The Value and Applicability of Bargaining in an Intergenerational Setting

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Abstract

This paper considers the effectiveness of a variation of Coasian bargaining as a policy instrument for internalizing one or multiple intergenerational externalities. The variation involves appointing a contemporary party to represent the interests of the affected parties who are currently unable to represent themselves, either because they are too young or have not yet been born. Potential criticisms of such a policy are considered and addressed, and precedents to such a policy are put forth.

To test the value of such a policy, a two-period model in which two externalities exist in the production/consumption decisions and with representative agents is used to compare the welfare effects of four scenarios: 1) The agent in each period chooses allocations to maximize utility in that period, 2) a benevolent social planner chooses allocations in both periods to maximize a social welfare function, 3) the government assigns and enforces property rights and acts as an intermediary in negotiations to determine allocations in each period, and 4) agents choose allocations to maximize period-specific utility subject to a tax-and-subsidy regime imposed by the government. The four scenarios are solved and comparative statics are analyzed analytically where possible and through simulations when the model become analytically intractable. The model is tested for robustness through sensitivity analysis of the model parameters, adjusting the functional form of the social welfare function, and extending the model to three periods.

I find that, contrary to general consensus in the literature, Coasian bargaining can be adapted in such a way as to make it applicable in an intergenerational framework. In addition, I find that the welfare outcomes of the Coasian bargaining scenario are marginally lower but comparable to that of the tax-and-subsidy regime, and that both policy instrument scenarios have similar comparative statics and sensitivity analyses. The main disparity between the two policy regimes pertains to how increasing the effectiveness of research and development (R&D) changes the optimal level of R&D. The tax-and-subsidy scenario finds that there is a positive relationship between this parameter and the equilibrium level of R&D, while the bargaining scenario yields a negative relationship.

Section 1: Introduction

When dealing with externalities that exist between two or more contemporary agents, the environmental economic literature has recognized many different methods of internalizing the external cost in order to achieve efficient outcomes (For a comparison of these different policies under uncertainty, see Weitzman (1974)). These methods range from regulating prices through taxes and subsidies (Pigou 1952, Cornes and Sandler 1985, Wittman 1985), to regulating quantities through quotas and cap and trade, to more “decentralized” methods like Coasian bargaining (Coase 1960). However, when attempting to resolve issues such as global warming, the use of nuclear power, and biodiversity loss, the relevant externalities are not limited to the current population, but instead extend to agents in future generations.

Coasian bargaining is generally considered an infeasible policy option when dealing with intergenerational externalities as it relies on negotiations between parties separated by decades (or even centuries). Padilla (2002) said, in reference to market solutions to intergenerational externalities, “In particular, the ‘Coasian’ analysis is out of place: there is no possible agreement between the parts because future generations are not present nor represented either.” (p. 72). This is a legitimate objection, and it focuses on the decentralized nature of Coasian bargaining. We face a permanent and inflexible constraint in which we are unable to move freely through time as we do space. This constraint seems to irrevocably damn decentralized bargaining, as well as any other potential decentralized policies, when the problem is intergenerational in nature. However, decentralization is only half of the Coasian bargaining story. The feasibility of a decentralized bargaining policy is dependent on not just the possibility of decentralization (meaning the “policy” is implemented by the effected parties and not the government), but also on the ability of these parties to bargain. This bargaining aspect is the baby that is thrown out with the decentralization bath water. Because decentralization and bargaining are tied so closely in the minds of economists, the profession often fails to consider the possibility of having one without the other.

One might be incredulous toward any bargaining scheme in which the two affected parties have no chance to negotiate. The future cannot sit opposite the present at any negotiating table. However, should it be possible for a contemporary party to represent the interests of the future, bargaining could once again be viable. If this party was the government, we would not be engaging in Coasian bargaining per se, but instead in centralized bargaining. Having today's government represent a faceless future that does not yet exist is enough to raise further objections (for example, how can today's government presume to know the preferences of future peoples?), but it would be erroneous to assume that centralized bargaining is unique among policy instruments in such weaknesses. For example, when calibrating an optimal tax aimed at internalizing an intergenerational externality, the government must be aware of the preferences and endowments of people who have yet to be born. If they do not know these preferences and endowment, or if their estimates are wildly inaccurate, the chosen tax rate is likely to be far from optimal. Thus, for any policy, bargaining or otherwise, the government must have a good estimate of future preferences to have any chance of implementing effective policy. It is reasonable to be skeptical about our estimates of future preferences, but such skepticism is equally damning to policies across the board.

In addition to possessing accurate estimates of future preferences and endowments, the government (or any party representing the future) must also be committed to representing the best interests of the future. This assumption is likewise fair game for skepticism and credulity. It seems unlikely that politicians will forgo the interests of their constituents in order to negotiate forcefully and effectively for parties who have no say in their reelection. This is the “missing voter” problem addressed by Doeleman and Sandler (1998). If this is true, centralized bargaining will not be effective. However, assuming that the government doesn’t actually care about the future causes ALL policies aimed at internalizing intergenerational externalities to be ineffective, not just centralized bargaining. If politicians care only about the interests of their constituents, not only would bargaining policies fail, but any regulation of quantity or price will fail in similar fashion. What hope is there for effective Cap and Trade legislation or carbon taxes that accurately reflect the social cost of carbon when the government is unconcerned about the interests of future generations, who are the beneficiaries of such action[1]? There is none.

It is also reasonable to suggest that transaction or information costs can be prohibitive when it comes to bargaining outcomes. In the case of many heterogeneous parties negotiating on either or both sides, it is likely that the costs of negotiating are high. Similarly, the existence of private information can lead to parties “holding out” in negotiations and failing to achieve efficient outcomes (Farrell 1987). Clearly, the existence of these real world frictions relegates any bargaining policy to the world of second best outcomes. However, the same is undoubtedly true for price and quantity regulations, as the cost of acquiring information on preferences, as well as the cost of monitoring and enforcement, is certainly nonzero and in many cases substantial. The question, then, is not whether bargaining policies are in all cases efficient or superior to price and quantity alternatives, but rather whether bargaining policies are comparable to these alternatives given the right circumstances.

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[1]One could argue that governments could appear to care about future generation, without actually doing so, by levying a tax to correct a contemporaneous externality if said tax has the unintended consequence of being beneficial to future generations. If, however, a tax was purely detrimental to the present and beneficial to the future, this caveat would not hold. In addition, even if the externality affects both contemporary and future parties, a tax that takes into account only the interests of contemporary parties will not be an optimal tax.

The concept of assigning property rights to future generations in order to protect their interests is not new. Pasqual and Souto (2003) argue that the assignment of resource rights can help alleviate externalities between generations. They also consider various property rights assignments and their respective implications for sustainability. The work of this paper deviates from these previous efforts in several ways. First, this paper does not consider sustainability, though the extension of the model presented herein to infinite periods would produce interesting implications for sustainability. Second, Pasqual and Souto consider the property rights assignment of a single resource that generates intergenerational externalities, while this paper presents a model in which multiple externalities exist from multiple sources, each of which can have rights assigned to it. Third, while previous work allows for the assignment and enforcement of property or resource rights to the future, they do not consider the prospect of bargaining between the present and the contemporary party representing the interests of the future.

Padilla (2002) advocates the assignment of property rights to future generations in the interest of sustainability, arguing that failing to do so implicitly assigns property rights to the present and is still "value laden." (p. 75). Padilla eschews bargaining solutions as well as "Pigouvian" solutions on the grounds that the market valuations assigned to the future are unreliable and somewhat arbitrary. In addition, he acknowledges the "compensation rule," in which the present generation's use of resources in a manner that violates the rights of future generations should bear with it compulsory compensation from present to future (how to determine appropriate compensation in the face of unreliable and arbitrary information is left unclear). This is similar to Bromley's (1989) liability rule. Padilla also advocates the development of institutions "acting as representatives, defenders, and tutors," of future generations' rights (2002, p. 80).

While there is no clear precedent in favor of representing the interests of future generations as a matter of policy, it is standard practice to appoint parties to represent the interests of children in both custody (Parley 1993) and neglect/abuse proceedings (Elrod 1995-1996). In this context, the policy tool suggested in this paper is akin to appointing a class-action guardian for future generations. In addition, it is common practice among many Native American tribes, both historically and today, to consider the impact of any decision on the next seven generations of the tribe (Trosper 1995). While such a system is not identical to the one proposed in this paper, as it involves no bargaining, it is similar in its intention of internalizing externalities affecting unborn generations.

The purpose of this paper is to demonstrate the usefulness of Coasian bargaining in the case of multiple intergenerational externalities. For the remainder of this paper, the term Coasian bargaining refers to bargaining in which a contemporary agency represents the interests of the future. This agency could be the government, in which case Coasian Bargaining is a misnomer. However, this agency can also be decentralized. For instance, in an attempt to protect biodiversity, organizations like the Sierra Club or the WWF could potentially represent the interests of the future in negotiations. The model that follows considers an economy with multiple externalities. This is done for two reasons. First, this is more realistic. Whether we like it or not, externalities abound, especially when taking an intergenerational outlook. Just as GHG emissions, biodiversity loss, and deforestation generate negative externalities, R&D research, carbon sequestration, and investing in education generate positive externalities. In addition, multiple externalities are examined because in a model with a single externality, the method of payment in bargaining situations is purely monetary. For all intents and purposes (especially if we are considering centralized bargaining), this is not much different from a tax. A model with multiple externalities, on the other hand, provides additional methods of compensation between the parties.

I develop a two period model (period 1 being the present and period 2 being the future) in which the choices of the present generate two externalities, one positive and one negative, for the future. I then solve the model under four different scenarios: 1) The representative agent in each period chooses allocations to optimize his own utility, 2) a benevolent social planner chooses allocations to maximize a social welfare function, 3) a Coasian bargaining scenario in which the present and future negotiate, through a government intermediary, to determine allocations, and 4) a tax-and-subsidy regime in which the government taxes the source of the negative externality and subsidizes the source of the positive externality. I compare the equilibria and comparative statics of these four scenarios, analytically where possible and using simulations when the problem becomes analytically intractable.

One obvious conclusion from this paper is that the planner's optimization produces significantly greater social welfare than does the individual period optimizations. In general, the Coasian bargaining solution does not achieve the first-best outcome, but is still significantly superior to the individual optimization scenario. I also find that the tax-and-subsidy regime is likewise superior to the individual optimization and marginally outperforms the Coasian bargaining regime, but not to the extent that it is justifiable to dismiss the Coasian bargaining regime out of hand when considering policy instruments.

The rest of the paper proceeds as follows. Section 2 presents the elements of the model. Section 3 solves the model in the case of individual periods optimizing separately and compares this equilibrium with equilibrium allocations derived from a social planner's problem. Section 4 solves the model using the Coasian bargaining framework of assigning property rights and entering into negotiations to decide the final allocations in the economy. Section 5 introduces and solves for a tax-and-subsidy regime. Section 6 presents a numerical analysis with which to compare the four scenarios. This section also provides sensitivity analyses for the parameters of the model, adjusts the functional form of the social welfare function, and extends the model to three periods in order to test for model robustness. Section 7 concludes and suggests possible extensions.

Section 2: Model

The model consists of a closed economy where agents produce a composite consumption good over two periods, t = 1, 2. Each period has one representative agent who exists for that period only. While each period has its own representative agent, all agents across periods are identical in their preferences, production function, and total labor endowment L. For simplicity I assume agents do not value leisure. They allocate their labor between resource extraction, L_r, and final good production, L_f. Resource extraction is a linear function of labor and follows:

$$r_t = r(L_{rt}) = L_{rt}, \tag{1}$$

Where r_t is the resources extracted for use in period t, so one unit of labor extracts one unit of resource. The resource stock available in the following period is defined as $R_{t+1} = R_t - r_t$. The use of resources in the production process generates pollution, which has a deleterious effect on welfare in future periods. The use of the resource in final good production generates pollution at a constant one-to-one rate, while pollution already in existence dissipates, giving rise to the pollution growth function

$$P_{t+1} = \delta P_t + r_t, \quad (2)$$

where P_t is pollution in period t and $0 \leq \delta \leq 1$. This may seem like a strong assumption, but it is based on a reasonable argument. Clearly an agent will not commit labor to extract resources and then not use the resources in production, so resources extracted will always equal resources used in production. Assuming the resource is homogeneous, the first unit used should not produce more pollution than the n^{th} unit. The one assumption that is unrealistic is the assumption that the marginal productivity of labor in resource extraction is constant. This assumption was made for simplicity and could be relaxed in future manifestations of this model. Production in each period is Cobb-Douglass and exhibits constant returns to scale. Production takes the form

$$Y_t = F(L_{ft}, r_t) = T_t L_{ft}^{\alpha} r_t^{1-\alpha} = T_t L_{ft}^{\alpha} L_{rt}^{(1-\alpha)}. \quad (3)$$

In this formulation $0 < \alpha < 1$ and T_t represents total factor productivity in period t. Output can be used as either current consumption or invested in research and development (R&D), $Y_t = C_t + A_t$, where C_t is consumption and A_t is R&D spending in time period t. Consumption represents the benefit of production for the current population, while R&D reflects production that improves total factor productivity for future periods. In this way, TFP evolves according to the rule

$$T_{t+1} = \gamma T_t + \rho A_t, \quad (4)$$

Where $\gamma > 1$ reflects advances in TFP that occur even in the absence of R&D and ρ reflects the marginal contribution of research and development to TFP. While I acknowledge that assuming R&D spending benefits only the future is at best tenuous and more likely highly inaccurate, such an assumption is made for the sake of model simplicity and exists without loss of generality. The important (and certainly not groundbreaking) finding regarding R&D spending is that the social planner will choose a level of R&D spending higher than the level chosen by an individual optimizer. If the social planner allocates X units to R&D, it makes no real difference whether the private optimizer allocates zero or X/2, the basic qualitative finding is the same.

Utility in each period is given by the utility function

$$U_t(C_t, P_t) = \log(C_t) - D(P_t) = \log(Y_t - A_t) - \varphi P_t^{1+\theta}, \tag{5}$$

Where D(.) is the pollution damage function and U(.) is monotonically increasing and concave in its first argument. $\theta > 0$, which implies that damages are convex in P_t. Convexity of the environmental damage function is a common assumption of the literature (see, for example, Babu, Kavi Kumar, and Murthy 1997). Often environmental quality enters positively and concavely into the utility function. This is equivalent to a convex environmental quality damage function. I also considered the model assuming values of θ between -1 and 0, reflecting strict concavity of the environmental damage function, and the results were not significantly different. Additionally and without loss of generality, we assume that $P_1 = 0$. We also assume that R_1 is sufficiently large so that resource constraints will not bind in either period.

Section 3: Individual and Planner Optimizations

In this section, I examine two possible outcomes: that of the agent in each period optimizing their individual utility function and that of a social planner optimizing an additive combination of welfare for both periods. In the individual optimization scenario, the first period faces the following problem:

$$\max_{L_{f1},\, L_{r1},\, A_1} \{\log(T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - A_1)\}, \tag{6}$$

subject to $L_{f1} + L_{r1} \leq L,$

$$0 \leq A_1, L_{f1}, L_{r1}.$$

In this scenario, the constraint on A_1 is binding, so no R&D spending occurs in equilibrium. The first order conditions for L_{f1} and L_{r1} are as follows:

$$L_{f1}: \quad \frac{\alpha T_1 L_{f1}^{\alpha - 1} L_{r1}^{(1-\alpha)}}{T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - A_1} = \mu, \tag{7}$$

$$L_{r1}: \quad \frac{(1\text{-}\alpha) T_1 L_{f1}^{\alpha} L_{r1}^{-\alpha}}{T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - A_1} = \mu, \tag{8}$$

where μ is the Lagrange multiplier for the labor constraint. Combining equations (7) and (8), we derive the following equality:

$$(1\text{-}\alpha) T_1 L_{f1}^{\alpha} L_{r1}^{-\alpha} = \alpha T_1 L_{f1}^{\alpha - 1} L_{r1}^{(1-\alpha)}. \tag{9}$$

Explicit values for L_{f1} and L_{r1} are easily found and shown in the appendix, but the important result is that period 1 allocates labor so as to equate the marginal products of the two labor choices, $MPL_{f1} = MPL_{r1}$. Period 2 is faced with a similar, but not identical, optimization problem:

$$\max_{Lf2,\ Lr2,\ A2} \{ \log(\gamma T_1 L_{f2}^{\alpha} L_{r2}^{(1-\alpha)} - A_2) - \varphi L_{r1}^{(1+\theta)} \}, \tag{10}$$

subject to $L_{f2} + L_{r2} \leq L,$

$$0 \leq A_2, L_{f1}, L_{r1}.$$

Once again, I find that the R&D constraint binds, leaving A_2 equal to zero. In addition, period 2 will also allocate labor in a manner that equates the marginal product of L_{f2} with the marginal product of L_{r2}.

I turn next to the central planner's problem. The goal of the central planner is defined here as maximizing the weighted sum of period-specific utilities. This can be formally written as

$$\max_{\substack{Lf1, Lr1, A1, \\ Lf2,\ Lr2,\ A2}} \quad \{ \log(T_1 L_{f1}{}^{\alpha} L_{r1}{}^{(1-\alpha)} - A_1) +$$

$$\beta[\log((\gamma T_1 + \rho A_1) L_{f2}{}^{\alpha} L_{r2}{}^{(1-\alpha)} - A_2) - \varphi L_{r1}{}^{(1+\theta)}]\} \qquad (11)$$

Subject to $\quad L_{f1} + L_{r1} \leq L,$

$$L_{f2} + L_{r2} \leq L,$$

$$0 \leq A_1, A_2, L_{f1}, L_{r1}, L_{f2}, L_{r2}.$$

In this formulation, β is the weight assigned to period 2 and the weight assigned to period 1 is normalized to 1. I use the term "weighted sum," as opposed to "discounted sum" because I put no restrictions on the value of β. The typical restriction in the literature is $\beta < 1$. This is sometimes due to mathematical necessity and sometimes stems from the observation that individuals tend to discount future consumption. In either case, I find it an unnecessary assumption for the purposes of this model.

As is demonstrated in the appendix, the planner's allocation of labor and R&D in period 2 is identical to the allocations achieved using the individual optimization method. There is, however, an important difference in period 1 allocations between the two solution methods, assuming $\beta \neq 0$ (If $\beta = 0$, the planner's problem becomes equivalent to the problem faced by period 1 in the individual optimization problem). This divergence can be seen by considering the first order condition with respect to L_{r1},

$$\frac{(1\text{-}\alpha)T_1L_{f1}^{\alpha}L_{r1}^{-\alpha}}{T_1L_{f1}^{\alpha}L_{r1}^{(1-\alpha)} - A_1} = \mu_1 + \beta\,\varphi(1+\theta)L_{r1}^{\theta}. \qquad (12)$$

In this formulation, μ_1 is the Lagrange multiplier associated with the period 1 labor constraint. Combining equation (12) with the first order condition with respect to L_{f1} (which is identical to the result in the individual optimization example, equation (7)) yields a new maximization condition:

$$\frac{(1\text{-}\alpha)T_1L_{f1}^{\alpha}L_{r1}^{-\alpha}}{T_1L_{f1}^{\alpha}L_{r1}^{(1-\alpha)} - A_1} = \frac{\alpha T_1L_{f1}^{\alpha-1}L_{r1}^{(1-\alpha)}}{T_1L_{f1}^{\alpha}L_{r1}^{(1-\alpha)} - A_1} + \beta\,\varphi(1+\theta)L_{r1}^{\theta}. \qquad (13)$$

A rather intuitive and well documented result can be seen from this equation. Individual welfare maximization yields different allocations for labor than does the social planner maximization, so long as the social planner uses a nonzero weight β. In this way, intergenerational externalities are no different than externalities imposed upon contemporary agents. In addition to this finding, we can derive an optimal level of A_1 from the first order condition as shown below:

$$A_1 = \frac{\rho\beta TL_{f1}^{\alpha}L_{r1}^{(1-\alpha)} - \gamma T}{\rho(1+\beta)}\,. \qquad (14)$$

Analysis of this finding enables us to state the following proposition:

Proposition 1: The equilibrium value of A_1 in the social planner's problem will be strictly positive (and therefore different from the individual optimization scenario) provided $\gamma < \rho\beta\, L_{f1}^{\alpha}L_{r1}^{(1-\alpha)}$. In addition, the equilibrium value of A_1 is negatively correlated with the parameter γ and positively correlated with β and ρ.

The derivations of the comparative statics that support Proposition 1 are in the appendix. These findings are supported by economic intuition, as one would expect that increasing the relative weight assigned to period 2, β, places more emphasis on future welfare and results in a higher equilibrium A_1. Similarly, increasing ρ (the marginal increase in TFP from R&D spending) increases the marginal future gains from research and development, and as such increases in ρ result in greater equilibrium A_1. Lastly, increasing γ (the multiplicative increase in TFP in the absence of R&D) while keeping ρ constant decreases the productivity gains from R&D relative to the baseline productivity gains achieved without R&D spending. In other words, increasing γ makes the future better off, and as such the need for R&D spending is lessened and equilibrium A_1 falls. In addition to the externality produced by the resource, the planner's scenario corrects the externality related to research and development. When optimizing individually, the first period underinvests in R&D, just as they overexploit the resource.

As mentioned earlier, setting $\beta = 0$ collapses the planner's problem into the period 1 individual optimization problem. Setting $\beta = 0$ in equation (14) returns a negative number. Combining this finding with the nonnegativity constraint presented in equation (11) yields an equilibrium level of R&D spending of zero, the same result found in the individual optimization problem.

Equations (13), (14), and the labor constraint give us three equations which we can use to find equilibrium solutions for the three variables in question: A_1, L_{f1}, and L_{r1}. The equilibrium values cannot be obtained analytically, but instead must be derived using numerical methods. This will be done for a variety of parameter values in Section 6.

Section 4: Coasian Bargaining

I now assume the existence of a societal agency that can assign and enforce property rights between different generations. Such an agency is not far-fetched, as governments routinely protect natural resources, such as forestry and wildlife, in order to ensure their existence for future generations. This, in essence, this is equivalent to the assignment of property rights to agents in the future. We will also assume that this agency performs its duties at no cost.

This agency could assign the resource rights to either period 1 or period 2. The pattern of property rights assignment has important welfare and equity implications for the model (for a more detailed elaboration, see Howarth and Norgaard 1990). In the context of our current model, it makes more sense to assign the resource rights to period 2 for several reasons. First, the model is composed in such a manner as to leave period 2 no means to pay period 1 in exchange for the right to use resources (There are, of course, viable methods of compensation from the future to the present, foremost among them being the ability of the present to acquire deficits that must be paid off by the future). In addition, there is reason to believe that compensation should be paid by the party that is imposing the externality, in this case period 1, rather than by the "victim." This is known as the polluter pays principle (Conversely, it may also be argued that productivity gains will make the future more affluent than their present counterparts, and as such the future is in a better position to bear the weight of compensation). Lastly, a positive externality exists in the model in the extent to which period 1 engages in R&D. By assuming that period 1 is under no obligation to generate research and development, I implicitly assign property rights to period 1 (i.e. the right to not engage in R&D). By assigning the resource rights to the future, I am assigning one set of rights to each period.

Once property rights have been accordingly assigned, I model negotiations between periods in the form of an ultimatum game similar to Schweizer (1988) in which the period 1 agent makes an offer (A_1, r_1) and the agency, representing the interests of the period 2 agent, can either accept or reject. In the offer, compensation will be paid to period 2 in the form of increased levels of period 1 R&D. This will be accompanied by period 2 granting the right of period 1 to extract and use a specified amount of the resource, r_1. Because period 2 controls the resource property rights and the resource stock is sufficiently large, the optimal allocation for period 2 will be identical to the allocations found in the previous section of the paper. Period 2 will accept any offer so long as the resultant utility from accepting the offer is greater than or equal to the utility achieved without the offer. Formally, the offer must satisfy the following condition:

$$\log((\gamma T_1 + \rho A_1)L_{f2}{}^{\alpha}L_{r2}{}^{(1-\alpha)}) - \varphi r_1{}^{(1+\theta)} \geq \log(\gamma T_1 L_{f2}{}^{\alpha}L_{r2}{}^{(1-\alpha)}). \tag{15}$$

Rearranging this condition, period 2 will accept any offer (r_1, A_1) that satisfies

$$r_1 \leq \varphi^{-1}(\log[\frac{(\gamma T_1 + \rho A_1)}{\gamma T_1}])^{1/(1+\theta)}. \tag{16}$$

This equation can be rewritten to solve for A_1 and combined with equation (1) to yield

$$A_1 \geq [\gamma T_1 \exp(\varphi L_{r1}{}^{(1+\theta)}) - \gamma T_1]/\rho. \tag{17}$$

Because period 1 gets no direct benefit from A_1, this will hold with equality.

The comparative statics (see appendix for derivations) for equation (17) allow me to make the following proposition:

Proposition 2: The equilibrium value A_1 in the Coasian bargaining scenario is increasing in L_{r1} and γ (the multiplicative increase in TFP in the absence of R&D) and is decreasing in ρ (the marginal increase in TFP from R&D spending).

This is an interesting finding, as the comparative statics for γ and ρ in the social planner's problem were decreasing and increasing, respectively. This difference can be explained by considering the different goals of the decision makers in each problem. In the planner's problem, the planner chooses a level of R&D in which the marginal benefits of research and development equal the marginal costs. Increasing ρ in this case increases the marginal benefits without affecting the marginal costs to the present, and as such A_1 increases with ρ. Conversely, increasing γ decreases the marginal effectiveness of R&D spending due to the concavity of the utility function, and as such A_1 decreases with increases in γ. In the Coasian bargaining solution the equilibrium equation is set by the agent in period 1. Her goal is to equalize the total benefits of R&D with the total damages incurred in period 2 from resource use in period 1.[2] In this case, increasing ρ increases the total benefits of A_1, so for a given level L_{r1} the amount of R&D spending needed to equalize total benefits and damages is lower. Increasing γ, on the other hand, effectively decreases the utility gained from a given level of R&D spending. As a result, period 1 must offer a greater level of A_1 to equalize utility gains with utility losses for period 2. Ergo, increasing γ increases equilibrium A_1.

Using equation (17), which I will call the acceptance constraint, I can now articulate the maximization problem faced by period 1:

[2] In a world where the resource constraint is binding, Period 1 must set the total benefits of R&D equal to the total damages in period 2 resulting from period 1 using the resource plus the disutility from lost production in period 2 due to the transfer of resources to period 1.

$$\max_{L_{f1},L_{r1}} \{ \log[T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - (\gamma T_1 \exp(\varphi L_{r1}^{(1+\theta)}) - \gamma T_1)/\rho] \} \tag{18}$$

Subject to $L_{f1} + L_{r1} \leq L$,

$0 \leq L_{f1}, L_{r1}$.

The first order conditions are as follows:

$$L_{f1}: \frac{\rho\alpha T_1 L_{f1}^{\alpha-1} L_{r1}^{(1-\alpha)}}{\rho T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - (\gamma T_1 \exp(\varphi L_{r1}^{(1+\theta)}) - \gamma T_1)} = \mu, \tag{19}$$

$$L_{r1}: \frac{\rho(1\text{-}\alpha) T_1 L_{f1}^{\alpha} L_{r1}^{-\alpha} - \gamma T \varphi(1+\theta) L_{r1}^{\theta} \exp(\varphi L_{r1}^{(1+\theta)})}{\rho T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - (\gamma T_1 \exp(\varphi L_{r1}^{(1+\theta)}) - \gamma T_1)} = \mu. \tag{20}$$

Solving for μ leaves two variables (L_{r1} and L_{f1}) and two equations (a combination of equations (19) and (20) as well as the labor constraint). The equilibrium solutions for these variables cannot be solved analytically, but they are obtained through numerical methods in Section 6.

Section 5: Tax and Subsidy Regime

I will now consider the equilibrium allocation of labor and R&D when a different policy instrument is being used, specifically a tax and subsidy regime. In this policy, the government will levy a per-unit tax τ on resource use in the present. The revenue from this tax will then be invested in research and development. The agent in each time period optimizes individually, but takes the government's tax/subsidy as given. We assume that the government can see the optimal response to the tax from both periods and can use this knowledge to choose a tax level that maximizes the government's social welfare function (SWF), which we take to be equivalent to the social planner's SWF outlined in Section 3. In this case, period 1 faces the following optimization problem:

$$\max_{L_{f1}, L_{r1}, A_1} \mathrm{Log}(TL_{f1}{}^{\alpha}L_{r1}{}^{1-\alpha} - \tau L_{r1} - A_1), \tag{21}$$

$$\text{Subject to} \quad L_{f1} + L_{r1} \le L,$$

$$0 \le A_1, L_{f1}, L_{r1}\,.$$

As in the individual optimization scenario, the chosen level of A_1 will be zero. The other two first order conditions can be combined to yield the following equality:

$$\alpha TL_{f1}{}^{\alpha-1}L_{r1}{}^{1-\alpha} = (1-\alpha)TL_{f1}{}^{\alpha}L_{r1}{}^{-\alpha} - \tau. \tag{22}$$

This equation shows that the optimal distribution of labor in period 1 depends on the tax rate τ. The allocations of L_{f2}, L_{r2}, and A_2 are not influenced by τ. A demonstration of this is included in the appendix.

The government is then faced with the following optimization problem:

$$\max_{\tau} \quad \{\mathrm{Log}[TL_{f1}(\tau)^{\alpha}L_{r1}(\tau)^{1-\alpha} - \tau L_{r1}(\tau)] +$$

$$\beta(\mathrm{Log}[(\gamma T + \rho\tau L_{r1}(\tau))L_{f2}(\tau)^{\alpha}L_{r2}(\tau)^{1-\alpha}] - \varphi L_{r1}(\tau)^{1+\theta}), \tag{23}$$

$$\text{Subject to} \quad 0 \le \tau.$$

This problem can equivalently be written:

$$\max_{Lf1,Lr1,\tau} \quad \mathrm{Log}[TL_{f1}{}^{\alpha}L_{r1}{}^{1-\alpha} - \tau L_{r1}] +$$

$$\beta(\mathrm{Log}[(\gamma T + \rho\tau L_{r1})L_{f2}{}^{\alpha}L_{r2}{}^{1-\alpha}] - \varphi L_{r1}{}^{1+\theta}), \tag{24}$$

Subject to $L_{f1} + L_{r1} \leq L$,

$$\alpha T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha} = (1-\alpha) T L_{f1}^{\alpha} L_{r1}^{-\alpha} - \tau.$$

This optimization problem cannot be solved analytically. However, using the second constraint in equation (24) I can eliminate τ in the maximization problem. After doing so, the first order conditions are as follows:

$$L_{f1}: \quad \frac{\alpha T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha} - \alpha(1-\alpha) T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha} + \alpha(\alpha-1) T L_{f1}^{\alpha-2} L_{r1}^{2-\alpha}}{\alpha T L_{f1}^{\alpha} L_{r1}^{1-\alpha} + \alpha T L_{f1}^{\alpha-1} L_{r1}^{2-\alpha}} +$$

$$\frac{\beta[\rho(\alpha(1-\alpha) T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha} - \alpha(\alpha-1) T L_{f1}^{\alpha-2} L_{r1}^{2-\alpha})]}{\gamma T + \rho[(1-\alpha) T L_{f1}^{\alpha} L_{r1}^{1-\alpha} - \alpha T L_{f1}^{\alpha-1} L_{r1}^{2-\alpha}]} = \mu, \qquad (25)$$

$$L_{r1}: \quad \frac{(1-\alpha) T L_{f1}^{\alpha} L_{r1}^{-\alpha} - (1-\alpha)^2 T L_{f1}^{\alpha} L_{r1}^{-\alpha} + \alpha(2-\alpha) T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha}}{\alpha T L_{f1}^{\alpha} L_{r1}^{1-\alpha} + \alpha T L_{f1}^{\alpha-1} L_{r1}^{2-\alpha}} +$$

$$\beta\left[\frac{\rho[(1-\alpha)^2 T L_{f1}^{\alpha} L_{r1}^{-\alpha} - \alpha(2-\alpha) T L_{f1}^{\alpha-1} L_{r1}^{1-\alpha}]}{\gamma T + \rho[(1-\alpha) T L_{f1}^{\alpha} L_{r1}^{1-\alpha} - \alpha T L_{f1}^{\alpha-1} L_{r1}^{2-\alpha}]} - \varphi(1+\theta) L_{r1}^{\theta}\right] \qquad (26)$$

$$= \mu,$$

where μ is the Lagrange multiplier for the labor constraint. Solving for μ leaves two variables and two equations (a combination of (25) and (26) as well as the labor constraint). The equilibrium allocations cannot be solved analytically, but may be solved using numerical methods.

Section 6: Numerical Methods and Robustness

In order to compare the welfare effects of the four scenarios outlined in Sections 3-5, numerical analysis is required. Welfare is evaluated using the weighted sum social welfare function (SWF) optimized in the social planner's problem. The baseline values used in the numerical analysis, as well as parameter ranges used in sensitivity analysis and a brief description of the parameter, are presented in Table 1.

Table 1: Parameter Ranges for Numerical Solutions

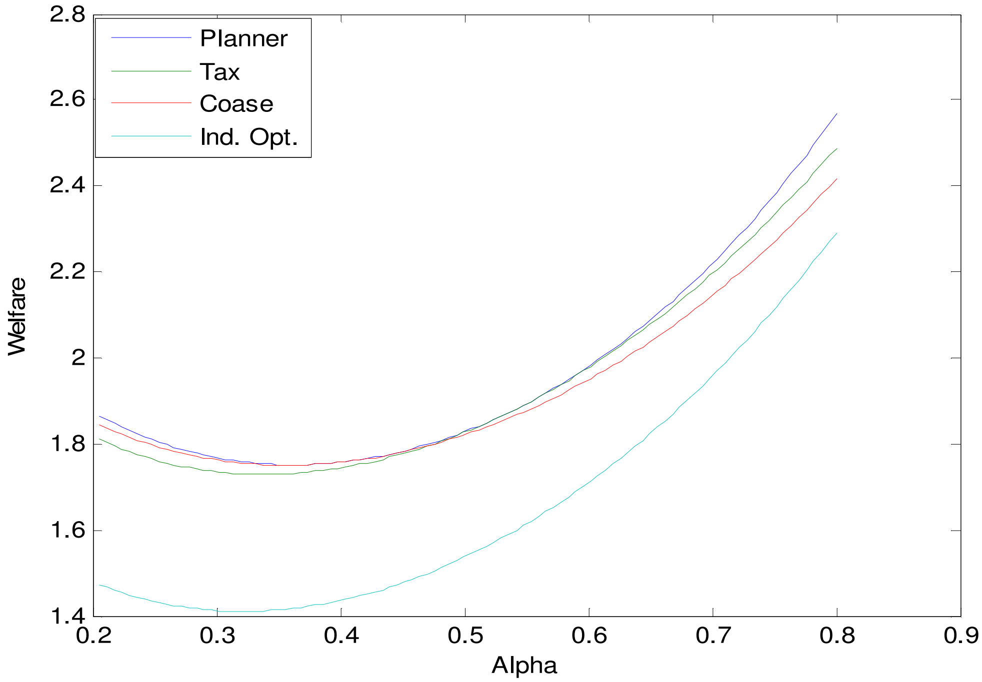
Parameter	Description	Baseline Value	Range
α	Output elasticity of L_{fi}, i=1,2; Exponential parameter for L_f in the production function	0.65	0.2 : 0.8
β	Weight assigned to 2^{nd} period utility in SWF	0.95	0.1 : 1.1
γ	Multiplicative increase in TFP in the absence of R&D	1.4	1 : 4
φ	Multiplicative parameter in the pollution damage function	0.2	0 : 1
ρ	Marginal increase in TFP from R&D spending	1.3	0.3 : 2.3
θ	Exponential parameter $(1+\theta)$ in the pollution damage function	0.2	0 : 2
L	Total endowment of labor in each period	5	None
T_1	TFP in period 1	1	None

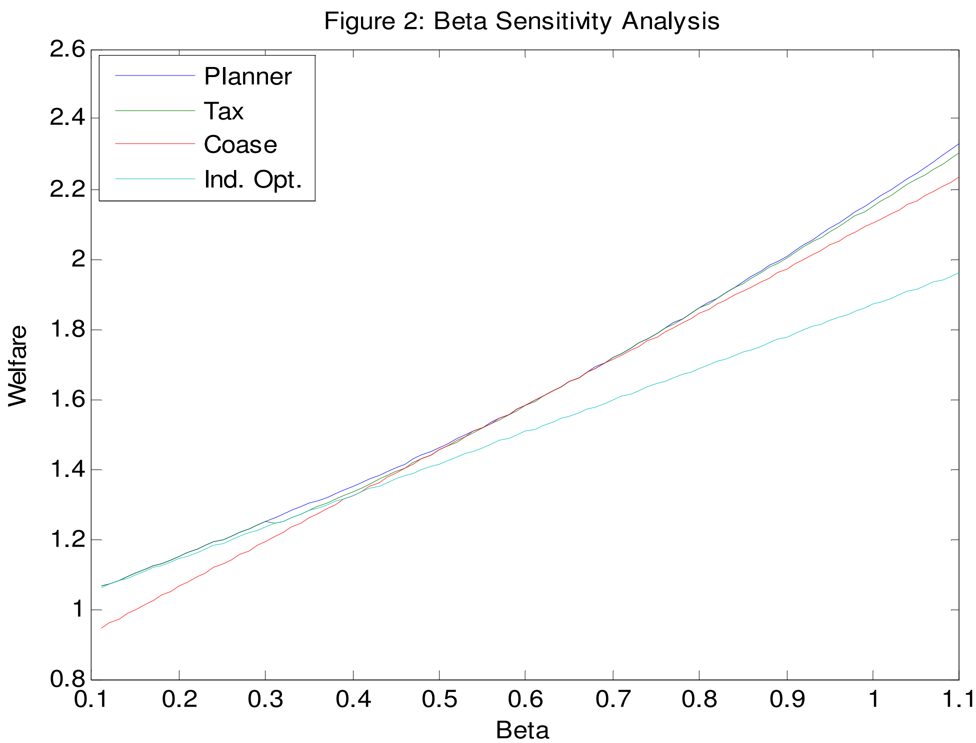
Figures 1 through 6 are sensitivity analyses for six different parameters in the model. They deal with α, β, γ, φ, ρ, and θ, respectively. Each graph illustrates welfare achieved in the four scenarios outlined in this paper: The individual optimization solution (IO), the planner's solution (P), the Coasian bargaining solution (C), and the tax-and-subsidy solution (TS). Three conclusions can be drawn from the sensitivity analyses.

Proposition 3: both the TS regime and the C regime are significant improvements over the IO solution. The welfare achieved in IO rivals that of TS and C only in two instances: very low values of ρ and very low values of β.

This outcome makes intuitive sense. The individual optimization scenario leads to no R&D spending and heavily favors utility in the present over utility in the future. Decreasing the value of ρ (the marginal increase in TFP from R&D spending) decreases the marginal benefit of

Figure 1: Alpha Sensitivity Analysis





R&D spending, while decreasing β (the weight assigned to 2^{nd} period utility in SWF) puts less importance on the future in the social welfare function.

Proposition 4: Each figure, with the exception of Figure 6 (θ Sensitivity Analysis), has a parameter value at which both C and TS achieve the first-best welfare level of the planner problem. The parameter values at which this convergence occurs for C and TS are similar.

The exception to this finding is the sensitivity analyses for θ (the exponential parameter in the pollution damage function). As illustrated in Figure 6, adjusting θ has an identical impact on welfare in both C and P. Therefore, if the parameter values are such that there is a disparity in welfare between C and P, adjusting θ cannot close the gap.

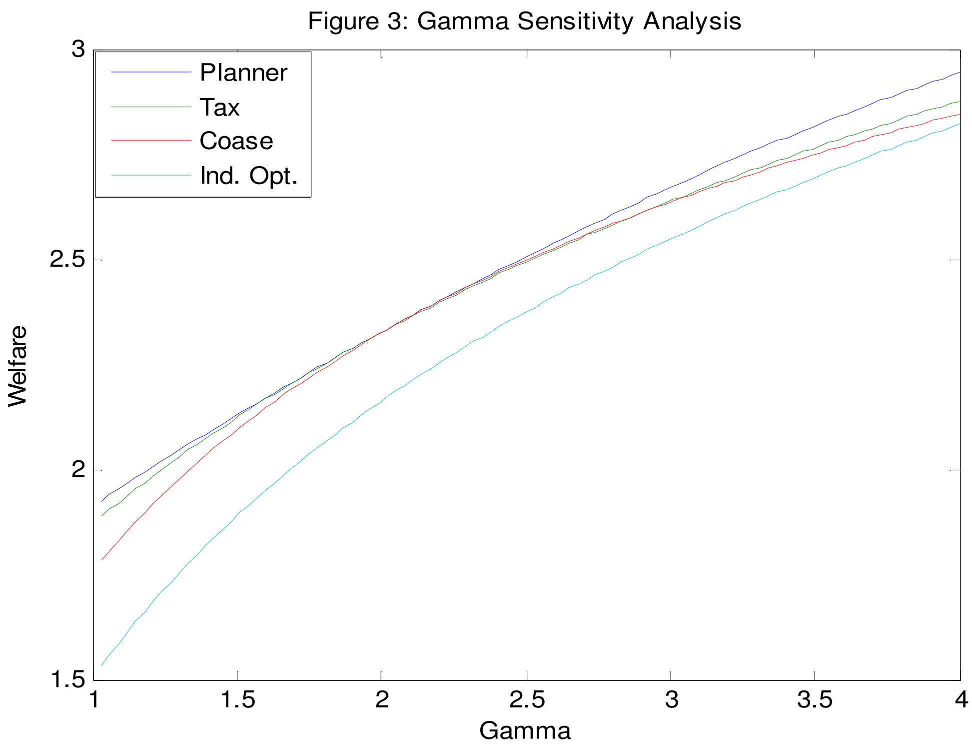


Figure 3: Gamma Sensitivity Analysis
Planner
Tax
Coase
Ind. Opt.
Welfare
Gamma
1.5
2
2.5
3
1
1.5
2
2.5
3
3.5
4

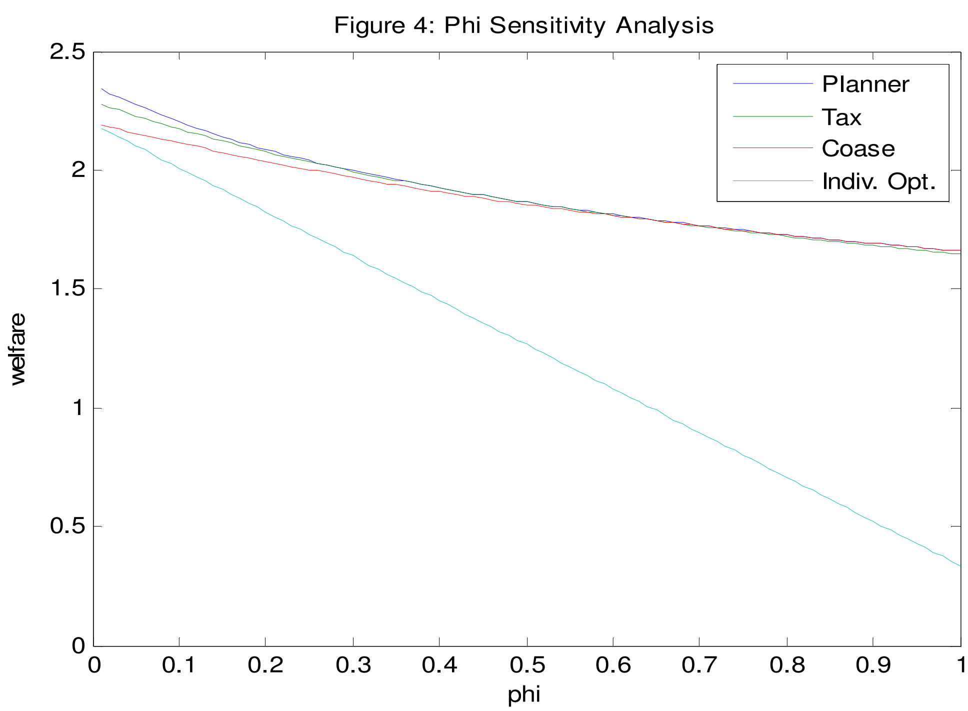


Figure 4: Phi Sensitivity Analysis
Planner
Tax
Coase
Indiv. Opt.
welfare
phi
0
0.5
1
1.5
2
2.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

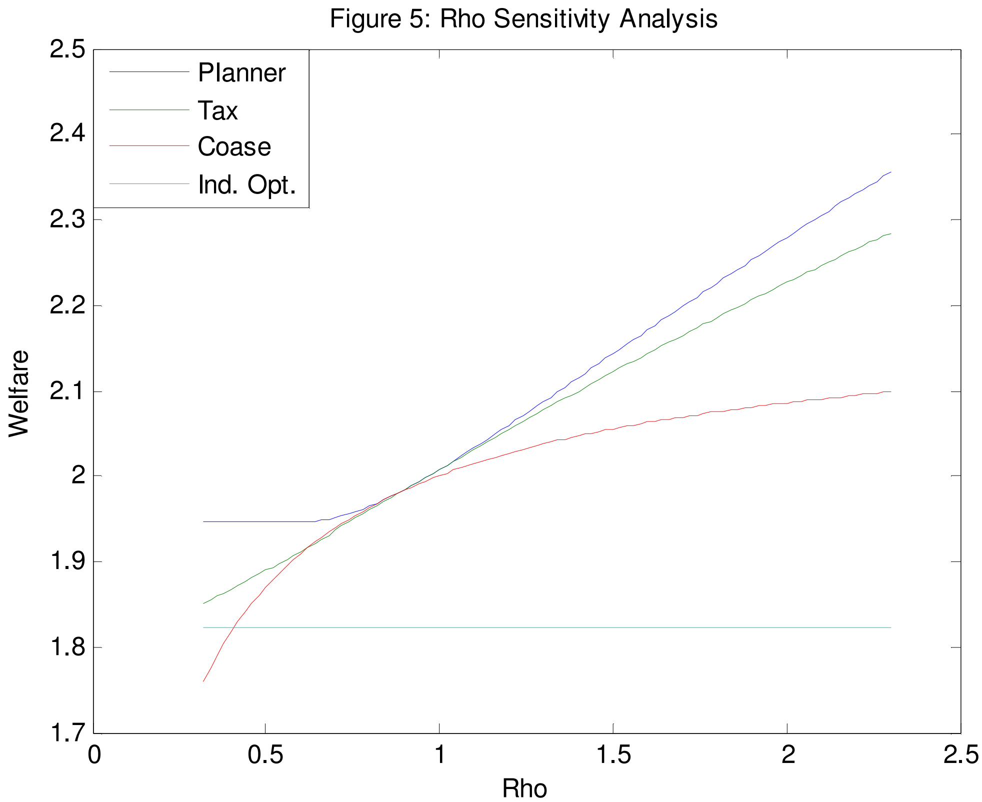


Figure 5: Rho Sensitivity Analysis
Planner
Tax
Coase
Ind. Opt.
Welfare
Rho
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
0
0.5
1
1.5
2
2.5

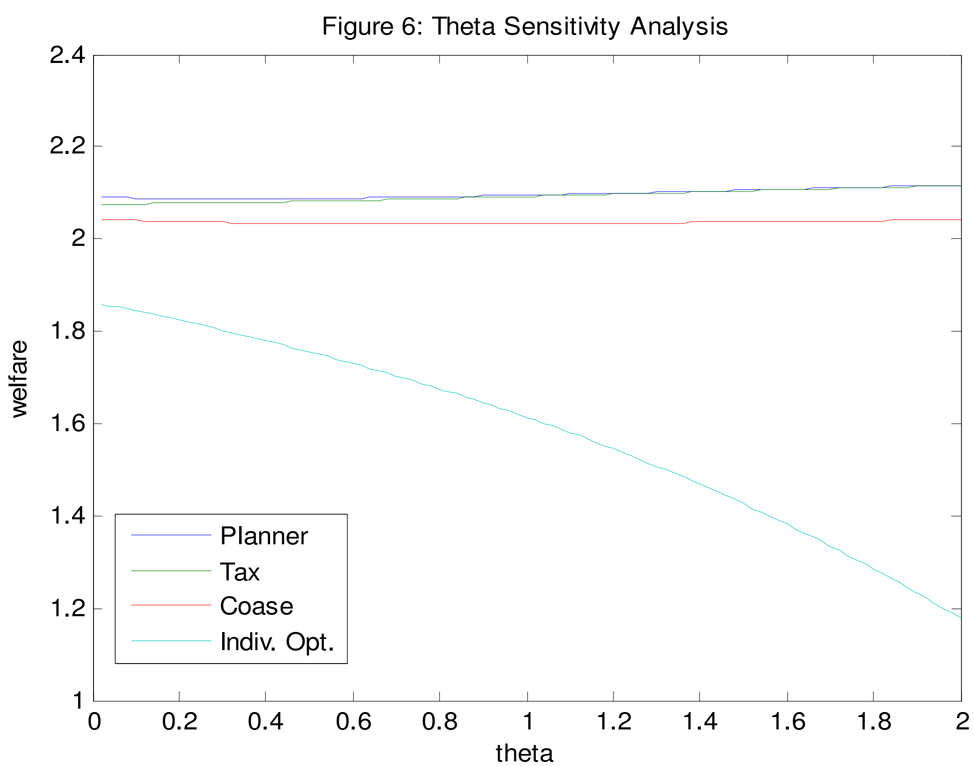
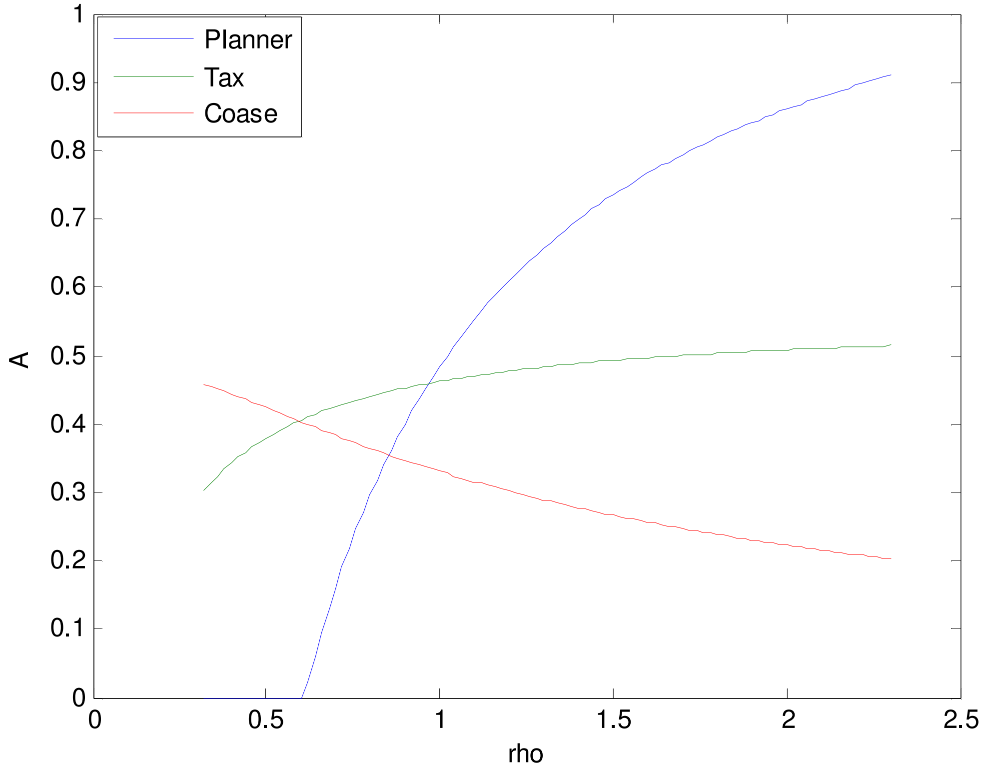


Figure 6: Theta Sensitivity Analysis
Planner
Tax
Coase
Indiv. Opt.
welfare
theta
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Proposition 5: As each parameter moves away from the range where both policy instruments achieve their first-best outcomes, TS tends to outperform C. The one exception is Figure 1 (α Sensitivity Analysis).

The difference is modest for all parameters except ρ (the marginal increase in TFP from R&D spending), where the divergence in welfare between a tax-and subsidy regime and the Coasian bargaining regime is significant. My discussion of the comparative statics for ρ in section 4 may explain this result, as changing ρ has different marginal effects in C than it does in P and TS. This difference is also highlighted in Figure 7, which shows that the Coasian bargaining solution has equilibrium R&D decreasing in ρ while the Planner and Tax-and-subsidy solutions have equilibrium R&D increasing in ρ. In addition, Figure 1 shows that C outperforms

Figure 7: Sensitivity Analysis Between Rho and Equilibrium R&D



TS for low values of α (the exponential parameter for L_f in the production function), while the converse is true for high values of α.

It is reasonable to question how robust these results are, given that they assume a specific SWF when evaluating welfare outcomes in each scenario. The specific social welfare function used throughout this paper is as follows:

$$W = U(C_1, P_1) + \beta\, U(C_2, P_2), \qquad (28)$$

where $U(C_i, P_i) = \log(C_i) - \varphi P_i^{1+\theta}$, $i = 1,2$. To test the robustness of my results, I reevaluate the four scenarios in the model and perform sensitivity analysis using a social welfare function that displays inequality aversion. This inequality averse (IA) SWF is as follows:

$$W = U(C_1, P_1) + \beta\, U(C_2, P_2) - \kappa[U(C_1, P_1) - U(C_2, P_2)]^2. \qquad (29)$$

Sensitivity analyses for both social welfare functions are shown side-by-side in the appendix. The propositions put forth earlier in this section all still hold using a social welfare function that displays inequality aversion with a few small caveats. First, C does significantly worse for high values of γ (the multiplicative increase in TFP in the absence of R&D) using the IA SWF, even achieving less welfare than IO. Second, unlike with the normal SWF, C does not outperform TS for low values of α using the IA SWF. Lastly, C does outperform TS (though not by much) in the sensitivity analysis of θ (the exponential parameter in the pollution damage function) using the IA SWF. With these small exceptions, the findings of this paper are borne out even under changes in the functional form of the social welfare function, which suggests that the results and conclusions herein are robust.

It is also reasonable to question whether the results presented above are due to the 2 period nature of the model. In order to test whether the above propositions hold when the number of periods is increased, the model was extended by adding a third period. In doing so, relatively few changes were necessary for the individual optimization and planner scenarios. The SWF used in the planner and tax scenarios becomes $W = U(C_1) + \beta U(C_2) + \beta^2 U(C_3)$. For the Coasian bargaining scenario, joint ownership of the resource in period 1 is given to the period 2 and 3 agents. This means that an offer must be made by the period 1 agent which is accepted by the agents of both subsequent periods in order for the period 1 agent to have access to the resource. However, this additional complication does not affect the resultant offer. This is made evident by the following proposition:

Proposition 6: Any offer accepted by the period 2 agent will be accepted by the period 3 agent so long as $\delta \leq 1$ (Proof in the appendix).

In period 2, ownership of the resource is given to the period 3 agent, so the period 2 and 3 agents must likewise bargain over allocation of the resource and R&D spending.

In the tax and subsidy scenario, two distinct taxes and subsidies are levied. The government chooses the optimal tax rates, and by extension the optimal subsidies, by maximizing the planner SWF subject to resource and feasability constraints as well as the constraints that outline how agents in periods 1 and 2 will react to taxes. For simplicity I assume that all of the period 1 tax is immediately spent on the period 1 subsidy. The assumption is trivial in the present model, as period 1 R&D spending is clearly more valuable to the social planner/government than period 2 R&D spending. This is a result of period 1 R&D being beneficial to production on both periods 2 and 3, while period 2 R&D is beneficial to production in period 3 alone. With the introduction of additional avenues of investment with some positive rate of return, however, this assumption may be more restrictive. While it is clear that one unit of A_1 is preferred to one unit of A_2, it is possible that (1+r) units of A_2 is preferred to one unit of A_1, where r is the rate of return on the alternative investment. For the purposes of the present model, however, this is not an issue.

As can be seen in the appendix, including a third period to the model does not significantly impact any of the findings presented above, and in fact the sensitivity analyses performed on the main parameters are strikingly similar between the 2- and 3-period models. This suggests that the results are not an artifact of the small number of periods, but in fact are robust to variations of model length.

Section 7: Conclusion

Intergenerational externalities add a layer of uncertainty that is generally absent in their intragenerational counterparts. In order to properly internalize such an externality, one must make assumptions about the endowments and preferences of a party that has not yet been born. This is true no matter what policy instrument one uses. It has, however, been argued that Coasian Bargaining is particularly ill-equipped to handle intergenerational externalities, as negotiations between the present and future are seen as impossible. However, the appointment of a contemporary party to represent the interests of the future in present-day negotiations allows bargaining policies to circumvent such difficulties. There are additional objections that may be raised regarding the ability and willingness of any contemporary party to know and represent the interests of the future, but I argue that these same problems also exist for any alternate policy option. Moreover, allowing a governing body to represent the future in property rights negotiations is appealing in the sense that it will drastically diminish transaction costs, one of the main inhibitors of Coasian bargaining theory. Declining negotiation costs is a common outcome whenever a governing body is able to adequately represent the interests of a large, diverse, and widespread group.

In this paper I consider a two period model in which two externalities exist. One externality concerns pollution created in resource extraction and production, while the other stems from underinvestment in research and development. I show that each time period maximizing their personal welfare leads to allocations that are different from the first-best allocations derived using the planner's problem. Next, I consider a Coasian bargaining situation in which the present has the right to invest nothing in R&D while the future controls the property rights of the resource needed for production. I derive the condition under which the equilibrium bargaining outcome achieves allocations equivalent to the planner's problem, as well as how deviations from this condition affect both externalities. I then compare the effectiveness of Coasian bargaining policy to a tax-and-subsidy policy. I find that, in general, the tax-and-subsidy policy fares slightly better than the Coasian bargaining policy, but not in such a significant way as to warrant completely dismissing Coasian bargaining as a potential policy instrument.

While it is true that the tax-and-subsidy regime marginally outperforms the Coasian bargaining regime in my model, I do not find this to be a discouraging result. The theme and important finding of this paper is not that Coasian bargaining is at all times a superior policy instrument when dealing with intergenerational externalities. Rather, this paper demonstrates that the traditional notion of Coasian bargaining, which makes no intuitive sense in intergenerational issues, can be adapted and adjusted into a form that is feasible and, from a welfare perspective, competitive with other potential policies. Clearly there will be issues for which the cost of enforcing property rights will be immense, or transaction cost will be prohibitive. For these issues, Coasian bargaining will not be feasible. However, if issues exist for which these problems are not as pronounced and a tax or quantity regulation has proven exceedingly difficult, either economically or politically, Coasian bargaining may be an effective and welcome alternative.

As an example, suppose a large quantity of fossil fuel was discovered on a tract of land owned by the government. Several companies are vying for the right to extract and sell the resource. The government is mindful of the intergenerational externalities that exist in fossil fuel consumption, and as such wish to increase the price in an attempt to optimize the extraction path of the resource. One method they could use to this end is to allow companies to submit bids and accept the bid that is deemed the best for the future, provided accepting the bid is considered to improve future welfare over letting the resource remain in the ground. These bids could contain multiple compensation methods, from money payments to R&D spending to emissions decreases in other areas of the company, so long as these compensations have a positive impact on future welfare. In this way, the adjusted Coasian Bargaining tool has more potential flexibility than a tax in the right situation.

This is a simple model that can be enriched in many different ways. Possible future extensions of the model include allowing the resource constraint to bind, increasing the number of periods in the model to some arbitrary number N or to infinity, using more general forms or comparing additional different forms of both the individual period utility functions and the social welfare function, and adding altruism to the period utility function. In addition to utility functions, several other functional forms were specified, from production and extraction functions to environmental damage functions. The model could be extended to treat these functional forms more generally. The model could also be changed to include some form of cash or output transfers, with transfers from the future to the present being in the form of debt accumulated by the present and paid by the future. The model could introduce additional frictions in the form of transaction and property rights enforcement costs for Coasian bargaining, as well as implementation and monitoring costs for other policy instruments. The negotiations that take place in the model could be expanded in complexity beyond that of a very basic ultimatum game. Lastly, the basic concept underlying this model could be applied to an overlapping generations (OLG) model form, either over a discrete or infinite time period. Each of these extensions would introduce an additional layer of complexity that could prove informative, both in our theoretical understanding of intergenerational externalities and in our comprehension of the policy options we possess when addressing these externalities.

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Appendix

I) Equilibrium labor allocations when each period optimizes individually

Using equation (9), we can solve for L_{f1} in terms of L_{r1}:

$$L_{f1} = \frac{\alpha}{(1-\alpha)} L_{r1}. \tag{A1}$$

Combining this with the resource constraint yields the equilibrium allocations

$$L_{f1} = \alpha L, \tag{A2}$$

$$L_{r1} = (1 - \alpha)L. \tag{A3}$$

Similarly, we can solve for L_{f2} in terms of L_{r2}:

$$L_{f2} = \frac{\alpha}{(1-\alpha)} L_{r2}. \tag{A4}$$

Combining this with the resource constraint yields the equilibrium allocations

$$L_{f2} = \alpha L, \tag{A5}$$

$$L_{r2} = (1 - \alpha)L. \tag{A6}$$

II) Equilibrium allocations under the social planner

The first order conditions, in addition to equation (12), are

$$L_{f1}: \quad \frac{\alpha T_1 L_{f1}^{\alpha-1} L_{r1}^{(1-\alpha)}}{T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - A_1} = \mu_1, \tag{A7}$$

$$A_1: \quad \frac{1}{T_1 L_{f1}^{\alpha} L_{r1}^{(1-\alpha)} - A_1} = \frac{\beta\rho\, L_{f2}^{\alpha} L_{r2}^{(1-\alpha)}}{(\gamma T_1 + \rho A_1) L_{f2}^{\alpha} L_{r2}^{(1-\alpha)} - A_2}, \tag{A8}$$

$$L_{f2}: \quad \frac{\beta\alpha(\gamma T_1 + \rho A_1) L_{f2}^{\alpha-1} L_{r2}^{(1-\alpha)}}{(\gamma T_1 + A_1) L_{f2}^{\alpha} L_{r2}^{(1-\alpha)} - A_2} = \mu_2, \tag{A9}$$

$$L_{r2}: \quad \frac{\beta(1-\alpha)(\gamma T_1 + \rho A_1)L_{f2}^{\alpha}L_{r2}^{-\alpha}}{(\gamma T_1 + \rho A_1)L_{f2}^{\alpha}L_{r2}^{(1-\alpha)} - A_2} = \mu_2, \tag{A10}$$

where, as noted in the body of the paper, μ_1 is the Lagrangian multiplier associated with the period 1 labor constraint. In addition, μ_2 is the Lagrangian multiplier in the period 2 labor constraint. As in the individual optimization problem, $A_2 = 0$ in equilibrium. Combining equations (A9) and (A10) yields the same equilibrium labor allocations of period 2 as in the individual optimization problem.

III) Comparative Statics for the Social Planner Equilibrium level of A_1

To determine the comparative statics, we take the partial derivative of equation (14) with respect to the parameters of interest (γ, ρ and β):

$$\partial A_1/\partial\gamma = -\frac{T}{\rho(1+\beta)} < 0, \tag{A11}$$

$$\partial A_1/\partial\rho = \frac{\gamma T(1+\beta)}{[\rho(1+\beta)]^2} > 0, \tag{A12}$$

$$\partial A_1/\partial\beta = \frac{\rho^2 T_1 L_{f1}^{\alpha} L_{r1}^{1-\alpha}(1+\beta) - \rho^2\beta T_1 L_{f1}^{\alpha} L_{r1}^{1-\alpha} + \gamma T\rho}{[\rho(1+\beta)]^2}. \tag{A13}$$

This can be simplified to,

$$\partial A_1/\partial\beta = \frac{\rho^2 T_1 L_{f1}^{\alpha} L_{r1}^{1-\alpha} + \gamma T\rho}{[\rho(1+\beta)]^2} > 0. \tag{A14}$$

IV) Comparative Statics for the Coasian Bargaining Equilibrium level of A_1

To determine the comparative statics, we take the partial derivative of equation (17) with respect to the parameters of interest (γ, ρ and L_{r1}):

$$\partial A_1/\partial\gamma = \frac{T}{\rho}\,[\exp(\varphi L_{r1}{}^{1+\theta}) - 1] \geq 0, \tag{A15}$$

$$\partial A_1/\partial\rho = -\frac{\gamma T}{\rho^2}\,[\exp(\varphi L_{r1}{}^{1+\theta}) - 1] \leq 0, \tag{A16}$$

$$\partial A_1/\partial L_{r1} = \rho^{-1}\gamma T\varphi(1+\theta)L_{r1}{}^{\theta}\exp(\varphi L_{r1}{}^{1+\theta}) > 0. \tag{A17}$$

In addition, equations (A15) and (A16) are strictly greater than zero if L_{r1} is strictly positive.

V) Evaluating the Period 2 allocations using the tax and subsidy regime

When the government initiates a tax and subsidy regime as described in section 5, period 2 faces the following optimization problem:

$$\max_{L_{f2},\,L_{r2},\,A_2}\ \mathrm{Log}[(\gamma T + \rho\tau L_{r1})L_{f2}{}^{\alpha}L_{r2}{}^{1-\alpha} - A_2] - \varphi L_{r1}{}^{1+\theta}, \tag{A18}$$

$$\text{Subject to} \qquad L_{f2} + L_{r2} \leq L,$$

$$0 \leq L_{f2},\ L_{r2},\ A_2.$$

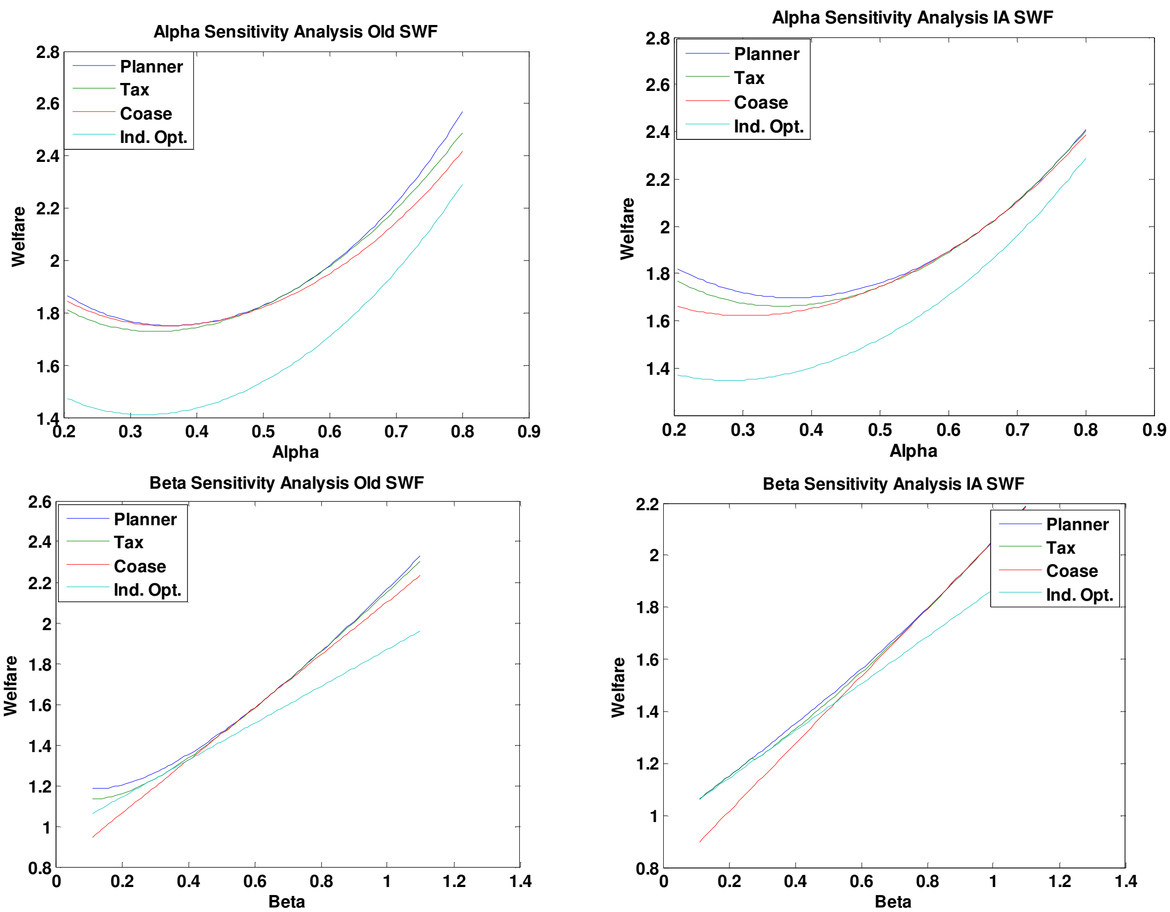
It is clear that $A_2 = 0$. Using the first order conditions of the Lagrangian with respect to L_{f2} and L_{r2} and combining them yields the equation:

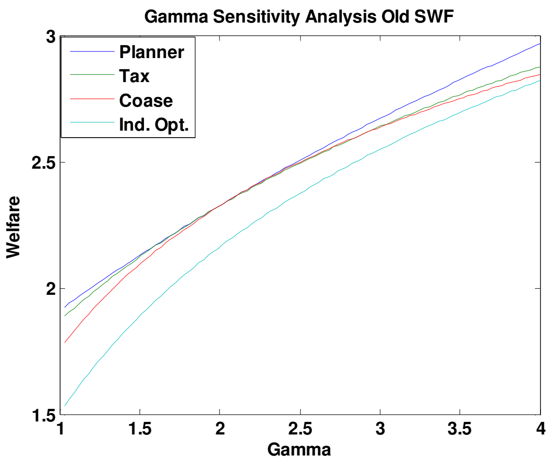
$$L_{f2} = \frac{\alpha}{(1-\alpha)}\,L_{r2}. \tag{A19}$$

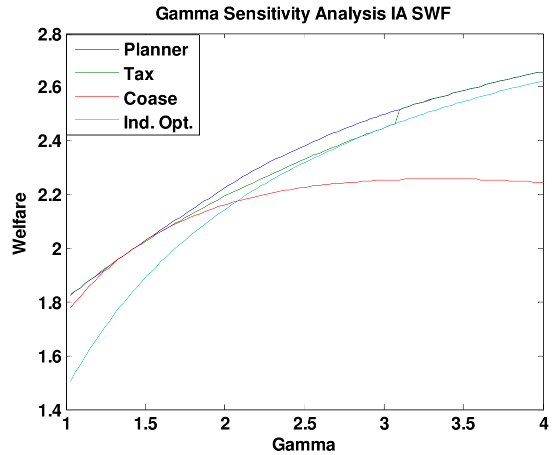
This demonstrates that period 2's optimization decisions are independent of the level of τ.

VI) SWF comparison

The following figures compare welfare outcomes using the SWF outlined in Section 3 (Old SWF) with welfare outcomes using the SWF that exhibits inequality aversion outlined in Section 6 (IA SWF):




Gamma Sensitivity Analysis Old SWF
Planner
Tax
Coase
Ind. Opt.
Welfare
Gamma


Gamma Sensitivity Analysis IA SWF
Planner
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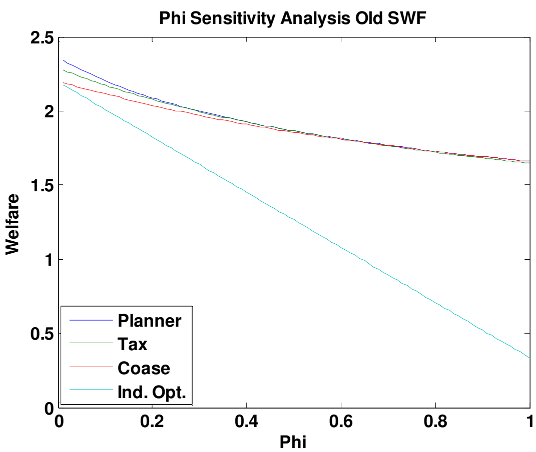
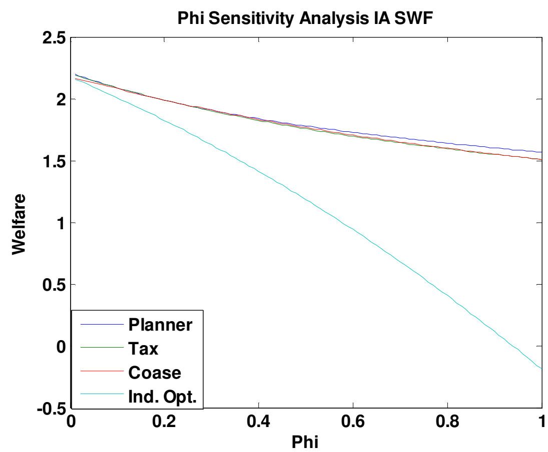
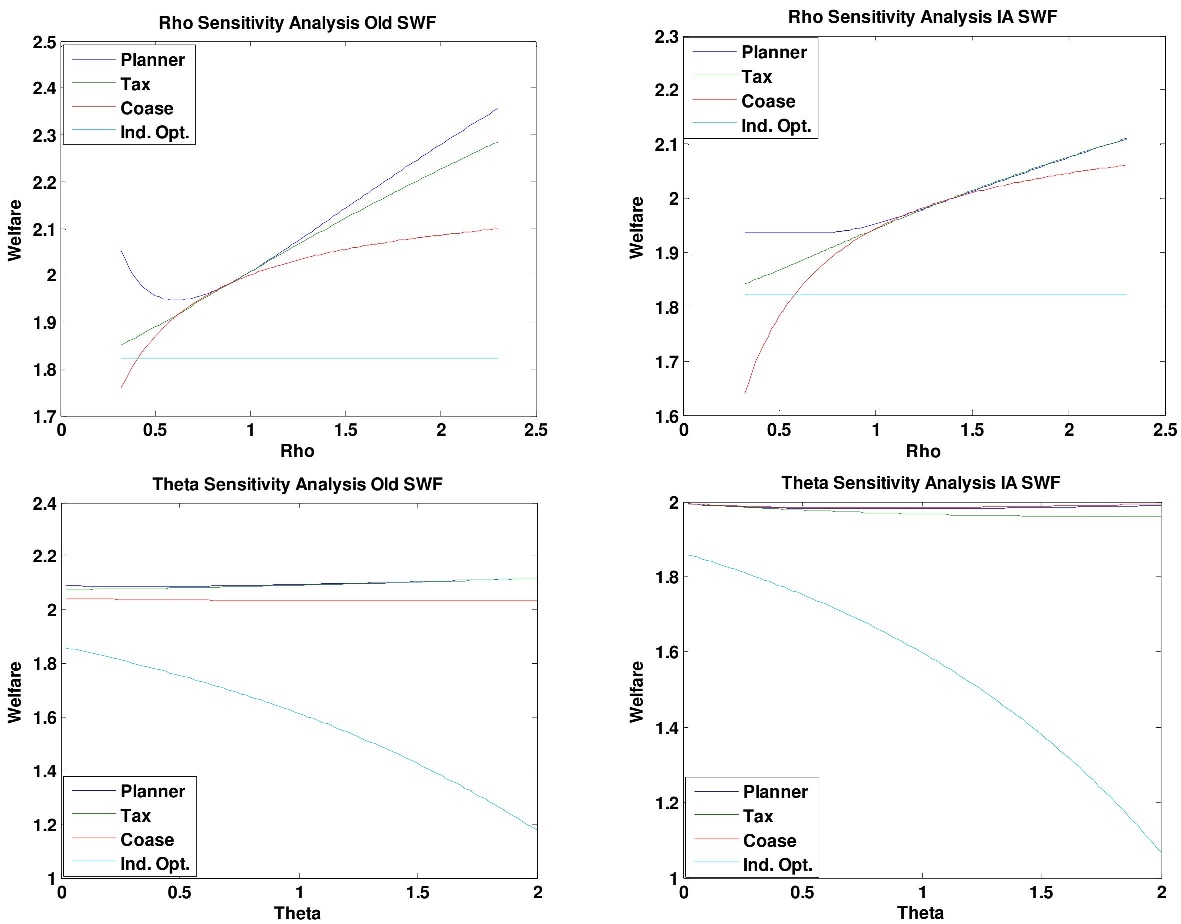
Ind. Opt.
Welfare
Gamma


Phi Sensitivity Analysis Old SWF
Planner
Tax
Coase
Ind. Opt.
Welfare
Phi


Phi Sensitivity Analysis IA SWF
Planner
Tax
Coase
Ind. Opt.
Welfare
Phi



VII) Proof of Proposition 6

The period 2 agent will accept any offer in which $U^*(C^*_2,P^*_2) \geq U(C_2,P_2)$, where U^*, C^*_2, and P^*_2 are the period 2 utility, consumption, and pollution achieved if the offer is accepted and U, C_2, and P_2 are the period 2 values achieved if the offer is rejected. This is captured by the following inequality:

$$\text{Log}((\gamma T + \rho A_1)L_{f2}^{\alpha}L_{r2}^{1-\alpha}) - \varphi L_{r1}^{1+\theta} \geq \text{Log}(\gamma T L_{f2}^{\alpha}L_{r2}^{1-\alpha}). \qquad \text{(A20)}$$

Similarly, the period 3 agent will accept any offer in which $U^*(C^*_3,P^*_3) \geq U(C_3,P_3)$, where U^*, C^*_3, and P^*_3 are the period 3 utility, consumption, and pollution achieved if the offer is accepted and U, C_3, and P_3 are the period 3 values achieved if the offer is rejected. This is captured by the following inequality:

$$\mathrm{Log}(\gamma(\gamma T + \rho A_1)L_{f3}{}^{\alpha}L_{r3}{}^{1-\alpha}) - \varphi(\delta L_{r1})^{1+\theta} \geq \mathrm{Log}(\gamma^2 T L_{f3}{}^{\alpha}L_{r3}{}^{1-\alpha}). \qquad \text{(A21)}$$

In order for Proposition 6 to hold, any offer (A_1, L_{r1}) for which (A20) holds with equality, inequality (A21) must hold as well. Assuming (A20) holds with equality and rearranging yields,

$$\mathrm{Log}\left(\frac{\gamma T + \rho A_1}{\gamma T}\right) = \varphi L_{r1}{}^{1+\theta}, \qquad \text{(A22)}$$

Which can be further simplified to

$$A_1 = \gamma T\left(\frac{\exp(\varphi L_{r1}{}^{1+\theta}) - 1}{\rho}\right). \qquad \text{(A23)}$$

Inequality (A21) can also be rearranged to yield,

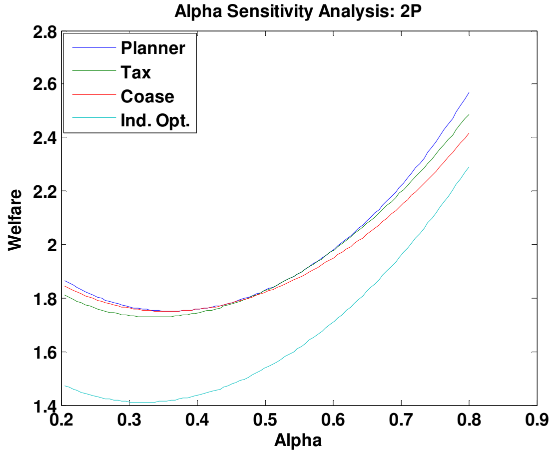
$$A_1 \geq \gamma T\left(\frac{\exp(\varphi(\delta L_{r1})^{1+\theta}) - 1}{\rho}\right). \qquad \text{(A24)}$$

The right sides of (A23) and (A24) are identical except for the δ in (A24). So long as $\delta \leq 1$, the right side of (A24) will be less than or equal to the right side of (A23). This means that any offer (A_1, L_{r1}) that satisfies (A20) with equality must satisfy (A21) so for any $\delta \leq 1$. QED

VIII) 2- and 3- Period Model Comparisons

The following figures compare welfare outcomes using the 2-period model outlined in Section 3 (2P) with welfare outcomes using the 3-period model outlined in Section 6 (3P).

Alpha Sensitivity Analysis: 2P



Alpha Sensitivity Analysis: 3P

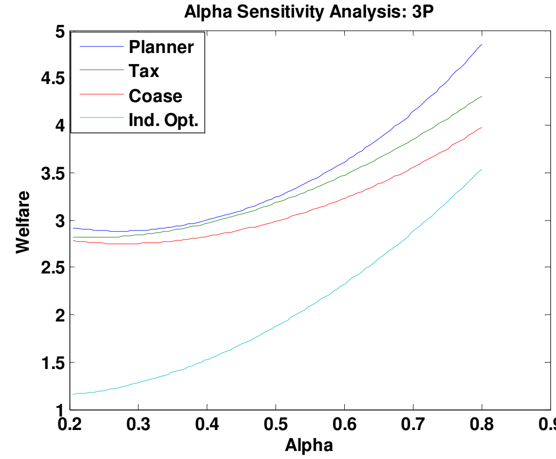
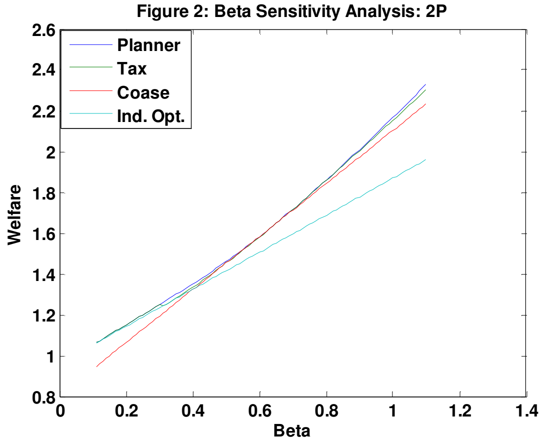


Figure 2: Beta Sensitivity Analysis: 2P



Beta Sensitivity Analysis: 3P

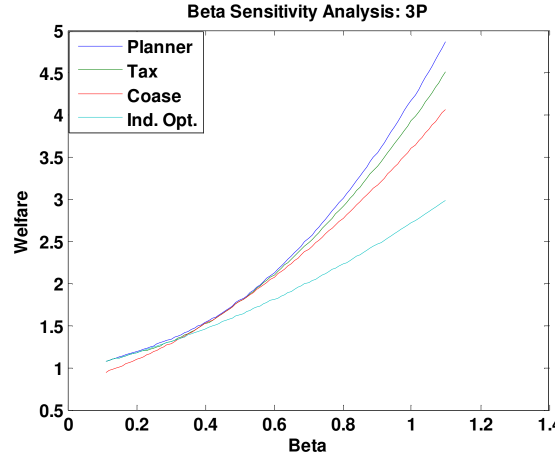
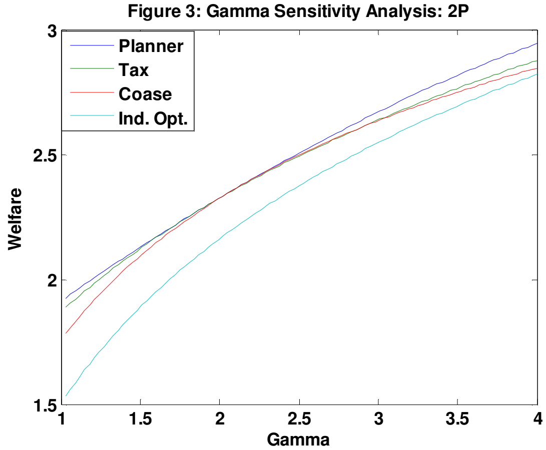
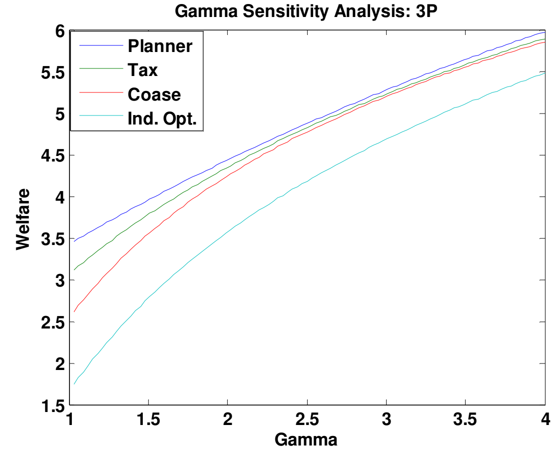
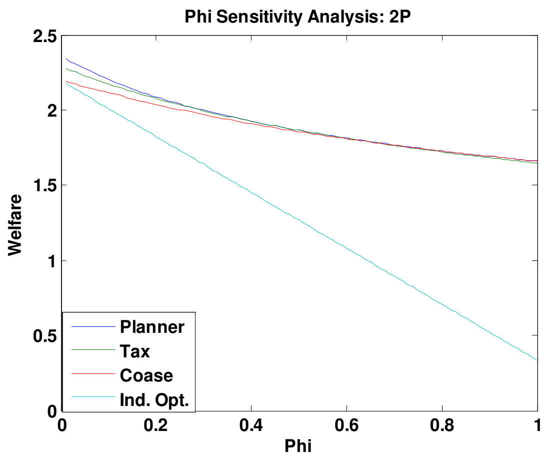


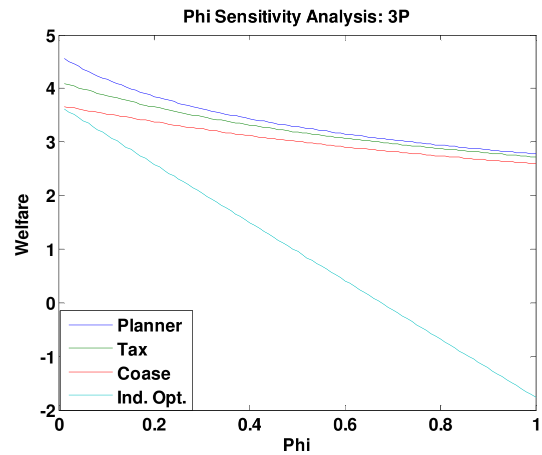
Figure 3: Gamma Sensitivity Analysis: 2P



Gamma Sensitivity Analysis: 3P




Phi Sensitivity Analysis: 2P
Welfare
Phi
Planner
Tax
Coase
Ind. Opt.


Phi Sensitivity Analysis: 3P
Welfare
Phi
Planner
Tax
Coase
Ind. Opt.

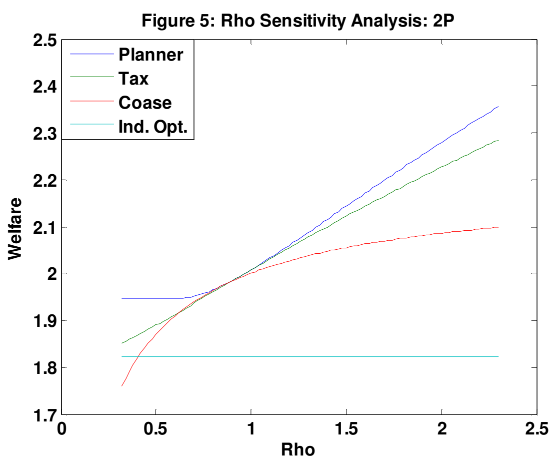
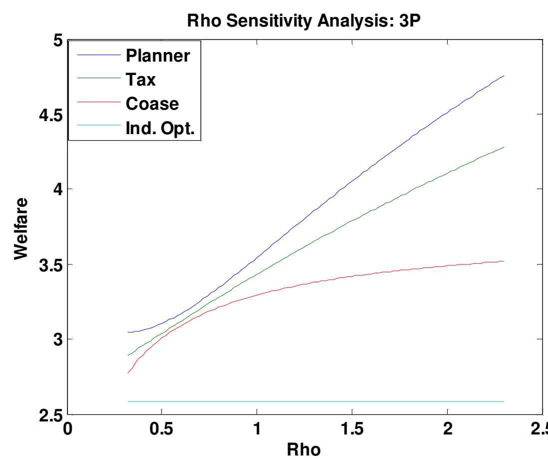
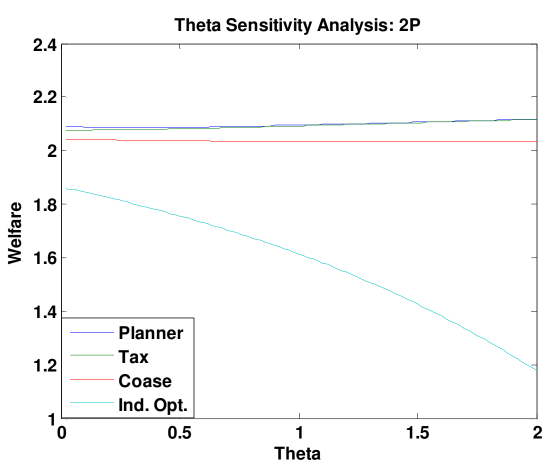
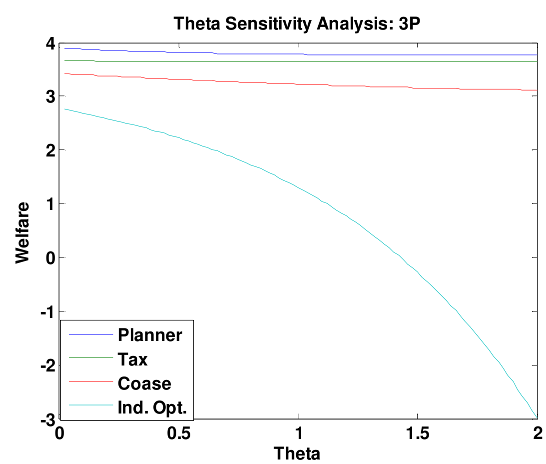


Figure 5: Rho Sensitivity Analysis: 2P
Welfare
Rho
Planner
Tax
Coase
Ind. Opt.


Rho Sensitivity Analysis: 3P
Welfare
Rho
Planner
Tax
Coase
Ind. Opt.


Theta Sensitivity Analysis: 2P
Welfare
Theta
Planner
Tax
Coase
Ind. Opt.


Theta Sensitivity Analysis: 3P
Welfare
Theta
Planner
Tax
Coase
Ind. Opt.