C^B\right) \tag{11}$$

As a result, the incentive constraint that makes the bilateral migration agreement enforceable from the point of view of country B is:

$$\Omega^B\left(L_C,t_C^A,t_C^B\right) \leq V^B\left(L_C,t_C^A,t_C^B\right) \tag{12}$$

An analogous condition can be derived for country A. Thus, a cooperative agreement will be enforceable if and only if the incentive constraints for both countries are satisfied. The policies that satisfy these enforcement constraints constitute a subgame perfect equilibrium of the repeated game.

9 Conclusions

Many bilateral agreements have addressed the regulation of migration flows during the past few years (176 such agreements involving OECD members existed in 2004; OECD (2004)). This paper addresses the economic rationale for such agreements. Emigrant-sending countries declare they are willing to sign migration agreements with immigrant-receiving countries in order to relieve their labor surplus. Immigrant-receiving countries, on their part, mainly want to combat irregular migration. In other words, there are migration agreements between countries wanting emigrants to leave and countries not willing to take them in.

The reason that makes these agreements possible is that closing the doors to economic migrants is not free. An immigrant-receiving country can only maintain its income differential with an emigrant-sending country by imposing a cost on those who would otherwise have an incentive to migrate. Enforcement policy accomplishes this goal but it must be financed by the immigrant-receiving country population. Thus, there is a trade-off between letting immigrants in and taxing nationals. Even without decreasing returns to scale in the enforcement technology, the immigrant-receiving country gets to a point where it is preferred to translate part of the enforcement effort to the emigrant-sending country in exchange for accepting more immigrants. From the point of view of the emigrant-sending country, at the margin, there is also a benefit from cooperating in the enforcement of the migration policy of the immigrant-receiving country by taxing its own inhabitants in exchange for a higher number of emigrants leaving their own country.

The decentralized equilibrium does not reach this optimal solution because countries do not internalize the effect of their migratory policies on other countries. When the immigrant-receiving country decides to restrict migration flows unilaterally, it restricts them too much and thus taxes its own citizens too much because it does not take into account how its action hurts the emigrant-sending country. The fact that there are economic gains from migration makes the cooperative solution, in which the overall level of migration is higher, a Pareto improvement.

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A Central Planner Solution

Remember that the objective function for the central planner is:

$$W = (1+l)\,W^A + (1-l)\,W^B$$

Concentrate on the derivative of the objective function with respect to the level of legal migration:

$\frac{dW}{dl} = W^A + (1+l)\,\frac{dW^A}{dl} - W^B + (1-l)\,\frac{dW^B}{dl}$

One of the assumptions is that the migration equilibrium equation is active as long as: $W^A - W^B > 0$. As for the rest of the expression:

$(1+l)\,\frac{dW^A}{dl} + (1-l)\,\frac{dW^B}{dl} =$

$= (1+l)\left(\frac{\partial W^A}{\partial l} + \frac{\partial W^A}{\partial i}\frac{di}{dl}\right) + (1-l)\left(\frac{\partial W^B}{\partial l} + \frac{\partial W^B}{\partial i}\frac{di}{dl}\right)$

We need to compute $\frac{di}{dl}$, using the implicit function theorem on the migration equilibrium equation:

$\frac{di}{dl} = -\frac{\frac{\partial W^A}{\partial l} - \frac{\partial W^B}{\partial l}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} = -1$ since $\frac{\partial W^A}{\partial l} = \frac{\partial W^A}{\partial i}, \frac{\partial W^B}{\partial l} = \frac{\partial W^B}{\partial i}$ by assumption.

Thus:

$(1+l)\,\frac{dW^A}{dl} + (1-l)\,\frac{dW^B}{dl} = (1+l)\left(\frac{\partial W^A}{\partial l} - \frac{\partial W^A}{\partial i}\right) + (1-l)\left(\frac{\partial W^B}{\partial l} - \frac{\partial W^B}{\partial i}\right) = 0$

As we know that $W^A > W^B$ This implies $\frac{dW}{dl} > 0$, which in turns implies that there is no interior solution for the legal migration quota. Since $\frac{dW}{dl}\left(0, t^A, t^B\right) > 0$, the solution cannot be at $l = 0$. As a result, the solution to the central planner problem is at the other corner: $l^* = 1$, because we have normalized country B's population to 1. This makes unnecessary any enforcement effort so that the central planner solution is: $l^* = 1; t^{A*} = t^{B*} = 0$

This is the case as long as $W^A > W^B$. However, there could be a level of legal migration that equates both countries' welfare (since migration from A to B has been ruled out), the level that solves:

$W^A(l', 0, 0) - W^B(l', 0, 0) = 0$

$l^* = l'; t^{A*} = t^{B*} = 0$ would then be the solution as long as $l' < 1$.

B Proof of proposition 1

The unilateral Nash solutions do not generally coincide with the optimal solution.

Proof. The unilateral solutions are obtained by maximizing the welfare functions of both countries, taking into account the migration equilibrium equation that defines the level of illegal migration: $i\left(l, t^A, t^B\right)$. In the case of country A, the Lagrangian is the following:

$$\mathcal{L}^A = W^A + \lambda_1^A t^A + \lambda_2^A l + \lambda_3^A (1 - l)$$

The Kuhn-Tucker conditions are:

$$\begin{aligned}
\frac{\partial \mathcal{L}^A}{\partial t^A} &= \frac{dW^A}{dt^A} + \lambda_1^A = 0 \\
\frac{\partial \mathcal{L}^A}{\partial l} &= \frac{dW^A}{dl} + \lambda_2^A - \lambda_3^A = 0 \\
\lambda_1^A t^A &= 0; \qquad \lambda_2^A l = 0; \qquad \lambda_3^A (1 - l) = 0 \\
\lambda_1^A &\geq 0; \qquad \lambda_2^A \geq 0; \qquad \lambda_3^A \geq 0 \\
t^A &\geq 0; \qquad 1 \geq l \geq 0
\end{aligned}$$

For country B, the Lagrangian and the first order conditions of the unilateral problem are:

$$\mathcal{L}^B = W^B + \lambda_1^B t^B$$

$$\begin{aligned}
\frac{\partial \mathcal{L}^B}{\partial t^B} &= \frac{dW^B}{dt^B} + \lambda_1^B = 0 \\
\lambda_1^B t^B &= 0 \\
\lambda_1^B &\geq 0 \\
t^B &\geq 0
\end{aligned}$$

Remember that the central planner solution was $l^* > 0, ; t^{A*} = t^{B*} = 0$.

Does this satisfy the first order conditions of the Nash problem?

Focusing on country A, it must be the case that:

$\frac{dW^A}{dl} + \lambda_2^A - \lambda_3^A = 0$

Since $l^* > 0$, then $\lambda_2^A = 0$. There are two possible situations: $l^* = 1$ or $l^* < 1$.

If $l^* = 1$, then $\lambda_3^A = \frac{dW^A}{dl} \geq 0$ should be satisfied.

$\frac{dW^A}{dl} = \frac{\partial W^A}{\partial l} + \frac{\partial W^A}{\partial i} \frac{di}{dl}$

Since $l^* = 1$, the migration equilibrium equation is not active so:

$\frac{dW^A}{dl}(1,0,0) = \frac{\partial W^A}{\partial l}(1,0,0) < 0 \qquad$ by assumption

This contradicts the first order condition: $\lambda_3^A \geq 0$

The remaining possibility is that $l^* = l' < 1$. In that case $W^A(l',0,0) - W^B(l',0,0) = 0$ so that there is no incentive for further legal or illegal migration. Still, we have to consider the first order condition:

$\frac{dW^A}{dl} + \lambda_2^A - \lambda_3^A = 0$

Since $0 < l' < 1 \Longrightarrow \lambda_2^A = \lambda_3^A = 0$

It must be the case that $\frac{dW^A}{dl}(l',0,0) = 0$

To see this:

$\frac{dW^A}{dl} = \frac{\partial W^A}{\partial l} + \frac{\partial W^A}{\partial i} \frac{di}{dl} = \frac{\partial W^A}{\partial l} - \frac{\partial W^A}{\partial i} = 0$

In fact, any $0 \leq l \leq l'$ would satisfy this condition.

The next step is to focus on the other first order condition:

$\frac{dW^A}{dt^A} + \lambda_1^A = 0$

$\frac{\partial W^A}{\partial t^A} + \frac{\partial W^A}{\partial i} \frac{di}{dt^A} + \lambda_1^A = 0$

Using the implicit function theorem, we can compute $\frac{di}{dt^A}$:

$\frac{di}{dt^A} = -\frac{\frac{\partial W^A}{\partial t^A} - \frac{\partial W^B}{\partial t^A} - k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} = \frac{-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} < 0$

because $\frac{\partial W^A}{\partial t^A} < 0, \frac{\partial W^A}{\partial i} < 0, \frac{\partial W^B}{\partial i} > 0$ and $k\frac{g'(e)}{(1-g(e))^2} > 0$ since all the elements in the expression are positive. Plugging in the value of this derivative:

$\frac{\partial W^A}{\partial t^A} + \frac{\partial W^A}{\partial i} \frac{di}{dt^A} + \lambda_1^A = 0$

$\frac{\partial W^A}{\partial t^A} + \frac{\partial W^A}{\partial i} \frac{-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} + \lambda_1^A = 0$

$\frac{\frac{\partial W^A}{\partial t^A}\left(\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}\right) + \frac{\partial W^A}{\partial i}\left(-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}\right)}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} + \lambda_1^A = 0$

$\frac{-\frac{\partial W^A}{\partial t^A}\frac{\partial W^B}{\partial i} + \frac{\partial W^A}{\partial i} k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} + \lambda_1^A = 0$

$\lambda_1^A = \frac{\frac{\partial W^A}{\partial t^A}\frac{\partial W^B}{\partial i} - \frac{\partial W^A}{\partial i}k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}}$

Evaluating this expression at the assumed equilibrium $(l^*, 0, 0)$:

$\lambda_1^A(l^*, 0, 0) = \frac{\frac{\partial W^A}{\partial t^A}(l^*,0,0)\frac{\partial W^B}{\partial i}(l^*,0,0) - \frac{\partial W^A}{\partial i}(l^*,0,0)kg'(0)}{\frac{\partial W^A}{\partial i}(l^*,0,0) - \frac{\partial W^B}{\partial i}(l^*,0,0)}$

For $(l^*, 0, 0)$ to constitute a Nash equilibrium, it must be the case that $\lambda_1^A(l^*, 0, 0) \geq 0$. This imposes a condition on k.

$\lambda_1^A(l^*, 0, 0) = \frac{\frac{\partial W^A}{\partial t^A}(l^*,0,0)\frac{\partial W^B}{\partial i}(l^*,0,0) - \frac{\partial W^A}{\partial i}(l^*,0,0)kg'(0)}{\frac{\partial W^A}{\partial i}(l^*,0,0) - \frac{\partial W^B}{\partial i}(l^*,0,0)} \geq 0$

Since the denominator is negative by assumption, this implies:

$\frac{\partial W^A}{\partial t^A}(l^*, 0, 0)\frac{\partial W^B}{\partial i}(l^*, 0, 0) - \frac{\partial W^A}{\partial i}(l^*, 0, 0)kg'(0) \leq 0$

$k \leq \frac{\partial W^A}{\partial t^A}(l^*, 0, 0)\frac{\frac{\partial W^B}{\partial i}(l^*,0,0)}{\frac{\partial W^A}{\partial i}(l^*,0,0)}\frac{1}{g'(0)}$

Thus, whenever $k > \frac{\partial W^A}{\partial t^A}(l^*, 0, 0)\frac{\frac{\partial W^B}{\partial i}(l^*,0,0)}{\frac{\partial W^A}{\partial i}(l^*,0,0)}\frac{1}{g'(0)}$, the Nash equilibrium will not coincide with the central planner solution.

q.e.d. ■

C Condition for $\left(l_N = 0, t_N^A > 0, t_N^B = 0\right)$ to constitute a Nash equilibrium

Suppose country B chooses $t^B = 0$. What is country A's best response?

$$\begin{aligned}
\frac{\partial \mathcal{L}^A}{\partial t^A} &= \frac{dW^A}{dt^A} + \lambda_1^A = 0 \\
\frac{\partial \mathcal{L}^A}{\partial l} &= \frac{dW^A}{dl} + \lambda_2^A = 0 \\
\lambda_1^A t^A &= 0; \qquad \lambda_2^A l = 0 \\
\lambda_1^A &\geq 0; \qquad \lambda_2^A \geq 0 \\
t^A &\geq 0; \qquad l \geq 0
\end{aligned}$$

Is it $t^A = 0$?

$\frac{dW^A}{dt^A} + \lambda_1^A = 0$

$\frac{\partial W^A}{\partial t^A} + \frac{\partial W^A}{\partial i}\frac{di}{dt^A} + \lambda_1^A = 0$

$\lambda_1^A = -\frac{\partial W^A}{\partial t^A} - \frac{\partial W^A}{\partial i}\frac{di}{dt^A} \geq 0$

We need $-\frac{\partial W^A}{\partial t^A}(l, 0, 0) - \frac{\partial W^A}{\partial i}(l, 0, 0)\frac{di}{dt^A}(l, 0, 0) \geq 0$

$\frac{di}{dt^A} = -\frac{\frac{\partial W^A}{\partial t^A} - \frac{\partial W^B}{\partial t^A} - k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} = \frac{-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} < 0$

Plugging in this expression:

$-\frac{\partial W^A}{\partial t^A} - \frac{\partial W^A}{\partial i}\frac{-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \geq 0$

$\frac{-\frac{\partial W^A}{\partial t^A}\left(\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}\right) - \frac{\partial W^A}{\partial i}\left(-\frac{\partial W^A}{\partial t^A} + k\frac{g'(e)}{(1-g(e))^2}\right)}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \geq 0$

$\frac{\frac{\partial W^A}{\partial t^A}\frac{\partial W^B}{\partial i} - \frac{\partial W^A}{\partial i}k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \geq 0$

$\frac{\frac{\partial W^A}{\partial t^A}\frac{\partial W^B}{\partial i}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \geq k\frac{\frac{\partial W^A}{\partial i}\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}}$

$k \leq \frac{\frac{\partial W^A}{\partial t^A}\frac{\partial W^B}{\partial i}}{\frac{\partial W^A}{\partial i}\frac{g'(e)}{(1-g(e))^2}}$

In this particular case:

$k \leq \frac{\partial W^A}{\partial t^A}(l,0,0)\frac{\frac{\partial W^B}{\partial i}(l,0,0)}{\frac{\partial W^A}{\partial i}(l,0,0)}\frac{1}{g'(0)}$

We need $k > \frac{\partial W^A}{\partial t^A}(l,0,0)\frac{\frac{\partial W^B}{\partial i}(l,0,0)}{\frac{\partial W^A}{\partial i}(l,0,0)}\frac{1}{g'(0)} > 0$ for $(l,0,0)$ not to be a solution.

What about $l = 0$? Can it be A's best response to $t^B = 0$?

$\frac{dW^A}{dl} + \lambda_2^A = 0$

$\frac{\partial W^A}{\partial l} + \frac{\partial W^A}{\partial i}\frac{di}{dl} + \lambda_2^A = 0$

$\lambda_2^A = -\frac{\partial W^A}{\partial l} - \frac{\partial W^A}{\partial i}\frac{di}{dl} \geq 0$

We need $-\frac{\partial W^A}{\partial l}\left(0,t^A,0\right) - \frac{\partial W^A}{\partial i}\left(0,t^A,0\right)\frac{di}{dl}\left(0,t^A,0\right) \geq 0$

$\frac{di}{dl} = -\frac{\frac{\partial W^A}{\partial l} - \frac{\partial W^B}{\partial l}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} = -1$

$-\frac{\partial W^A}{\partial l} + \frac{\partial W^A}{\partial i} = 0$

Thus, $l_N = 0$ can be the optimal legal migration quota for country A.

Now, why is $t^B = 0$ country B's best response?

The required conditions are $\frac{dW^B}{dt^B}\left(0,t_N^A,0\right) + \lambda_{1N}^B = 0$ and $\lambda_{1N}^B \geq 0$. Putting them together:

$\lambda_{1N}^B = -\frac{dW^B}{dt^B}\left(0,t_N^A,0\right) \geq 0$

$\frac{dW^B}{dt^B}\left(0,t_N^A,0\right) = \frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right) + \frac{\partial W^B}{\partial i}\left(0,t_N^A,0\right)\frac{di}{dt^B}\left(0,t_N^A,0\right) \leq 0$

$\frac{di}{dt^B} = -\frac{\frac{\partial W^A}{\partial t^B} - \frac{\partial W^B}{\partial t^B} - k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} = \frac{\frac{\partial W^B}{\partial t^B} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}}$ Ambiguous sign

$\frac{\partial W^B}{\partial t^B} + \frac{\partial W^B}{\partial i}\frac{\frac{\partial W^B}{\partial t^B} + k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \leq 0$

$\frac{\frac{\partial W^B}{\partial t^B}\left(\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}\right) + \frac{\partial W^B}{\partial i}\left(\frac{\partial W^B}{\partial t^B} + k\frac{g'(e)}{(1-g(e))^2}\right)}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} \leq 0$

$\frac{\frac{\partial W^B}{\partial t^B}\frac{\partial W^A}{\partial i} + k\frac{g'(e)}{(1-g(e))^2}\frac{\partial W^B}{\partial i}}{\frac{\partial W^A}{\partial i} - \frac{\partial W^B}{\partial i}} < 0$ since $\frac{\partial W^B}{\partial t^B} < 0$, $\frac{\partial W^A}{\partial i} < 0$, $k\frac{g'(e)}{(1-g(e))^2} > 0$, $\frac{\partial W^B}{\partial i} > 0$ and the denominator is negative as shown above.

This is the required condition because it implies $\frac{dW^B}{dt^B}\left(0,t_N^A,0\right)<0$.

D Proof of proposition 2

If the unilateral solution is of the form $\left(l_N=0,t_N^A>0,t_N^B=0\right)$ *and*

$k>-\frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right)\frac{\left(1-g\left(t_N^A\right)\right)^2}{g'\left(t_N^A\right)}$, *then*

$\exists\left(l_0,t_0^A,t_0^B\right)$ *close enough to* $\left(0,t_N^A,0\right)$ *with either* $l_0>0$ *or* $t_0^A<t_N^A$ *and* $t_0^B>0$ *such that*

$W^A\left(l_0,t_0^A,t_0^B\right)>W^A\left(0,t_N^A,0\right)$ *and* $W^B\left(l_0,t_0^A,t_0^B\right)>W^B\left(0,t_N^A,0\right)$

Proof. Since it has been proved that $\left(0,t_N^A,0\right)$ is not a Pareto optimum, we know that there exists some $\left(l_0,t_0^A,t_0^B\right)$ with $W^A\left(l_0,t_0^A,t_0^B\right)>W^A\left(0,t_N^A,0\right)$ and $W^B\left(l_0,t_0^A,t_0^B\right)>W^B\left(0,t_N^A,0\right)$. We just need to show that $l_0>0$, $t_0^A<t_N^A$ and $t_0^B>0$.

Assume to the contrary that $l_0=0$ and that $t_0^A\geq t_N^A$. We know that:

$\frac{dW^B}{dl}=\frac{\partial W^B}{\partial l}+\frac{\partial W^B}{\partial i}\frac{di}{dl}$

$\frac{\partial W^B}{\partial l}>0$, $\frac{\partial W^B}{\partial i}>0$ by assumption but the third term is:

$\frac{di}{dl}=-\frac{\frac{\partial W^A}{\partial l}-\frac{\partial W^B}{\partial l}}{\frac{\partial W^A}{\partial i}-\frac{\partial W^B}{\partial i}}=-1$

Plugging it into the first expression:

$\frac{dW^B}{dl}=\frac{\partial W^B}{\partial l}-\frac{\partial W^B}{\partial i}=0$

We also know that:

$\frac{dW^B}{dt^A}=\frac{\partial W^B}{\partial t^A}+\frac{\partial W^B}{\partial i}\frac{di}{dt^A}=\frac{\partial W^B}{\partial i}\frac{di}{dt^A}<0$

because $\frac{\partial W^B}{\partial t^A}=0$, $\frac{\partial W^B}{\partial i}>0$ and $\frac{di}{dt^A}=\frac{-\frac{\partial W^A}{\partial t^A}+k\frac{g'(e)}{(1-g(e))^2}}{\frac{\partial W^A}{\partial i}-\frac{\partial W^B}{\partial i}}<0$ from last section.

Then, $W^B\left(l_0,t_0^A,t_0^B\right)\leq W^B\left(l_0,t_0^A,0\right)$ since 0 is country B's best response for any policy country A may undertake in a neighborhood of $\left(0,t_N^A,0\right)$. Remember from last section that $\frac{dW^B}{dt^B}<0$.

$W^B\left(l_0,t_0^A,t_0^B\right)\leq W^B\left(l_0,t_0^A,0\right)\leq W^B\left(0,t_N^A,0\right)$ since $l_0=0$ and $t_0^A\geq t_N^A$ with $\frac{dW^B}{dt^A}<0$. But this contradicts the initial statement $W^B\left(l_0,t_0^A,t_0^B\right)>W^B\left(0,t_N^A,0\right)$. Thus it must be the case that either $l_0>0$ or $t_0^A<t_N^A$.

Once this is established, assume again to the contrary that $t_0^B=0$. We have:

$\frac{dW^A}{dt^B}=\frac{\partial W^A}{\partial t^B}+\frac{\partial W^A}{\partial i}\frac{di}{dt^B}=\frac{\partial W^A}{\partial i}\frac{di}{dt^B}$

We know that $\frac{\partial W^A}{\partial t^B}=0$ and $\frac{\partial W^A}{\partial i}<0$ by assumption. As for the other term, when is $\frac{di}{dt^B}\left(0,t_N^A,0\right)<0$ so that $\frac{dW^A}{dt^B}\left(0,t_N^A,0\right)>0$?

$$\frac{di}{dt^B}\left(0,t_N^A,0\right)=\frac{\frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right)+k\frac{g'\left(e\left(0,t_N^A,0\right)\right)}{\left(1-g\left(e\left(0,t_N^A,0\right)\right)\right)^2}}{\frac{\partial W^A}{\partial i}\left(0,t_N^A,0\right)-\frac{\partial W^B}{\partial i}\left(0,t_N^A,0\right)}<0\Leftrightarrow$$

$$\frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right)+k\frac{g'\left(t_N^A\right)}{\left(1-g\left(t_N^A\right)\right)^2}>0$$

$$k>-\frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right)\frac{\left(1-g\left(t_N^A\right)\right)^2}{g'\left(t_N^A\right)}$$

which is the established additional condition[10].

Then:

$W^A\left(l_0,t_0^A,t_0^B\right)\leq W^A\left(l_{BR}\left(t_0^B\right),t_{BR}^A\left(t_0^B\right),t_0^B\right)$ where $\left\{l_{BR}\left(t_0^B\right),t_{BR}^A\left(t_0^B\right)\right\}$ is A's best response function.

$W^A\left(l_0,t_0^A,t_0^B\right)\leq W^A\left(l_{BR}\left(t_0^B\right),t_{BR}^A\left(t_0^B\right),t_0^B\right)=W^A\left(l_{BR}\left(t_0^B\right)=0,t_{BR}^A\left(0\right)=t_N^A,0\right)$ since $t_0^B=0$ (but close enough to 0) and $\frac{dW^A}{dt^B}\left(0,t_N^A,0\right)>0$ and continuous in a neighborhood of $\left(0,t_N^A,0\right)$. But this contradicts the initial statement: $W^A\left(l_0,t_0^A,t_0^B\right)>W^A\left(0,t_N^A,0\right)$. So: $t_0^B>0$.

q.e.d. ■

[10]This condition might be redundant as long as $-\frac{\partial W^B}{\partial t^B}\left(0,t_N^A,0\right)\frac{\left(1-g\left(t_N^A\right)\right)^2}{g'\left(t_N^A\right)}<\frac{\partial W^A}{\partial t^A}\left(0,0,0\right)\frac{\frac{\partial W^B}{\partial i}(0,0,0)}{\frac{\partial W^A}{\partial i}(0,0,0)}\frac{1}{g'(0)}$ The right-hand-side expression is the condition on $\left(0,t_N^A,0\right)$ to constitute a Nash equilibrium.