Atoms for Peace, Redux

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Abstract

The likelihood that North Korea possesses nuclear weapons is a clear and present danger to sustained stability in the Korean peninsula. Unfortunately, the traditional notion of "Atoms for Peace" has been a failure in the engagement of the North. In this paper we propose a novel approach to mutual cooperation in energy provision on the Korean peninsula, premised on having North Korea host reactors that deliver energy to South Korea. We establish conditions where there exists a stable, time-consistent equilibrium where the North never finds it in its interest to disrupt energy supplies to the South, and where the South is willing to pay the fixed costs of nuclear plant construction, in exchange for a discounted stream of energy supply from the North.

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> If you took a battery out of a car and just left the battery next to the car, that would not be real disablement because you could just put the battery right back in the car.
>
> *U.S. Assistant Secretary of State*
> *Christopher Hill, October 9, 2007*

1 Introduction

Most observers of world affairs would argue that the issue of stability on the Korean Peninsula is one of utmost concern. The October 2006 test is a confirmation that North Korea—widely regarded as a rogue state in the international system—has the potential to develop usable nuclear weapons and, importantly, the means for their delivery. This presents a clear and present danger to sustained stability on the Korean peninsula.

While sustained cooperation between the DPRK and ROK faces numerous obstacles, the possibility of codependency serves as an untapped vehicle for improved relations. We consider one example of a type of codependency that could sustain cooperation well into the future. Among the many proposals forwarded for engaging North Korea is the idea of "Atoms for Peace," first proposed by then-U.S. President Dwight D. Eisenhower in 1953; essentially, the plan involves the provision of nuclear technology by existing nuclear powers for the purposes of energy generation, in exchange for a relinquishment of indigenous efforts to develop such technology. However, history has not been kind to the idea in its present form: Indeed, North Korea arguably exploited the technology transfer inherent in the program to develop their own nuclear capabilities in the first place. This paper casts a new light on such a proposal by demonstrating that sharing nuclear energy and materials can serve as a means by which cooperation—though not necessarily full disarmament—becomes self sustaining on the Korean peninsula.

The needs for new solutions to the Korean problem are manifestly evident. Recent developments in the six-party talks were nearly scuttled over the issue of energy provision to the North. In particular, the sequencing of denuclearization vis-à-vis energy aid has been a major stumbling block (Yardley & Sanger 2007). Pyongyang has insisted on energy delivery before denuclearization, regarding nuclear capability as the only bargaining chip that brought the rest of the world to the dealing table. The other parties instead have wanted to guarantee the decommissioning of the Yongbyon nuclear facility and a halt to uranium enrichment before providing a "modest" amount of heavy fuel oil (Cooper & Yardley 2007).

The simple inability to sequence the implementation of agreements has plagued cooperation between the mistrusting parties for over a decade. The 1994 Agreed Framework failed when the North made progress on uranium enrichment while the KEDO countries delayed the construction of two light water reactors. The breakthrough agreement on February 13, 2007 initially sputtered out of the gate, as the U.S. reluctantly released USD $25 million from a bank in Macao before the North verifiably shut down its Pyongyang reactor. While some progress was recently made in disabling the Yongbyon 5MW reactor, to a greater extent than during the "nuclear freeze" between 1994 and 2002, there are still plenty of opportunities for North Korea to renege and return to developing material usable for atomic weapons. That is, the DPRK has been reluctant to take actions that would prohibit a return to their plutonium program—such as making the Yongbyon reactor permanently unusable. It also has made little movement on disclosing the details of its proliferation activities or dismantling its uranium program (Kessler 2007). Again, the sequencing of the implementation of the February 2007 agreement has yet to be resolved, as the DPRK will be reluctant to fully give up the bargaining position and security that its weapons afford it.

The primary objective of this paper is to propose an alternative approach to mutual cooperation in energy provision between interdependent states, such as on the Korean peninsula. In particular, we turn the idea of energy provision on its head by suggesting that North Korea, which currently has no existing capabilities for nuclear energy generation, host reactors that deliver energy to South Korea, which currently imports much of its energy. This relationship can be augmented by income transfers from third parties in the international system. In effect, this has the potential to address the concomitant problems faced by each: First, the fear experienced by the North that the South would threaten its energy independence were the reactors located in the South, and second, the need by the South to be assured that the North will not engage in weapons production (while also satisfying its growing energy needs at the minimum cost). We demonstrate that, contrary to the conventional proposal of having the South deliver energy to the North, this approach is more stable in the long run.

Scholars in both political science and economics—especially those studying in the international context—often consider how actors are able to cooperate without external enforcement. Jervis (1978) and others have shown how states merely striving for self-preservation in a system of anarchy find it difficult to cooperate because of the security dilemma. Recent scholarship by Kydd (2005) has shown that mistrust—when actors suspect each other of having incentives to renege on an agreement—is a fundamental cause for cooperation failure in international politics. Similarly, in bargaining models of war, the inability for actors to credibly commit to their promises is a barrier to peace (Powell 2004, 2006). We propose an arrangement that could be made between the DPRK and the ROK to overcome the commitment barriers and enable long-term cooperation between the two neighbors. The security dilemma on the Korean peninsula is stronger than perhaps anywhere else on the globe—after years of mistrust, failed peace initiatives, and the potential for devastating attacks from each side. While sustainable cooperation will be difficult, we propose an arrangement that could be in both sides' best interests and could open the door to additional future cooperation.

In addition to its long-run sustainability, our approach sidesteps the tricky issue of sequencing and energy aid. Since nuclear energy production is a rational response that substitutes weapons production, there is no immediate need for delivery of alternative energy, or for the closure of nuclear power plants *per se* (centrifuge facilities, however, would have to be shut down).

The analysis here does not pretend to envision an easy solution to DPRK disarmament. Indeed the relevant cooperation realistically only involves a halt to further weapons production and not necessarily the abandonment of previously developed arms. While we are of the view that long-run denuclearization in the context of the NPT regime is both desirable and feasible, we regard this goal as a long-run diplomatic effort that is distinct from energy codependency. Indeed, the greater normalization of relations between the DPRK and the ROK through energy codependence may serve as a stepping stone that enhances the prospects of such long-run goals. Kydd (2005) treats trust building as a process that requires repeated demonstrations of compliance, so cooperation over energy provision has the potential to lead to cooperation over disarmament.

Nor is our approach limited to either energy codependency or the Korean peninsula. Mutually beneficial economic cooperation between North and South Korea that shares some features of the logic presented here has already been attempted in the form of Special Economic Zones (SEZs), considered below. Energy codependency is also a potential option to stabilize contentious relations in South Asia and the Middle East. Since the model is extended to consider the role of third parties, the analysis is additionally able to demonstrate the means by which outside actors, negatively affected by these conflicts, can be stabilizing forces instead of stumbling blocks.

Our approach is premised on game theory. We set up a model where both the North and the South have energy needs, but that of the South exceeds its capacity for new plant construction. Moreover, energy generation is possible in both countries, although due to input cost differentials, it is more economical to generate energy in the North. We then allow for each country to make their optimal decisions concerning new investment versus increased production (for the South), and energy provision versus weapons development (for the North).

The timing of the game is as follows. In the first stage, the South decides whether or not to engage in the fixed cost of investment in the construction of nuclear energy facilities in the North. In the second stage, the North decides on the optimal amount of energy to produce, given its own needs as well as any that is transferred to the South. In deciding on this, it weighs the net benefits of energy production against the net benefits of weapons production. In the final stage, any energy that is produced for delivery to the South is transferred. We establish conditions where there exists a stable, time-consistent equilibrium where the North never finds it in its interest to disrupt energy supplies to the South, and where the South is willing to pay the fixed costs of nuclear plant construction, in exchange for a discounted stream of energy supply from the North.

The remainder of the paper is structured as follows. Section 2 describes the current problems plaguing cooperation witnessed in the failure of the Agreed Framework and the six-party talks. Section 3 develops the formal model, as well as our central result (Proposition 1). This is followed by a discussion of the model's main findings (Section 4), as well as its policy implications (Section 5). A final section concludes.

2 Problems with the Status Quo

The Agreed Framework between the United States and the Democratic People's Republic of Korea, signed in 1994, was plagued by problems since its inception. The six-party talks that arose after the collapse of the Framework in 2002 have tried to both engage and pressure Pyongyang into compliance with very limited success.

It would appear that energy aid is a key to the prospects of success. Free oil from the U.S. and South Korea has consistently been dangled in front of the North in exchange for a halt to its weapons program, but such cooperation has proven unsustainable. After discovering the DPRK's uranium program in October of 2002, the U.S. refused to send any more oil shipments, which led the North to unfreeze its plutonium production and expel IAEA inspectors. While the exchange of energy for a nuclear freeze had endured for eight years, it could not last longer as both sides had fears of being exploited.

The success of the February 2007 agreement hinges on the provision of energy aid to the DPRK in exchange for verifiable disabling of its nuclear program. From the perspective of the U.S. and the South, the egregious past violations of international and bilateral agreements cast a pall over any confidence that the North will do what it promises. If they deliver oil to the North, there is little guarantee that it will not continue to make progress on its uranium enrichment or weapons development. From the perspective of the North, complete dismantling of its uranium and weapons programs would make it vulnerable to exploitation. Once the DPRK disarms or permanently disables its fissile material production capability, there is much less reason for the U.S. and the South Korea to follow through on their provision of oil or to not attempt regime change.

The ongoing failure is perhaps best understood in the context of a hypothetical setup, shown in Figure 1 in normal form. This is the well-known prisoner's dilemma in which cooperation is actually an irrational strategy and unsustainable in equilibrium.

		US	
		D	ND
DPRK	NP	c, c	a, d
	P	d, a	b, b

Figure 1: Hypothetical payoff matrix for Agreed Framework.

Let the United States (North Korea) play the strategies represented by columns (rows), and let the payoffs be ranked ordinally as $d > c > b > a$ (with

DPRK payoffs listed first). The strategies available to the United States are to deliver (D) or not (ND), while North Korea can choose to produce weapons (P) or not (NP). The payoffs may be justified as follows: Given that the DPRK chooses not to produce weapons, the U.S. can experience a higher payoff (d) by choosing not to deliver the promised energy to the North, since delivery would entail incurring the costs of energy provision (yielding a lower payoff c). If the DPRK chose instead to produce, the U.S. could continue with delivery (for the worst possible payoff a), but this is clearly inferior to simply not delivering as a result of the violation of the agreement (payoff b, which is in turn less preferred to the situation where the North did not renege at all). We can rationalize the payoffs for the DPRK in a similar fashion.

In the simultaneous move game, the (Nash) solution is for North Korea to produce weapons while the United States chooses not to deliver the energy (P, ND). This is, in fact, the current status since 2002. Embedded in our assumed payoff structure is the classic Prisoner's Dilemma setup: With neither side willing to accept the sucker's payoff, the temptation to renege on any agreement is simply too high. While informational asymmetries coupled with a repeated play nature of the game may potentially offer the possibility of cooperation (Kreps, Milgrom, Roberts & Wilson 1982), the likelihood of collapse is very much an inherent component of the Framework. In fact, the final breakdown of the agreement could be attributed, in part, to the continual insistence by the DPRK of its right to maintain nuclear enrichment facilities (which can potentially be used for clandestine nuclear weapons production), while North Korea blames the U.S. for delaying fuel supplies.

To further understand why timing issues have been such a stumbling block, imagine, instead, if the United States had first-mover advantage in the sequential game, as shown in Figure 2 in extensive form. Now, if the United States were to somehow commit to delivery in the first stage (thus moving down the left branch of Figure 2), the rational choice for North Korea is to simply choose to produce weapons. While this outcome must involve irrational behavior on the part of the U.S. (which would rule it out in any stable solution), it is not difficult to see why timing issues are as contentious as they are. Similarly, if the North went first and permanently dismantled its programs, the US would have little incentive to follow through on the provision of energy.

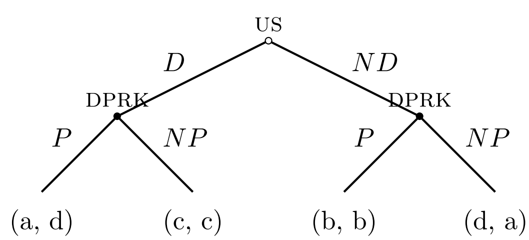

Figure 2: Hypothetical sequential game for Agreed Framework.

Given the current *status quo*, these issues are not likely to go away. Unless there is a rethinking of the process of nuclear energy delivery vis-à-vis weapons production, the six-party process appears to be setting itself up for a similar outcome. We develop an alternative framework to promote cooperation on the peninsula. The focus is on the exchange of energy and investment between the North and the South, but we will consider implications to non-proliferation as both a direct and indirect consequence of the cooperative equilibrium.

3 Energy Codependency as a Credible Assurance

3.1 The Baseline Model

The environment is comprised of two states, the North (N) and the South (S). The South seeks to choose optimal amounts of investment in nuclear energy facilities in the North, I, against increased energy consumption using existing facilities in both the North and South, E_S:

$$\max_{\hat{E}_S, I} U_S\left(I, E_S\right), \tag{1}$$

where the total quantity of energy consumption is given by

$$E_S = \hat{E}_S + \alpha E_N, \tag{2}$$

with $0 \leq \alpha \leq 1$ being the fraction of total energy produced by the North, E_N, which is delivered to the South, and $\hat{E}_S$ is indigenous production of energy in the South.[1] In addition to (2), the South faces a resource constraint limited by total income, Y_S:

$$P_{E_S}\hat{E}_S + P_I I \leq Y_S, \tag{3}$$

where P_{E_S} and P_I are the prices of energy in the South and investment, respectively. In contrast, the North has an objective function that comprises (nuclear) weapons, W, and energy consumption, E_N:

$$\max_{\hat{E}_N, W} U_N\left(W, E_N\right), \tag{4}$$

which is in turn subject to a resource constraint given by

$$D \cdot P_{E_N} E_N + P_W W \leq Y_N\left(K\right), \tag{5}$$

where prices of energy and weapons are given by P_{E_N} and P_W, respectively, and income in the North (Y_N) is a function of the accumulated stock of investment capital, K. The variable D is a binary that takes on the values:

$$D = \begin{cases} 1-\alpha & \text{if delivery occurs,} \\ 1 & \text{otherwise,} \end{cases} \tag{6}$$

[1] Indigenous energy includes energy imported from elsewhere.

where the decision to deliver is determined by an infinitely repeated interaction between the North and South with the South choosing an investment stream $\mathbf{I} = \{I_t\}_{t=0}^{\infty}$, and the North choosing a share $\boldsymbol{\alpha} = \{\alpha_t\}_{t=0}^{\infty}$, with time discounted by the factor $0 \leq \delta \leq 1$. In doing so, the South plays a simple reversion strategy such that

$$I_t = \begin{cases} \hat{I}_t & \text{if } \alpha_{t-1} > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

The North, in contrast, chooses to deliver when the present discounted value of energy flows with delivery to the South exceeds that with no delivery; more formally, when

$$\sum_{t=0}^{\infty} \delta^t \left(1-\alpha\right) P_{E_N,t} E_{N,t}\left(K_t\right) \geq \sum_{t=0}^{\infty} \delta^t P_{E_N,t} E_{N,t}\left(K_1\right),$$

where $K_{t+1} = K_t + I_t$ is the accumulated stock of (physical reactor) capital at time $t+1$, and $K_0 = 0$. Note that energy production in the North at any given point in time is a function of this capital stock.

The sequence of events is as follows: (a) The South chooses the optimal quantities of investment and energy consumption, subject to both constraints in both energy (2) and resource (3); (b) The North decides on the optimal amount of energy consumption and weapons production, given its own resource constraint (5); (c) Energy that is produced for delivery to the South is transferred for each period into the indefinite future. The timing assumptions are summarized as Figure 3.[2]

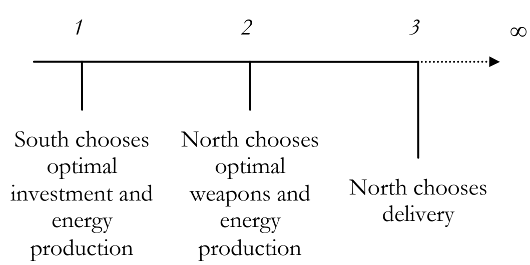

Figure 3: Sequence of events.

In order to obtain closed-form solutions, we make several assumptions about functional forms. In particular, let (4) be represented by a linear additive function

$$U_N\left(W, E_N\right) = \beta W + \left(1-\beta\right) E_N,$$

and let (1) be represented by the Cobb-Douglas form

$$U_S\left(I, E_S\right) = I^{\chi} E_S^{1-\chi}.$$

[2]Note that we have abstracted from the issue of *payment* for energy delivered to the South. That is, for a given price of Northern energy, the North's decision to deliver is directly contingent on the size of α and not on whether the South pays for the delivered energy.

For computational simplicity, we also make the following assumptions about the investment and delivery decisions.

Assumption 1. (a) Investment in each period is the fixed, positive amount invested in the first period; (b) Energy prices in the North are constant; (c) Energy production displays constant returns to scale in capital.

We are now in a position to state our central proposition.

Proposition 1 (Atoms for peace redux)**.** *Given specific forms for North and South objective functions, and Assumption 1, if*

$$\frac{\beta}{1-\beta} < \frac{P_W}{(1-\delta)\, P_{E_N}},$$

then the optimal investment by the South in the North is given by

$$\hat{I}^* = \frac{\chi}{P_I}\left(Y_S + \frac{\delta}{1-\delta}\frac{P_{E_S}}{P_{E_N}}Y_N\right) > 0. \tag{8}$$

Proof. See appendix. □

The detailed proof of the proposition is given in the appendix. We restrict our discussion here to an intuitive understanding of the derivations.

The stage game is solved by backward induction. In the final stage, the North takes investment and energy production as given and chooses to deliver if and only if the present discounted value of reneging on delivery with no future subsequent investment from the South is less than the present discounted value of continued energy delivery (and hence continued investment by the South). Given our assumptions, this simplifies to a simple condition: $\alpha \leq \delta$, which states that the optimal share of Northern energy delivered to the South is less than the discount factor. At the margin, then, $\alpha = \delta$.

This result is then used in the penultimate stage, where, taking investment as given, the North chooses energy production. Given the linear nature of the objective function for the North, the corner solution results when the slope of the indifference curve exceeds that of the resource constraint. This is the condition given in the proposition.

Substituting these results into the first stage, we obtain the optimal amount of investment by the South, which depends on the elasticity of substitution between investment and indigenous energy production (χ), the ratio of Southern income to the price of investment (Y_S/P_I), the relative price of Southern to Northern energy production (P_{E_S}/P_{E_N}), the discount factor (δ), and Northern income (Y_N). Intuitively, optimal investment is simply the standard Marshallian demand in a Cobb-Douglas-type objective function, adjusted by an expression that is the annuity value of real Northern output, expressed in terms of Southern prices.

The optimal level of investment responds to changes in the costs of energy and investment, as well as the elasticity of substitution between the two, as summarized by the proposition below.

Proposition 2 (Comparative statics)**.** *The optimal investment by the South in the North given by* (8) *is decreasing in the cost of energy in the North,* P_{E_S}*, and the cost of investment,* P_I*, while* (8) *is increasing in the cost of energy in the South,* P_{E_S}*, the elasticity of substitution between investment and indigenous energy production,* χ*, and relative cost of energy,* P_{E_S}/P_{E_N}*.*

Proof. See appendix. □

3.2 The Baseline Model with a Third Party

One significant shortcoming of the baseline model is that it does not take into account the influence of third parties, such as the United States, that have a vested interest in regional stability by bringing about a cooperative outcome. The importance of external factors is not trivial: Some analysts have argued that such outside pressure was critical in overcoming the deadlock in the North Korean case (Sanger 2007). We therefore extend the analysis by allowing for a Third Party (X), with an objective function that seeks to

$$\max_{\tau_t, C_t} \sum_{t=0}^{\infty} \delta_X^t U_X \left(C_t, \epsilon\left(\tau_t\right)\right), \tag{9}$$

where utility is dependent on consumption, C, as well as externality benefits received from sustained cooperation between the North and South, $\epsilon\left(\tau\right)$, which is in turn dependent on a stream of real transfers $\boldsymbol{\tau} = \{\tau_t\}_{t=0}^{\infty} > 0$—denominated in terms of units of $E_{N,t}\left(K_1\right)$—offered to induce cooperation. More formally, per period externality benefits are given by

$$\epsilon\left(\tau_t\right) = \begin{cases} \tilde{\epsilon} \cdot \tau_t & \text{if } \tau_t > 0 \text{ and } I_t > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

The transfer changes the decision calculus of the North in making the delivery, as it now tampered by the additional transfer from the Third Party:

$$\sum_{t=0}^{\infty} \delta^t P_{E_N,t} \left[\left(1-\alpha\right) E_{N,t}\left(K_t\right) + \tau\right] \geq \sum_{t=0}^{\infty} \delta^t P_{E_N,t} E_{N,t}\left(K_1\right),$$

so that the incentive to effect the delivery is now stronger. Finally, the Third Party faces a period resource constraint

$$P_C C + P_{E_N} \tau \leq Y_X, \tag{11}$$

where the price of consumption is given by P_C, and income by Y_X.

The sequence of events is as before, but our setup now includes the related "linked" game (Bernheim & Whinston 1990): This involves the Third Party choosing optimal quantities of consumption and transfer, subject to its resource constraint (11) and taking into account that it receives externality benefits from

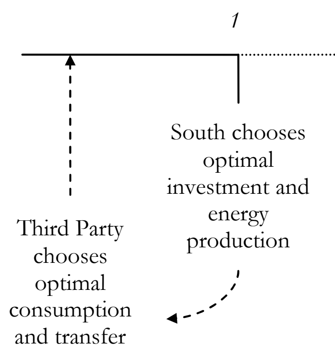

Figure 4: Extended sequence of events.

successful cooperation between the North and the South. The extension to the timing assumptions are summarized as Figure 4.

We once again make functional form assumptions in order to render a closed-form solution. Specifically, let (9) be the linear quadratic

$$\frac{C^2}{2} + \epsilon(\tau) C.$$

As before, we keep the computation simple by making additional assumptions.

Assumption 2. The Third Party fully discounts the future.

We can now state the following proposition.

Proposition 3 (Three-party atoms for peace redux)**.** *Given specific forms for North, South, and Third Party objective functions, and Assumptions 1 and 2, if*

$$\frac{\beta}{1-\beta} < \frac{P_W}{(1-\tau)(1-\delta) P_{E_N}},$$

and

$$\tilde{\epsilon} > \frac{Y_X/P_C - 1}{Y_X/P_{E_N} - 2},$$

then the optimal investment by the South in the North is given by

$$\hat{I}^{*\prime} = \frac{\chi}{P_I}\left(Y_S + \frac{\delta + \tau(1-\delta)}{(1-\tau)(1-\delta)} \frac{P_{E_S}}{P_{E_N}} Y_N\right) > 0. \tag{12}$$

Proof. See appendix. □

The steps of the proof are analogous to that of Proposition 1. The distinction here is that we solve a parallel linked (sub)game, and require that both are in (Nash) equilibrium. We again restrict the discussion of the proof to an intuitive level.

The two subgames are solved separately, taking as given the outcome of the other being optimal. For the Third Party, the optimization is an allocative choice between consumption goods and the transfer, conditioned on successful cooperation between the North and South. This transfer is then taken as given in the modified stage game between the North and South.

The stage game between the North and South is solved, as before, by backward induction. The final stage, conditioned on a transfer from the Third Party, now has the North now taking investment, energy production, and the transfer as given and choosing to deliver if the present discounted value of energy after reneging is less than the present discounted value of the *sum* of both continued energy delivery and the transfer to induce cooperation. Simplifying, we now have $\alpha^* \leq \delta + \tau(1-\delta)$, which adjusts the condition of the baseline model by $\tau(1-\delta)$.

The rest of the proof proceeds with this new condition, which modifies both the condition of the original proposition, as well as the optimal level of investment by the South (which as before is positive in equilibrium). This positive level of investment, which indicates cooperation, is then taken as given in Third Party decision making. This investment is affected by the size of the transfer, as summarized in the proposition that follows.

Proposition 4 (Comparative statics)**.** *The optimal investment by the South in the North given by* (12) *is increasing in the size of the transfer, τ.*

Proof. See appendix. □

4 Comments on the Codependency Model

The baseline result of our paper (Proposition 1) is an equilibrium level of investment that is positive. Hence, as long as the condition in the proposition is satisfied,[3] it is possible for the two countries to sustain a peaceful relationship based on mutual codependence.

What does this condition mean? Essentially, it requires that the present value of the relative price of weapons to energy be sufficiently large. To see this, suppose that the North places an equal weight on weapons and energy production ($\beta = 0.5$). In this case, the condition simplifies to

$$\frac{P_W}{P_{E_N}} > 1 - \delta$$

which, for reasonable values of the discount rate δ, requires that the price of weapons be so much larger than that of energy so as to discourage the allocation resources to its production altogether. In other words, the incentive to produce weapons can be severely diminished by either raising the price of weapons or

[3]There is, actually, an additional condition that is implicit in our solution of the model: That $\alpha \leq \delta$, or that the optimal share of Northern energy delivered to the South is less than the discount factor. This is likely to be satisfied for most reasonable values of the discount factor.

lowering the price of energy.[4] Intuitively, the North cannot *afford* to produce weapons when the opportunity cost of not devoting resources to the energy sector is so large.

Interestingly, this result suggests that the South (or another entity) can actually induce its own continued participation in the game by somehow subsidizing energy production in the North; this lowers the price of energy there and hence raises the relative price between the two. Such a subsidy, in turn, sustains a cooperative equilibrium with continued investment by the South. While we have not worked out the mechanics of such a subsidy, the model provides some basis for understanding why it may be in the best interest of the South to help the North in building and designing its nuclear energy program.[5]

Another way to interpret this condition is that the relative price of weapons has to be raised. How can this be done? Recent advances in the design of compact liquid metal reactor technology offer the promise of largely exploitation-proof reactors (Fahlen, Kim & Lyles 2007). Such "protected" reactor designs implicitly raise the cost of acquiring unprocessed nuclear material for the purposes of enrichment, and has the additional benefit of allaying concerns over the potential abuse of civilian reactors.

The optimal amount of investment in equilibrium is positive even when prices are equal, as clearly illustrated by the example below.

Example 1. Consider the special case where the price of investment and energy in both the North and the South are equivalent and normalized to unity ($P_I = P_{E_N} = P_{E_S} = 1$). Equation (8) simplifies to

$$\hat{I}^* = \chi \left(Y_S + \frac{\delta}{1-\delta} Y_N \right) > 0,$$

which is still positive. Therefore, the optimal amount of investment in this case is simply the sum of Southern and (the annuity value of) Northern output, weighted by the elasticity of substitution.

This special case illustrates the fact that the crucial relative price that is relevant to the problem is not that of energy between the South and the North (P_{E_S}/P_{E_N}) (although, as discussed in Proposition 2, this is increasing), but that of weapons and Northern energy prices (P_W/P_{E_N}).

In our simple setup, weapons and energy are treated as perfect substitutes by the North. While this assumption allows for a more tractable model, there are technological, economic, and political reasons why this is also not too far from reality. To extract plutonium from the Yongbyon reactor, it has to be

[4]It is important to realize here that we have taken these prices as exogenous. While this is clearly a simplification of reality, the point is that a stable equilibrium is attained by sufficiently high relative prices.

[5]One important consideration is how the subsidy, if offered by the South, would alter the net benefits from cheaper energy production in the North. This would, ultimately, be an empirical issue, especially if there is a nonpecuniary benefit from the South's investment to begin with. Alternatively, we could posit a subsidy offered by an external party, such as the United States or Japan, which has a vested interest in the stable equilibrium outcome.

temporarily shut down, since the more proliferation-resistant next-generation nuclear make it much more infeasible to have a fully functioning energy reactor that can simultaneously be exploited for weapons-grade fuel. Such activity can easily monitored.

In addition, making weapons out of plutonium carries the opportunity cost that the plutonium cannot be used for energy production. If the economic returns from energy sales exceeds the monetized benefits of weapons, then energy production would be the economically rational course of action. Finally, if we ultimately regard nuclear weapons as a source of political power, it is entirely possible that the North will regard their control of the energy needs of the South's as an equally—if not more—desirable substitute source of such power.

Does relaxing this assumption, however, allow for the possibility that the South's investment may be diverted into weapons production? Not necessarily. Since the South plays a simple reversion strategy—see (7)—undertaking such an action would mean that the North effectively chooses nondelivery ($\alpha = 0$) in the next period. This would then cause the entire equilibrium to unwind, which, of course, does not occur as long as the condition in Proposition 1 is fulfilled.[6]

Another issue with the model is that, by including investment as an argument in the objective function of the South, we have implicitly assumed that the South has an incentive to invest in the North. In order to guarantee such an outcome, however, we would need to extend the setup to allow for either sufficiently large input cost differentials—mainly wage differentials—or nonpecuniary targets, such as a desire in the South for rapprochement and reunification with the North.

This is less of an issue in practice, since the South has already demonstrated a willingness to invest in civilian nuclear energy facilities in the North. Indeed, the ROK currently has almost $1 billion sunk into the construction of two 1,000 MWe light-water reactors located on the DPRK's eastern coast (Uranium Information Centre 2007).

Our extension of the model to include a Third Party is motivated by both theoretical and empirical considerations. There is a body of theoretical work that suggests that strategies tied across two separate games or "domains" can successfully enforce endogenous cooperation (see, for example, Aoki (2001)). Empirically, we also observe external parties being actively involved in bringing about cooperative behavior in international relations. In the context of the Korean Peninsula, for example, the United States has been involved as a third party in nuclear issues since the 1980s.

The main decision-making process for the Third Party is to optimize between consumption goods and the transfer to the North. This transfer is not

[6]In addition, our results are not critically sensitive to this stylized representation. A richer (but more complicated) setup would allow imperfect substitutability, but set the reversion strategy such that the minimal delivery share is a lower bound $\underline{\alpha}$ (chosen to ensure zero weapons production). Alternatively, by treating weapons and energy production as tradable, substitute sources of political power, specialization in the production of energy is an entirely possible outcome even with a Cobb-Douglas style production function (so long as the opportunity costs of economic power are lower than that of military power). This is just an application of the principle of comparative advantage.

made for altruistic reasons, however: A positive transfer potentially yields externality benefits from successful cooperation between the North and South. We can construe such benefits as arising from either pecuniary sources—such as increased trade flows with the region—or nonpecuniary sources, such as an enhanced sense of peace and security. Therefore, the Third Party has an incentive to make the transfer only when two conditions are fulfilled: First, when cooperation is successful, since—by (10)—these benefits only materialize when there is successful cooperation; and second, when making the transfer raises net welfare.

The first of these two will be satisfied in any stable (Nash) equilibrium. The second, however, requires that the externality multiplier be sufficiently large. The size of this multiplier, in turn, is related to the income of the Third Party (Y_X) and relative prices of consumption (P_C) to the transfer (which, recall, is in terms of P_{E_N}). More specifically, the threshold size of the externality coefficient in the second condition of Proposition 3 is decreasing in the relative price, as can be seen from the following example.

Example 2. Let $Y_X = 10$ and $P_{E_N} = 1$, and let $P_C \in [0.2, 200]$. The threshold levels of the externality coefficient are then given by

$$\tilde{\epsilon} > \frac{10/P_C - 1}{10/P_{E_N} - 2}.$$

Table 1: Selected threshold values of the externality coefficient.

Y_X	P_C	P_{E_N}	$\frac{P_C}{P_{E_N}}$	$\tilde{\epsilon}$
10	0.2	1	0.2	6.125
10	1	1	1	1.125
10	2	1	2	0.500
10	10	1	10	0.000
10	20	1	20	-0.063
10	200	1	200	-0.119

Using numerical methods, we obtain the range of values of $\hat{\epsilon}$ and corresponding values of the relative price (of consumption to transfers). These values are summarized in Table 2, and the accompanying graph plots the relationship (note that the horizontal axis has a discrete break).

The externality coefficient is clearly decreasing in the relative price. This is intuitive: When the price of consumption is high, the Third Party can raise its welfare by simply substituting away from consumption goods toward the transfers, which indirectly raise welfare through increasing the externality benefits received. Therefore, when relative prices are large, we require a smaller critical value of this coefficient in order for a given amount of transfer to yield the benefit.

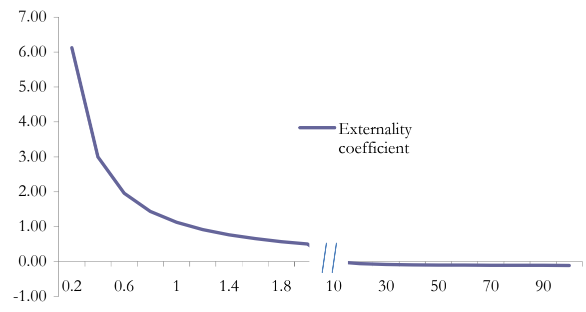

Figure 5: Threshold values of the externality coefficient.

This example illustrates more clearly how externality spillovers may potentially affect Third Party willingness to make the transfer. This depends, in large part, on relative prices between consumption and transfers. If this value is small, the multiplier effect of the externality coefficient needs to be much larger. But even for reasonable values of relative prices—say, for relative prices greater than two—the size of the externality coefficient becomes relatively negligible.[7]

The relative price of two (or greater) holds additional significance. When relative prices are at least double, the externality coefficient responds positively to the income of the Third Party. More precisely, the derivative of $\hat{\epsilon}$ with respect to Y_X is[8]

$$\frac{d\tilde{\epsilon}}{dY_X} = \frac{1/P_{E_N} - 2/P_C}{(Y_X/P_{E_N} - 2)^2},$$

which is positive when $P_C > 2P_{E_N}$, or when relative prices are at least double. This means that (economically) larger Third Parties, such as the United States and Japan, will be more likely to effect the transfer when the relative price of consumption is *small*. This is intuitive: When the opportunity cost of direct consumption of goods is reasonably small, a large country would be more willing to "invest" in a transfer in order to reap externality benefits. Once this becomes too large, it makes more sense to devote resources toward the direct benefits of consuming goods.

What role does the transfer play insofar as the North and South is concerned? The transfer makes cooperation more likely by lowering the incentive to deviate from the cooperative strategy. This translates to a lower relative price of weapons to energy required to support cooperation. This is seen most clearly by considering the first condition listed in Proposition 3, which is re-

[7]In fact, as evident in Figure 5, the threshold level of the externality coefficient falls rapidly as relative prices approach unity. The coefficient remains small, but positive, for values above two and falls below zero when $P_C = 10$ (as expected, since $Y_X = 10$). While these values are dependent on the specific parameterization assumptions of the numerical solution, the qualitative nature of the finding is robust to different parameterizations.

[8]Note that we have used the independence of income and prices to write the partial derivative as the total.

quired for mutual codependence between the North and South (assuming again that $\beta = 0.5$):

$$\frac{P_W}{P_{E_N}} > (1-\tau)(1-\delta).$$

This implies that the requirement that the price of weapons be greater than energy is now moderated by the presence of $(1-\tau)$. Thus, even modest amounts of the transfer would make cooperation much more likely: With $\tau > 1$, the right hand side of the expression becomes negative, and so $P_W > P_{E_N}$ will always be fulfilled (since prices are always positive). The introduction of a Third Party with the ability—and willingness—to make a transfer in order to guarantee cooperation dramatically increases the likelihood of a sustained, cooperative outcome.

5 Codependence in Practice

The idea of codependence as a policy solution to bring about improved relations is not new. However, in the context of a broader nuclear strategy to enhance relations on the Korean peninsula, the role that codependence can play in acting as a credible assurance warrants close consideration.

Considerable debate persists over whether the DPRK should be engaged, contained, or compelled into compliance (Cha & Kang 2003; Laney & Shaplen 2003; Saunders 2003). The DPRK nuclear test has seriously jeopardized the "Sunshine Policy" and threatened the heretofore promising engagement between the North and the South. Kim Dae Jung's original intent of beginning that policy in 1998 was to use the promise of economic cooperation as a means to secure necessary economic reforms in the North and to set the tone for cooperation on more essential security matters (Cha & Kang 2003). The nuclear test, however, appears to have validated the concerns of Sunshine Policy critics. Engagement had not turned North Korea away from confrontational posturing, or toward an embracing of economic reforms. Instead, the skeptics have maintained, the policy has only encouraged intransigence by signaling a lack of resolve to hold the DPRK in check.

The difficulty of engaging North Korea—not just by the ROK, but by the entire international community—has been in maintaining control over where the foreign aid and investment monies are spent. It has been difficult to devise policies that encourage perpetual cooperation that is in the interest of both the North and the South. One potential solution that has some promise is the creation of Special Economic Zones (SEZs) (Park 2004).

Hyundai and many other South Korean firms have already committed to a joint project in developing Kaesong Industrial Park, 6 miles north of the DMZ. These projects have the appeal of combining abundant South Korean capital with cheap North Korean labor. The employment will benefit the DPRK, while ROK companies will enjoy larger profit margins in their manufacturing. The potential for manipulation by the perfidious Pyongyang government is dampened, as the investment dollars are ongoing and, if pulled, will lead to a halt in the project. Isard & Azis (1999) similarly propose that such joint ventures close to the DMZ have the potential to open up cooperation on the entire peninsula.

While the SEZs have the potential to improve cooperation on the peninsula, recent frustrations that led to the expulsion of South Korean workers from these zones have placed their future viability in jeopardy. The SEZs are limited because the wage differential is actually not much greater than that between the ROK and China, and the Pyongyang government has meddled with the labor pool to limit the SEZs' potential productivity (Jung, Young-Soo & Kobayashi 2003). The issue of timing has also not been completely resolved. New ROK president Lee Myung-bak has recently threatened to pull back on these cooperative initiatives if the DPRK does not fulfill its promises made in February 2007 and if progress is not made on the release of ROK POWs and captives. That is, President Lee appears to sense that the DPRK is taking advantage of their cooperative endeavors. Despite the continuous flow of capital and labor in the SEZs, there is still the potential to exploit the timing of the situation. The DPRK can renege on its commitments once the industrial infrastructures are in place and the technological knowhow is passed on to the DPRK collaborators. That is, if the DPRK reaches a point in which it no longer needs the ROK involvement, it has little incentive to abide by the agreed conditions.

These SEZs demonstrate that there is willingness on the part of both sides to attempt cooperative ventures, but they also demonstrate the continuous difficulty of self-sustaining cooperation when either side has the incentive to exploit the timing of the quid pro quo. Building on the tempered promise of these SEZs, we have demonstrated that a similar arrangement, which is even more self enforcing because neither side can exploit the timing, can be arranged with regard to nuclear energy. Just as the ROK economy has generated high labor prices that makes low-wage DPRK labor attractive, the ROK economy demands a substantial amount of energy that would make cheap DPRK energy attractive. Currently, the ROK is one of the leading petroleum importers in the world. To meet its energy demands, it is expanding its nuclear energy production facilities, but space for siting reactors remains a premium due the dense population. Given the availability of land in the North and the proximity of Seoul to the border, using Northern reactors for Southern energy has the potential for mutual gains in efficiency.

By investing in nuclear power plants just north of the border, and running the initial power lines south, the ROK can gain access to energy, for which it has a high demand. Since the power lines would be running south and the backward infrastructure is such that the DPRK cannot easily tap into the power, the DPRK would only be able to benefit if it keeps the power on. The timing problem is minimized because, without the necessary infrastructure of an adequate power grid, the DPRK cannot benefit from coopting the nuclear reactor(s) and running them without ROK involvement. Even when the North can tap into the new power flows, the corresponding decrease in energy prices for the North will enhance the mutual benefits of cooperation. In addition, the proliferation resistance of the next-generation reactors and the fact that the DPRK already has a history of using nuclear reactors means that there is little in the transfer for the

DPRK to exploit. The ROK is not supplying material that could be weaponized, nor are they providing knowledge that the DPRK does not already have.

The DPRK will also be able to stay true to its ideology of *Juche* and not be too beholden to foreign governments. Since the power plants are in the North, it actually has some non-trivial amount of leverage to hold the ROK in check. That is, the DPRK can always turn the power off if it feels unfairly treated. The ROK in turn will simply stop its flow of investments and return to the *status quo* sources of energy if the North fails to deliver. While such a turn of events would cause a loss in the sunk costs of constructing the reactors, that burden can be shared by the international community.[9]

Beside posing the mere possibility of cooperation, the model has suggested specific mechanisms to ensure that the proposed framework succeeds. Once the reactors are built, the South could further offer a subsidy to keep the price of energy low in the North. This would maximize the amount of energy that the North delivers to the South and minimize the incentives to produce weapons. In addition, the international community can insist that the reactors built in the North are proliferation-resistant. The more difficult it is to extract weapons-grade material from spent fuel, the more exchanging energy for investment looks more attractive. While this may be common sense, it is worth emphasizing that the reactor technology has improved since 1980, when the DPRK started constructing the proliferation-enabling Yongbyon reactor.

As an extension to the baseline model, we have considered the role that third parties can play in sustaining cooperation on the peninsula to further encourage the bilateral cooperation. Foreign interests, especially related to U.S. and Japanese actions, have tended to destabilize tensions in the recent past. Here, we propose that it is possible for third parties such as the U.S. and Japan to sweeten the pot for the North by providing income transfers. While the model only demonstrates that such an equilibrium is possible, we can derive some practical policy approaches. Since there is likely to be political opposition to direct income transfers to a vilified DPRK, an indirect transfer mechanism would have the U.S. look the other way in response to its counterfeiting activities. Presumably this is what occurred when the U.S. authorized the release of $25 million from a bank in Macao (Choe 2007). Of course, stepping up economic aid is probably the best option—if feasible domestically—to avoid any acquiescence of illegal activity.

The main point of the extension is to show that the incentives for cooperation on the Korean peninsula need not be isolated to the Korean peninsula. Outside actors can encourage the exchange of energy. Moreover, the international community need not promote cooperation for purely altruistic reasons.

[9]The typical capital costs for a Generation III 1,000 MWe reactor such as an Advanced Boiling Water Reactor (ABWR) is around $2 billion (GE Nuclear Energy 2000). While this figure is not trivial to the ROK and may require additional transfers from third parties, the South will only risk losing this upfront cost for the first reactor. Additional reactors in the North would be constructed from the investment flows modeled here, such that the ROK only provides the capital for more reactors as the DPRK delivers the requisite energy from the first reactor.

As long as there is some gain from positive externalities due to cooperation (or negative ones from noncooperation), there are incentives for the transfers to be made. With the threat of transnational terrorist networks and the prodigious costs a second Korean war would entail, the existence of large externalities is probably not a limiting factor.

Finally, we can derive implications related to non-proliferation. The model is set up such that weapons and energy are perfect substitutes and that energy delivery is impossible if the North does produce nuclear weapons. While such strict constraints might not exist in reality, we have discussed how minor modifications of the model would ensure that no material can be diverted to weapons. These modifications would have added analytical complexity with no real gain in insight. In addition, energy and weapons would demonstrate fairly high elasticities of substitution, since the more the energy the North delivers to the South, the less opportunity there is for weapons manufacturing. Weapons production capabilities will gradually degrade. As a result, cooperation in and of itself will necessarily be good for reducing the North's potential for growing its stockpile, and continued cooperation would sow the seeds for even greater future cooperation.

The outstanding issues of the DPRK's uranium enrichment program and its existing weapons remain unaddressed by the model.[10] This would certainly ask too much at the present time, as elimination of both would leave the North no leverage to ensure the international community adheres to its commitments. Adding a contingency for verifiable dismantling of just the uranium program would be more realistic. The cooperative framework we propose, moreover, will lay the foundation for greater trust. If Kydd (2005) is right in that learning can allow a trustworthy actor to be perceived as such, and if the ROK and its international supporters are in fact trustworthy, then repeated cooperation should decrease the DPRK's sense of vulnerability and resistance to disarmament as well.

6 Conclusion

The current attempts of trying to leverage the DPRK away from producing weapons-grade plutonium in exchange for energy from the other six-party participants has proven instable in the past and present. The incentives for either side to defect are too great, and sequencing is near impossible. However, we have shown that cooperation on the Korean peninsula is possible by assessing one possible mechanism in which nuclear reactors are constructed in the North and the energy is sent to the South in exchange for investment. When considering the positive externalities of cooperation between these contentious states, we also show that the international community can strengthen the prospects of cooperation through transfers to the North.

[10]Indeed, the U.S. will particularly be very reluctant to see progress in cooperation on the civilian nuclear front when the North remains in non-compliance with its previous commitments.

The scope of the analysis has been isolated to a specific exchange on the Korean peninsula. The core findings can be generalizable to other situations of foreign investment between contentious countries. For example, the special economic zones already in place in North Korea demonstrate the possibility of cooperation when one antagonist delivers goods to another in exchange for investment. While the SEZs follow a flow of goods from a country with cheap labor to a country with cheap capital, the model here calls for a flow of energy from a country with cheap land to a country with cheap capital. This opens the possibility that the model is also applicable to other regions with states that have similar nuclear ambitions, such as the Middle East. Even with the specific issue of energy codependency, the approach is not limited to the Korean peninsula. Our setup is analytically pliable to additional emerging nuclear states. For example, Western states involved in reconstructing Iraq and Afghanistan can use their capital to develop proliferation-resistant reactors in Iran that could supply energy to its desperate neighbors.

While this paper has demonstrated that cooperation over nuclear energy is possible on the Korean peninsula, it is important to remember that hasty implementation of our proposal is neither guaranteed nor advisable. The repeated game setup allows for other, non-cooperative equilibria to exist, generating a non-trivial amount of risk to even attempt cooperation. To hedge against such potential for failed cooperation both sides will want to proceed with caution. For example, the ROK would prudently insist on the DPRK implementing full IAEA safeguards. The potential for no cooperation may deter policy makers from such an ambitious proposal, but the point is that the status quo method of sequential guarantees that depend critically on timing cannot be sustainable in the long run. New thinking of the type assessed here will be crucial to even make a self-enforcing cooperative mechanism possible.

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Appendix

Proof of Proposition 1. We employ subgame perfect Nash equilibrium as our solution concept.

Definition A.1. The (pure strategy) subgame perfect Nash equilibrium in the energy provision game is a triplet $\{\boldsymbol{\alpha}^*, E_N^*, \mathbf{I}^*\}$ such that: (a) $\nexists\ \alpha' > \alpha^*$ such that $\sum_{t=0}^{\infty} \delta^t (1-\alpha') P_{E_{N,t}} E_{N,t}(K_t) > \sum_{t=0}^{\infty} \delta^t P_{E_{N,t}} E_{N,t}(K_0)\ \ \forall t$; (b) $\forall E_N \in \mathcal{E} : \{\nexists\ E_N' \neq E_N^*$ such that $U_N(W, E_N') > U_N(W, E_N^*)\}$; (c) $\forall I \in \mathcal{I} : \{\nexists\ I_t' \neq I_t^*$ such that $U_S(I', E_S) > U_S(I^*, E_S)\}\,\forall t$.

We restate Assumption 1 here in formal terms.

Assumption A.1. (a) If $\alpha > 0$, $\hat{I}_t = K_1 > 0\ \forall t \geq 0$; (b) $P_{E_N,t} = P_{E_N}\ \forall t$; (c) $E(t \cdot K) = t \cdot E(K)$.

The stage game is solved via backward induction. In the final stage, delivery occurs at a given time $t = 0$ if and only if

$$\sum_{t=0}^{\infty} \delta^t (1-\alpha) P_{E_N,t} E_{N,t}(K_t) \geq \sum_{t=0}^{\infty} \delta^t P_{E_N,t} E_{N,t}(K_1).$$

By Assumption A.1(a) and (b), we can rewrite this as

$$P_{E_N}(1-\alpha) \sum_{t=0}^{\infty} \delta^t E_N((t+1)K_1) \geq P_{E_N} \sum_{t=0}^{\infty} \delta^t E_N(K_1).$$

Exploiting the homogeneity (of degree 1) property in Assumption A.1(c), this is

$$P_{E_N} E_N(K_1)(1-\alpha) \sum_{t=0}^{\infty} \delta^t (t+1) \geq P_{E_N} E_N(K_1) \sum_{t=0}^{\infty} \delta^t,$$

which simplifies to

$$P_{E_N} E_N(K_1) \frac{1-\alpha}{(1-\delta)^2} \geq P_{E_N} E_N(K_1) \frac{1}{1-\delta} \Leftrightarrow \alpha^* \leq \delta. \tag{A.1}$$

At the margin, set $\alpha^* = \delta$. Substituting this into the assumed functional form for (4) yields the constrained optimization problem for the second stage:

$$\max_{W, E_N} U_N(W, E_N) = \beta W + (1-\beta) E_N$$
$$\text{s.t. } Y_N = (1-\delta) P_{E_N} E_N + P_W W \leq Y_N(K),$$

where we have omitted time subscripts to reduce notational clutter. The corner solution where $W = 0$ obtains when

$$\frac{1-\beta}{\beta} > \frac{(1-\delta) P_{E_N}}{P_W},$$

which is the first condition listed in the proposition. Optimal energy production in the North in this case is given by

$$E_N^* = \frac{Y_N}{(1-\delta) P_{E_N}}. \tag{A.2}$$

Using (A.2) and (A.1) (measured at the margin) in the assumed functional form for (1) gives the first stage problem

$$\max_{\hat{I}, \hat{E}_S} U_S(I, E_S) = \hat{I}^{\chi} \Psi^{1-\chi}$$
$$\text{s.t. } P_{E_S} \hat{E}_S + P_I \hat{I} \leq Y_S,$$

where we have used (2) in defining $\Psi \equiv \hat{E}_S + \frac{\delta Y_N}{(1-\delta)P_{E_N}}$. For an interior solution, the first order necessary conditions simplify to

$$\frac{\chi\Psi}{(1-\chi)\,\hat{I}^*} = \frac{P_I}{P_{E_S}},$$

which, after rearrangement, yields the expression for optimal investment listed in the proposition. Moreover, since all the terms on the RHS of (8) are positive (recall, $0 < \delta < 1$), optimal investment is also positive.

For completeness, note that we also require the satisfaction of the Kuhn-Tucker complementary slackness condition

$$\hat{I}^* \cdot \left(\chi \hat{I}^{*\chi-1} + \Psi^{1-\chi} - \lambda P_I\right) = 0,$$

where λ is the Lagrangian multiplier, in order to rule out the corner solution. □

Proof of Proposition 2. Taking the partial derivatives of I^* with respect to P_I and P_{E_N} yields:

$$\frac{d\hat{I}^*}{dP_I} = -\frac{\chi}{P_I^2}\left(Y_S + \frac{\delta}{1-\delta}\frac{P_{E_S}}{P_{E_N}}Y_N\right) < 0, \tag{A.3a}$$

$$\frac{d\hat{I}^*}{dP_{E_N}} = -\frac{\delta\chi}{1-\delta}\cdot\frac{P_{E_S}Y_N}{P_{E_N}^2} < 0, \tag{A.3b}$$

where we have used the fact that the independence of the variables allows us to write the partial derivative as the total derivative. Repeating the process for the partial derivatives with respect to P_{E_S}, χ, and $\frac{P_{E_S}}{P_{E_N}}$ yields:

$$\frac{d\hat{I}^*}{dP_{E_S}} = \frac{\delta\chi}{1-\delta}\cdot\frac{Y_N}{P_{E_N}P_I} > 0, \tag{A.4a}$$

$$\frac{d\hat{I}^*}{d\chi} = \frac{Y_S}{P_I} > 0, \tag{A.4b}$$

$$\frac{d\hat{I}^*}{d\left(\frac{P_{E_S}}{P_{E_S}}\right)} = \frac{P_{E_S}Y_N}{P_{E_N}P_I}\cdot\frac{\chi\,(1-2\delta)}{(1-\delta)^2} > 0, \tag{A.4c}$$

which concludes the proof. □

Proof of Proposition 3. We expand the Nash equilibrium of Definition A.1 to include the additional party.

Definition A.2. The (pure strategy) Nash equilibrium in the 3-party energy provision game is a quartet $\{\boldsymbol{\alpha}^*, E_N^*, \mathbf{I}^*, \boldsymbol{\tau}^*\}$ such that: (a) $\nexists\ \alpha' > \alpha^*$ such that $\sum_{t=0}^{\infty}\delta^t(1-\alpha')\,P_{E_N,t}E_{N,t}(K_t) > \sum_{t=0}^{\infty}\delta^t P_{E_N,t}\left[\tau^* + E_{N,t}(K_0)\right]\ \forall t$; (b) $\forall E_N \in \mathcal{E}\ :\ \{\nexists\ E_N' \neq E_N^*$ such that $U_N(W, E_N'; \tau^*) > U_N(W, E_N^*; \tau^*)\}$; (c) $\forall I \in \mathcal{I}\ :\ \{\nexists\ I_t'' \neq I_t^{*\prime}$ such that $U_S(I'', E_S) > U_S(I^{*\prime}, E_S)\}\ \forall t$; (d) $\forall\tau \in \mathcal{T}\ :\ \{\nexists\ \tau' \neq \tau^*$ such that both of the following are satisfied: (i) $U_X(C[\epsilon(\tau')]) > U_X(C[\epsilon(\tau^*)])$ (ii) $U_X(C[\epsilon(\tau=0)]) > U_X(C[\epsilon(\tau^*>0)])\}$.

Assumption 2 simply implies that the discount factor for the Third Party is zero.

Assumption A.2. $\delta_X = 0$.

This assumption, together with the assumed functional form for (9), allows us to rewrite the dynamic program faced by the Third Party as a period-by-period static optimization problem as

$$\max_{\tau,C} \frac{C^2}{2} + \tilde{\epsilon} \cdot \tau C, \tag{A.5}$$

when there is cooperative behavior between the North and South. Maximizing (A.5) with respect to (11) yields, for the interior solution, the optimal level of transfer

$$\tau^* = \frac{Y_X \left(P_C \tilde{\epsilon} - P_{E_N}\right)}{P_C P_{E_N} \left(2\tilde{\epsilon} - 1\right)}. \tag{A.6}$$

This expression is positive if

$$\tilde{\epsilon} > \frac{Y_X/P_C - 1}{Y_X/P_{E_N} - 2},$$

which is the second condition in the proposition. Note that this is only a necessary condition; the Kuhn-Tucker Theorem states that we also require the complementary slackness condition

$$\tau^* \left[\tilde{\epsilon} C^* - \frac{P_{E_N}}{P_C} \left(C^* + \tilde{\epsilon}\tau^*\right)\right] = 0.$$

We solve the modified stage game via backward induction. The solution to the final stage, when the Third Party makes a transfer, now simplifies to

$$\alpha^* \leq \delta + \tau \left(1 - \delta\right). \tag{A.7}$$

We set $\alpha^* = \delta + \tau (1 - \delta)$ and repeat the substitution and optimization process to obtain the level of energy production in stage two:

$$E_N^* = \frac{Y_N}{(1 - \tau)(1 - \delta) P_{E_N}}. \tag{A.8}$$

where the condition for the corner solution with $W = 0$ is now

$$\frac{1 - \beta}{\beta} > \frac{(1 - \tau)(1 - \delta) P_{E_N}}{P_W},$$

which is the first condition in the proposition. The interior solution to the first order conditions in the first stage is

$$\frac{\chi \Omega}{(1 - \chi) \hat{I}^{*\prime}} = \frac{P_I}{P_{E_S}},$$

where $\Omega \equiv \hat{E}_S + \frac{\delta+\tau(1-\delta)Y_N}{(1-\tau)(1-\delta)P_{E_N}}$. Rearranging the expression yields the level of optimal investment listed in the proposition. Finally, since all the terms on the RHS of (8) are positive, optimal investment is also positive in the extended game. □

Proof of Proposition 4. Taking the partial derivative of $\hat{I}^{*\prime}$ with respect to τ gives

$$\frac{d\hat{I}^{*\prime}}{d\tau} = \frac{P_{E_S}Y_N}{P_{E_N}P_I} \cdot \frac{\chi\left[1+\tau\left(1-\delta\right)\right]}{\left(1-\delta\right)\left(1-\tau\right)^2} > 0, \tag{A.9}$$

where we have again used the independence of the variables to write the partial derivative as the total derivative. □