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Asymmetric Nash Bargaining Solutions: A Simple Nash Program

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Abstract

This article proposes a simple Nash program. Both our axiomatic characterization and our noncooperative procedure consider each distinct asymmetric and symmetric Nash solution. Our noncooperative procedure is a generalization of the simplest known sequential Nash demand game analyzed by Rubinstein, Safra and Thomson (1992). We then provide the simplest known axiomatic characterization of the class of asymmetric Nash solutions, in which we use only Nash's crucial Independence of Irrelevant Alternatives axiom and an asymmetric modification of the well-known Midpoint Domination axiom.

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1 Introduction

In an important paper, Harsanyi and Selten (1972) proposed and axiomatically characterized the asymmetric (generalized) Nash solutions. Kalai (1977) provided a much simpler axiomatic characterization of these solutions by using three of the original axioms of Nash (1950), namely Weak Pareto Optimality (WPO), Scale and Origin Invariance (SOI) and Independence of Irrelevant alternatives (IIA).

In a variation of Nash demand game considered in Rubinstein, Safra and Thomson (1992), Player 1 has the first mover advantage to make a proposal s but Player 2 is free to accept 1's proposal, to continue negotiations even if he doesn't accept 1's proposal or to terminate negotiations. In case Player 2 rejects 1's proposal, 2 is more likely to continue negotiations if 1's proposal is more to his liking. Player 2 announces his probability $p \in [0, 1)$ to continue negotiations after he hears Player 1's proposal and rejects it (clearly Player 1 too can calculate Player 2's continuation probability p). If Player 2 continues negotiations, Player 1 will have to choose either the new proposal $\widetilde{s}$ made by Player 2 or to scale his original proposal down by p.

We first provide a simple generalization of the above game. Our generalization conceptually separates the latter scale-down p and the continuation probability p in that they do not have to be equal. Our game, however, still keeps a link between them by making the former a function of the latter; each different link between them in our game gives rise to a distinct subgame-perfect equilibrium outcome which coincides with the outcome of a distinct asymmetric (or symmetric) Nash solution.

We then provide an axiomatic characterization of the class of asymmetric Nash solutions, in which we use only Nash's crucial Independence of Irrelevant Alternatives (IIA) axiom and an asymmetric modification of the well-known Midpoint Domination (MD) axiom.[1]

Ours is a very simple Nash program[2] because it provides (i) the simplest known ax-

[1] MD was proposed by Sobel (1981) and Moulin (1983) provided the simplest axiomatic characterization of the (symmetric) Nash solution by using MD and IIA only. MD requires the solution outcome to weakly dominate the expected utility of the case where each party is selected to impose their most favorite outcome with equal probabilities.

[2] The Nash program attempts to bridge the gap between the cooperative (axiomatic) and non-cooperative (strategic) strands of game theory by providing non-cooperative procedures that yield cooperative solutions' outcomes as their equilibrium outcomes.

Nash (1953, p. 128): "We give two independent derivations of our solution of the two-person cooperative game. In the first, the cooperative game is reduced to a non-cooperative game. To do this, one makes the players' steps in negotiations in the cooperative game become moves in the non-cooperative model. Of course, one cannot represent all possible bargaining devices as moves in the non-cooperative game. The negotiation process must be formalized and restricted, but in such a way that each participant is still able to utilize all the essential strength of his position. The second approach is by the axiomatic method. One states as axioms several properties that would seem natural for the solution to have, and then one discovers that the axioms actually determine the solution uniquely. The two approaches to the problem, via the negotiation model or via the axioms, are complementary. Each helps to justify and clarify the other."

iomatic characterization of the asymmetric (generalized) Nash solutions axioms, and (ii) a noncooperative procedure is a generalization of the simplest sequential Nash demand game analyzed by Rubinstein, Safra and Thomson (1992).

2 Relevant Literature

Nash (1950) provided the first axiomatic characterization of a cooperative bargaining solution. Nash (1953) provided the first noncooperative justification of his solution concept by using his own (Nash) demand game (NDG). In that game, two players simultaneously make demands; each player receives the payoff he/she demands if the demands are jointly feasible, and nothing otherwise. NDG has a major downside, however: every point on the Pareto frontier is a Nash equilibrium outcome. Nash (1953) himself tried to rectify this problem by utilizing a "smoothing" approach in which with some positive probability, incompatible demand combinations did not lead to zero payoffs . This smoothing approach uniquely provided non-cooperative foundations for the Nash solution as the above-mentioned probability tends to zero; however, it was not deemed reasonable by game theorists and several alternatives have been proposed.[3]

In Carlsson (1991), the set of feasible payoffs is known to both players, but their actions are subject to some errors; in addition, unlike in the NDG, if players make demands which do not exhaust the available surplus, the remainder is distributed according to an exogenously fixed rule. In the limit as the noise vanishes, the equilibrium outcome converges to one of the asymmetric Nash solution outcomes. The rule about the proportion of the unclaimed surplus that is supposed to go to each of the players determines which particular asymmetric Nash solution outcome will be obtained.

Howard (1992) proposed a one-shot (multiple-stage) noncooperative foundation for the (symmetric) Nash solution, which was later significantly simplified by Rubinstein, Safra and Thomson (1992), which will be described in detail later.

Binmore, Rubinstein and Wolinsky (1986) showed that as the time between alternating offers by players in the Rubinstein (1982) bargaining game tends to zero, the unique subgame perfect equilibrium outcome corresponds to one of the asymmetric Nash solutions, depending on the relative discount factors of the players. Kultti and Vartiainen (2010) generalize Binmore et al. (1986); they show that differentiability of the payoff set's Pareto frontier is essential for the convergence result if there are at least three players.

Recently, various noncooperative multilateral bargaining game models provided noncooperative support to the $n-$person asymmetric Nash solutions; see Britz, Herings and Predtetchinski (2010), Laruelle and Valenciano (2008), and Miyakawa (2011). In these games, in the first period of an infinitely repeated bargaining game, one out of the n players is recognized as the proposer. If a proposal is rejected, negotiations break down with

[3] Luce and Raiffa (1957) described it "a completely artificial mathematical escape from the troublesome nonuniqueness," and questioned its "relevance to the players." Schelling (1960) argued that smoothing was "in no sense logically necessary" in such a prototypical bargaining setup.

an exogenous probability and the next round starts with the complementary probability. There is a probability distribution with which the proposing player is selected in each bargaining round. As the risk of exogenous breakdown vanishes, stationary subgame perfect equilibrium payoffs converge to the weighted Nash bargaining solution outcome, where the above-mentioned probability distribution serves as the weight vector.

3 Asymmetric Nash Solutions: A Simple Nash Program

A two-person *bargaining problem* is a pair (S, d), where $S \subset \mathbb{R}^2$ is the *set of utility possibilities*, and $d \in S$ is the *disagreement point*, which is the utility allocation that results if no agreement is reached by the two parties. It is assumed that (1) S is compact and convex, and (2) $x > d$ for some $x \in S$.[4] Let Σ be the class of all two-person problems satisfying (1) and (2) above. Define $IR(S, d) \equiv \{x \in S | x \geq d\}$ and $WPO(S) \equiv \{x \in S | \forall x' \in \mathbb{R}^2$, with $x' > x \Rightarrow x' \notin S\}$. A *solution* is a function $f : \Sigma \to \mathbb{R}^2$ such that for all $(S, d) \in \Sigma$, $f(S, d) \in S$. The asymmetric Nash solution with weight $\alpha \in (0, 1)$, N^α, selects $N^\alpha(S, d) = \arg\max\{(x_1 - d_1)^\alpha (x_2 - d_2)^{1-\alpha} | x \in IR(S, d)\}$ for each $(S, d) \in \Sigma$.[5]

For simplicity in our noncooperative analysis let's normalize d such that $d = (0, 0)$.

Consider the following Nash demand game proposed by Rubinstein et al. (1992):

Stage 1. Player 1 proposes a division $s \in S$.

Stage 2. Player 2 proposes an alternative division $\widetilde{s} \in S$ and a probability $p \in [0, 1]$.

Stage 3. The game continues with probability p and terminates at $(0, 0)$ with probability $1 - p$.

Stage 4. Player 1 chooses between $\widetilde{s}$ and ps.

In the Introduction, we gave an intuitive description of this game. We can add the following explanation of how the equilibrium is obtained. Observe that at Stage 4, ps and $\widetilde{s}$ depend on 1's initial proposal s. Player 2 will reciprocate with a higher continuation probability p and with a more favorable ps as well as a more favorable counter-offer $\widetilde{s}$ for Player 1, if 1's initial proposal is more favorable for 2. On the other hand, the less s is to 2's liking, the lower ps and the less favorable $\widetilde{s}$ are for Player 1. Thus, if at Stage 1 s is less to 2's liking, at Stage 2 Player 2 will continue negotiations with a lower probability p and force Player 1 to choose between worse new alternatives $\widetilde{s}$ and ps at Stage 4.

In turn, Player 1 can avoid all of this and obtain Player 2's immediate acceptance of s if s is above some particular threshold. The setup is symmetric. This particular threshold for s would be the same if players reversed roles, i.e., if Player 2 instead of Player 1 started the procedure by proposing s.

Observe that by proposing a low p, Player 2 is potentially punishing himself as well since the game will continue with a lower probability. But once Player 2 continues negotiations, the punishment by the scalar p pertains primarily to Player 1 which will

[4] Given $x, y \in \mathbb{R}^2$, $x > y$ if $x_i > y_i$ for each i, and $x \geq y$ if $x_i \geq y_i$ for each i and $x_i > y_i$ for some i.

[5] Observe that each $N^\alpha(S, d)$ is strongly Pareto optimal.

make Player 1 settle for $\widetilde{s}$ instead. But since the continuation probability p at Stage 2 and the scalar p at Stage 4 are the same, Player 2 must pick a lower continuation probability p in order to name a lower scalar p to punish primarily Player 1 (who doesn't care about the scaling down of Player 2's payoff s_2 in s, but only cares about the scaling down of his own payoff s_1 in s).

Note that in the above game by Rubinstein et al. (1992) there is no reason why the continuation probability p proposed by Player 2 as well as the fraction p of s proposed by Player 2, that Player 1 has to choose against $\widetilde{s}$ in Stage 4 have to be equal. As a matter of fact, these two p's pertain to two totally different things. The former is the probability with which Player 2 will continue negotiations, and the latter is a proposed fraction of the payoff s by 2.

Consider the following variation of the above Nash demand game, which deliberately separates the continuation probability p and the fraction of payoff s (while still keeping a link between them):

Stage 1. Player 1 proposes a division $s \in S$.

Stage 2. Player 2 proposes an alternative division $\widetilde{s} \in S$ and a probability $p \in [0, 1]$.

Stage 3. The game continues with probability p and terminates at $(0, 0)$ with probability $1 - p$.

Stage 4. Player 1 chooses between $\widetilde{s}$ and qs, where $q = p^{\theta}$ and $\theta \in (0, \infty)$.

We call this $\theta-$weighted Nash demand game. Note that when $q = p$, then this game boils down to the original Rubinstein et al. game. The use of this more general form for q in Stage 4 suggests that, if there is a need to link q and p, then this link need not always be in the strict form of $q = p$.

Apart from separating p and q, the two games share a similar intuitive description as the one mentioned in the Introduction; likewise, an explanation as to how the equilibrium outcome is obtained, similar to the one mentioned after the original game by Rubinstein et al. (1992), applies here as well.

Proposition 1 *For any $\alpha \in (0, 1)$, the only subgame perfect Nash equilibrium (SPNE) outcome of the $\frac{1-\alpha}{\alpha}-$weighted Nash demand game is $N^{\alpha}(S, 0)$.*

Proof. Fix some $\alpha \in (0, 1)$ and consider the $\frac{1-\alpha}{\alpha}-$weighted Nash demand game. Consider the subgame following Player 1's proposal of s in Stage 1. First note that for any SPNE (of this subgame) in which Player 1 chooses qs in Stage 4, there is a corresponding SPNE in which Player 1 chooses $\widetilde{s}$ in Stage 4 that yields the same outcome. In this SPNE, Player 2 simply proposes $\widetilde{s} = qs$ and the same probability p in Stage 2, and Player 1 picks $\widetilde{s}$ in Stage 4. Hence, we can restrict our analysis to all SPNE in which Player 1 chooses $\widetilde{s}$ in Stage 4. Let $(\widetilde{s}, p)$ be Player 2's proposal in Stage 2 in such a SPNE. $(\widetilde{s}, p)$ is a maximizer of the following problem: $\max_{p \in [0,1], \widetilde{s} \in S} p\widetilde{s}_2$ such that $\widetilde{s}_1 \geq qs_1 = p^{\frac{1-\alpha}{\alpha}} s_1$. The constraint must be binding: $\widetilde{s}_1 = p^{\frac{1-\alpha}{\alpha}} s_1$. $(\widetilde{s}, p)$ can be solved as follows: (i) If $s_1 \leq N_1^{\alpha}(S, 0)$, then $p = 1$ and $\widetilde{s} = \arg\max_{\widetilde{s}=(s_1, \widetilde{s}_2) \in S} \widetilde{s}_2$. In this SPNE, Player 1's expected utility is s_1, and

(ii) If $s_1 > N_1^\alpha(S,0)$, then $\widetilde{s} = N^\alpha(S,0)$ and $p = (\frac{\widetilde{s}_1}{s_1})^{\frac{\alpha}{1-\alpha}} = (\frac{N_1^\alpha(S,d)}{s_1})^{\frac{\alpha}{1-\alpha}} < 1$. In this SPNE, Player 1's expected utility is $p\widetilde{s}_1 < N_1^\alpha(S,0)$. Then Player 1's best response is to propose any s such that $s_1 = N_1^\alpha(S,0)$ in Stage 1, and the SPNE outcome is $N^\alpha(S,0)$. ■

Now we turn to our axiomatic analysis.

Nash (1950) showed that $N^{\frac{1}{2}}$ is the unique solution that satisfies the following four axioms:

Weak Pareto Optimality (WPO): For all $(S,d) \in \Sigma$, $f(S,d) \in WPO(S)$.

Symmetry (SYM): For all $(S,d) \in \Sigma$, if $[d_1 = d_2$, and $(x,y) \in S \Rightarrow (y,x) \in S]$, then $f_1(S,d) = f_2(S,d)$.

A function $T : \mathbb{R}^2 \to \mathbb{R}^2$ is a *positive affine transformation* if $T(x_1,x_2) = (a_1x_1 + b_1, a_2x_2 + b_2)$ for some positive constants a_i and b_i.

Scale Invariance (SI): For all $(S,d) \in \Sigma$ and all positive affine transformations T, $f(T(S),T(d)) = T(f(S,d))$ holds.

Independence of Irrelevant Alternatives (IIA) For all (S,d), $(T,e) \in \Sigma$ with $d = e$, if $T \supset S$ and $f(T,e) \in S$, then $f(S,d) = f(T,e)$.

Denote the *ideal point* of (S,d) as $b(S,d) \equiv (b_1(S,d), b_2(S,d))$, where $b_i(S,d) = \max\{x_i | x \in IR(S,d)\}$; the *midpoint* of (S,d) is $m(S,d) \equiv \frac{1}{2}(b_1(S,d),d_2) + \frac{1}{2}(d_1, b_2(S,d))$. Sobel (1981) proposed the following axiom:

Midpoint Domination (MD): For all $(S,d) \in \Sigma$, $f(S,d) \geq m(S,d)$.

The intuition is that the two parties should not do worse than the expected utility of the case where each party is selected as the random dictator with equal probabilities (i.e., the solution outcome should be at least as large as the average of the bargaining problem's dictatorial outcomes).

Denote $\alpha-$weighted Midpoint of (S,d) as $m^\alpha(S,d) \equiv \alpha(b_1(S,d),d_2) + (1-\alpha)(d_1,b_2(S,d))$. The following variation of MD considers the setups in which parties can be selected as the random dictator with unequal probabilities:

$\alpha-$Weighted Midpoint Domination ($\alpha-$MD): For all $(S,d) \in \Sigma$, $f(S,d) \geq m^\alpha(S,d)$.

Our next result parallels Moulin (1983)'s result of $N^{\frac{1}{2}}$ is the unique solution satisfying IIA and MD:

Proposition 2 *N^α is the unique solution satisfying IIA and $\alpha-$MD.*

Proof. It is straightforward to see that N^α satisfies IIA and $\alpha-$MD. Suppose f satisfies IIA and $\alpha-$MD. We will show that $f = N^\alpha$. Consider a problem (S,d). Let $(\widetilde{S},d)$ such that $\widetilde{S} \supset S$ and $IR(\widetilde{S},d) = conv\{d, (d_1 + \frac{N_1^\alpha(S,d)-d_1}{\alpha}, d_2), (d_1, d_2 + \frac{N_2^\alpha(S,d)-d_2}{1-\alpha})\}$. By $\alpha-$MD, $f(\widetilde{S},d) = N^\alpha(S,d)$. By IIA, $f(S,d) = f(\widetilde{S},d) = N^\alpha(S,d)$. ■

Note the following: Harsanyi and Selten (1972) and Kalai (1977) axiomatically characterize the class of all asymmetric (and symmetric) Nash solutions in a lump-sum fashion. I.e., there is no parameter in those characterizations which can help characterizing any of distinct asymmetric (or symmetric) Nash solution.[6] Our axiomatic characterization, on the other hand, characterizes each distinct member of the class of Nash solutions for each α.

4 Asymmetric Nash Solutions in Economic Modelling

The asymmetric Nash solutions have been used extensively in economic modelling since then.[7] As Pissarides (forthcoming) states, "two approaches dominate in the [economics of search] literature. The first and more commonly-used approach employs the solution to a Nash bargaining problem. ... The second approach to wage determination postulates that the firm 'posts' a wage rate for the job, which the worker either takes or leaves." Except for very infrequent use of the Kalai/Smorodinsky solution and of the Egalitarian solution, the workhorse in the economics of search literature is the asymmetric Nash solutions.[8]

Earlier work in search such as Diamond (1982), Pissarides (1987), Mortensen and Pissarides (1994), and Trejos and Wright (1995) used the standard (symmetric) Nash solution, and later work such as Mortensen and Pissarides (1999a, b), Pissarides (2000), Lagos and Wright (2005), Rocheteau and Wright (2005), Rogerson, Shimer and Wright (2005), Berentsen, Menzio and Wright (2011) use the asymmetric Nash solutions.

The catalyst of the sky-rocketing use of asymmetric Nash solutions was the paper by Binmore, Rubinstein and Wolinsky (1986) in the context of the Nash program. As mentioned before, Binmore et al. showed that as time between alternating offers by players in the Rubinstein (1982) bargaining game becomes smaller, in the limit the unique subgame perfect equilibrium outcome corresponds to the asymmetric Nash solutions; the relative discount factors of players act as the determinants of the bargaining weights.[9]

There were two problems though. First, in these setups of economics of search for

[6] Hence, in that sense, Harsanyi and Selten (1972)'s and Kalai (1977)'s characterizations of generalized (asymmetric) Nash solutions simply boil down to characterizing the class of all solutions that are individually rational and strongly Pareto optimal.

[7] The use of asymmetric Nash solutions is not confined to economics anymore. It is now being used in International Relations and Political Science literatures as well. See Avenhaus and Zartman (2007) and Kaplan (2007).

[8] Note that even "the second approach" (i.e., the take-or-leave-it one) is nothing but the Dictatorial solution outcome which coincides with the asymmetric Nash solution outcome as well as with the asymmetric Proportional solution outcome when the firm has the entire bargaining power, i.e., when the bargaining weight of the firm is one and that of a worker is zero.

[9] Trejos and Wright (1995, p. 129), among others, provided such a justification of the use of this result in the context of money-search literature: "The basic bargaining solution can be thought of either as the axiomatic model of Nash (1950) or as the strategic model of Rubinstein (1982), since the latter has a reduced form that approaches the former as the time between rounds in the bargaining game goes to zero. However, as is well known, the exact Nash representation can depend critically on details of the underlying strategic formulation (see Binmore, Rubinstein, and Wolinsky 1986; Osborne and Rubinstein 1990) ..."

simplicity all agents are supposed to discount the future at the same rate, not at different rates that would generate the Binmore et al. convergence result above. That is, these setups' assumptions about relative discount factors of their agents on two sides of the market (i.e., of buyers and sellers, of firms and workers) actually contradicts those of the Binmore et al. convergence result. To incorporate such a justification of the asymmetric Nash solutions, these setups of economics of search should too have agents who discount the future at different rates instead, which would surely make these setups compatible and consistent with the Binmore et al. result but would also make them very complicated - if not intractable - setups.

Second, the Rubinstein bargaining game is an infinite-horizon game and could potentially go on forever with out-of-equilibrium strategies. In other words, in the standard infinite-horizon setup of search models (be it a money-search or a labor-search model), a buyer and a seller had to open another infinite-horizon digressive window by using the Rubinstein scheme for their negotiations, and this could be deemed problematic especially for applied work in macro, labor and monetary economics with significant policy suggestions. Coles and Wright (1998) had the sole purpose of remedying that problem, i.e., "to characterize equilibria in a way that is useful for applications in macro, labor and monetary economics."[10]

In this paper, like Coles and Wright, we too have characterized equilibria in a way that is useful for applications in macro, labor and monetary economics but we have proceeded in the direction of providing a very simple Nash program of which (1) noncooperative procedure is a one-shot game and (2) both the axiomatic characterization and the noncooperative procedure consider each distinct asymmetric - and symmetric - Nash solution.

For the practitioners of economics of search (as well as the practitioners of other fields such as macroeconomics and labor economics), who intend to use the asymmetric Nash solutions as the reduced form for an explicit strategic bargaining game, our noncooperative procedure will provide an intuitive, simple and practical support since it will not pose additional, technical burdens of reducing an infinite-horizon bargaining game to a finite one and of having to use different discount factors for buyers and sellers or for firms and workers.[11]

[10] Coles and Wright described their methodology as follows: "suppose there is no delay in bargaining and therefore immediate trade (in this paper we focus exclusively on such equilibria). If $q(t)$ denotes the terms of trade between two agents who meet at time t, then as the length of the period between moves in the bargaining game becomes small, the limiting path $[q(t)]_{t=0}^{\infty}$ will satisfy a simple differential equation. One can use this characterization in dynamic economic models in the same way that one uses the Nash solution in stationary models, as a 'reduced form' for an explicit strategic bargaining game."

[11] There is a recent implementation strand in the money-search literature, pioneered by Hu, Kennan and Wallace (2009). Suppose that, each time they meet, the players (i.e., buyers and sellers) are supposed to pay the mechanism designer for the number of periods the mechanism designer commits himself to monitoring them as to whether they always follow the four stages of the $\theta-$weighted Nash demand game. Then our mechanism that implements an asymmetric Nash solution and surely terminates the procedure in one period even if any of the players (i.e., a buyer or a seller) is not rational would be socially more efficient than implementation of a Rubinstein procedure between buyers and sellers since the Rubinstein

5 Concluding Remarks

Our marginal contributions in this paper, which proposes a simple Nash program, are as follows. (1) In terms of axiomatic bargaining theory, we provide the simplest known axiomatic characterization of asymmetric Nash solutions using Nash (1950)'s crucial IIA axiom, and an asymmetric version of another well-established axiom of Sobel (1981), MD, which was used by Moulin (1983) in tandem with IIA to characterize the standard Nash solution, $N^{\frac{1}{2}}$. The asymmetric version of MD is tailored for each asymmetric Nash solution, indexed by α. This is an improvement over Harsanyi and Selten (1972) and Kalai (1977) characterizations of the asymmetric Nash solutions which characterize these solutions in a lump-sum or whole-sale fashion without paying any special attention to each N^{α}.

(2) In terms of noncooperative bargaining theory, we generalize Rubinstein et al. (1992)'s game by separating the continuation probability and the scale-down factor, albeit by still linking them in a specific form as we provide noncooperative foundations for asymmetric Nash solutions. We also provide an intuitive description of this general class of noncooperative games in terms of reciprocity between 1's proposal and 2's inclination to continue negotiations as well as his counterproposal alternatives.

(3) In terms of the use of the asymmetric Nash solutions in economic modelling, we motivate our noncooperative justification of these solutions by noting some pitfalls of the typical noncooperative justification of these solutions in models of economics of search. We first note the contradictory use of the identical discount factors by buyers and sellers or by firms and workers in these models although their noncooperative justification of these solutions, Rubinstein (1982)'s alternating offers mechanism as time between offers tends to zero, is based on differing discount factors of agents. We also note that these models typically use a potentially infinite-horizon game, namely the above mentioned Rubinstein mechanism, within an already infinite-horizon setup, which may cast shadow on the policy-oriented nature of such applied research.

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