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Essays in Climate Change and Forest Management

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Abstract

This thesis consists of four papers

Paper I analyses the exhaustion of oil resources, and the transition to a backstop technology as a strategic game between two blocks: the consumers and producers of oil which we simply refer to as “OPEC” and “OECD”. The OECD has two instruments: it can tax fuel consumption and decide when to switch to the carbon neutral backstop technology. The tax in the OECD is found to serve the purpose to both reduce climate damage and to access some of the resource rent. OPEC on the other hand can retaliate by choosing a strategy of price discrimination selling oil cheap on domestic markets and of course they can implicitly determine the price and thus the timing of resource depletion. The results show that price discrimination enables OPEC to better avoid the adverse consequences from the tax and backstop technology in OECD by consuming a larger share of the oil in their domestic market.

Paper II studies the effects of reputation on compliance with social norms of behavior, and in particular, the role of information in mediating this relationship. A prevailing view in the literature states that social sanctions can support, in equilibrium, high levels of obedience to a costly norm. In contrast, the model introduced in this paper shows that imperfect observability causes the expected social sanction to be at its lowest precisely when obedience is more common. Unless actions are fully observable, society finds it hard to conceive that someone is in disobedience when disobedience is rare. In this line of argumentation, the failure of an environmental norm as an internalization mechanism can be explained.

Paper III uses forest data across 28 provinces during the reform period to examine some frequently discussed questions about macroeconomic and population impacts on the forest. The data support a theoretical argument for separating forests into four components, managed and natural forests administered by either state or private agents. Our regressions suggest as incomes rise, the natural forest is first drawn down then, when incomes rise above some level, the natural forest begins to recover. As incomes continue to rise, the managed forest eventually grows even more rapidly and offsets any continuing draw on the natural forest—with an aggregate impact of net expansion for all forests, managed and natural combined.

Paper IV uses firm level data in China's timber industry to evaluate the impact of manager turnover on firm productivity. We find that due to differences in selecting and screening manager candidates, the impacts of manager change on firm productivity are heterogeneous across ownership types. In state-owned firms, manager change is mainly driven by bureau leaders who may want to control the rent from firms and hence appoint new managers loyal to them. Consequently, deterioration of firm productivity can be observed following a change. For private firms, it is found that manager selection is based on the human capital of candidates. Therefore, firm productivity improves after a change. The results from both a regression analysis and a matching approach provide similar evidence.

Keywords: *Dynamic games; Stock externalities; Carbon tax; Social Norms, Moral Hazard, Environmental Regulation; Energy pricing; Chinese forests, Economic growth; manager turnover; ownership; selection of managers; firm productivity*

JEL: *D62; H23; Q34; Q54; Q52;H23;D82; Q23; Q28; P28; P34; P26; G34 ; P28*

Preface

Though I do not feel quite finished with my work here, the time has already come for me to balance reality with expectations. I have to sit here and wrap up my thoughts on what I have done over the last several years. I still remember the time when I was a young boy coming here with the curiosity and ambition to achieve something. The long experience here finally has made me think like an economist.

I have learned a lot from the process of writing this thesis. It requires devotion, hard work, and sometimes anxiety to finish a PhD thesis. Numerous hours of work have witnessed my growing up and I am happy that somehow I have succeeded in overcoming all these challenges.

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Introduction of the thesis

Global warming is the greatest example of market failure caused mainly by anthropogenic emissions of carbon dioxide (Stern, 2006). Among the contributions to greenhouse gas (GHG) emissions between 1970 and 2004, the burning of fossil fuel and human induced land use change including deforestation are the main sources, and account for 56 and 17 percent of the total respectively (IPCC,2007). If the current emission rate continues, human society may suffer severe adverse consequences on the natural environment and significant losses of biodiversity and human life (IPCC,2007).

To avoid the worst kinds of outcome from climate change, public policies to reduce carbon emissions have to be taken very soon. The choice may include carbon taxes and trading permits to reduce the consumption of fossil fuel, or policies to increase the stringency of various technology standards. Policy adjustment to reduce deforestation is a highly cost-effective way of reducing GHG emissions and slowing down the process of global warming. These policies differ in behavioral incentives to achieve the emission targets, and their respective economic efficiency.

This thesis attempts to contribute to the discussion of policies to address climate change and to understand deforestation and forest management in China. It consists of four self-contained chapters. The first two chapters are more theoretical, driven by their emphasis on policies to reduce carbon emissions and increase abatement by firms. The remaining two chapters are empirical exercises to investigate the cause of deforestation and the institutional constraints on managing forest products at the micro level in China.

Chapter 1 discusses carbon taxation to address climate change but takes into consideration some intricacies on the supply side. We are particularly concerned with energy pricing under the title “Fossil Endgame? Strategic interaction, pricing and taxation of dwindling oil stocks in a World of Climate change”. The paper analyses the strategic game between two blocks: the consumers and producers of oil. The consumers in the “OECD” want to buy the oil, worry about depleting stocks but also about climate effects due to carbon emissions. The OECD can tax fuel consumption either for Pigouvian reasons (to reduce climate risks) or for strategic motives (to access some of the resource rent). “OPEC” (or resource exporting countries) can retaliate by price discriminating between domestic and international markets. The results show that price discrimination enables OPEC to counteract the tax and backstop technology in OECD by consuming a larger share of their own oil in their domestic markets. The improvement of backstop technology can lead to larger total emissions in the early stage due to OPEC's incentive to sell oil cheaply to both markets to reduce the impact of earlier replacement of their oil by the backstop in OECD.

The results from this chapter suggest the need of coordination of energy pricing and taxation policies to address climate change issues. The linkage of energy markets will make the tax on energy in one country reduce the rent and price of oil, hence increase energy consumption in other countries. The leakage of carbon in other markets without climate policies such as a carbon tax will offset the reductions in carbon emissions in individual countries that impose taxes. Hence, the effort towards pushing oil production countries to cancel their dual pricing strategy can slow the accumulation of carbon emissions and reduce the adverse effects of global warming.

In chapter 2, we also focus on policy design in enforcing environmental regulation. With the increasing importance of social responsibility to push firms to make more environmental friendly investments, this paper discusses the impact of reputation concerns on social equilibrium when firms face abatement decisions under both perfect and imperfect information. The reputation of a firm depends on its obedience of the norm of compliance with regulations and also on the portion of the population who comply with the norm. The obedience to the norm would assure a good reputation. The larger the degree of compliance, the more reputation would be lost for the firm by disobedience. However, with high rates of compliance we also get lax monitoring since no one expects disobedience and hence the *temptation* to cheat surges.

The results from the analysis of this model show that society can end up with multiple equilibriums under both perfect and imperfect information. For the perfect information case, in addition to the full compliance equilibrium, low compliance and even full violation equilibria could coexist since losses in reputation are low at high levels of disobedience. In the presence of information asymmetries the full compliance to a costly norm cannot be supported due to the way beliefs are formed since one's actions are not fully observable, it is hard to conceive that someone is in disobedience when disobedience is rare. A society can have a stable high compliance equilibrium under fairly restrictive assumptions about the information availability and accuracy. If the information is poorly provided, society can only stay in the equilibrium of full violation, which is robust to any small change or shock in the market.

The policy problem for a typical environmental regulator, is to solve an information asymmetry between polluters and the judiciary. In fact its budget is spent in two different activities, namely monitoring and enforcement. If provision of information to the general public is relatively cheap, as seems to be the case with today's information technologies, the regulator could publicly disclose polluters' environmental indicators and make use of social sanctions as a substitute for conventional enforcement. By doing so, the government may move society from the stable full violation equilibrium to an equilibrium with a fairly high level of compliance. The results also suggest that it might be important for communities or NGOs to disclose information on firms' environmental regulation behavior to help society achieve a more efficient outcome.

Conserving scarce forest resources is a challenge for both high and low income countries. The rate of tropical deforestation has accelerated in the past decade. In 1989, approximately 1.8 percent of the remaining 8 million square kilometers of tropical forests was being destroyed annually. If current rates of exploitation continue, and some evidence suggests an acceleration of deforestation (Repetto 1988), then tropical forests may virtually disappear in just over 50 years. Since the forests contain over half of the world's species, and sequester large amounts of carbon and play an important role in soil conservation, the clearing of these forests would have a significant impact on the earth's genetic diversity, agricultural productivity and most notably climate change.

The management in China's forest sector has experienced a remarkable change since 1978. The pre-reform forest management system relied on command and control instead of market based incentives to implement the central government's forest sector plan. The reform initiated liberalization of the timber market and allocation of user rights to the households. The reform implied enormous changes for China's forests. In some areas, especially in the southern part of China, more than half the forest lands were allocated to rural households, while in northeast and southwest China, even though most of the forest lands are still under government control, the forest industry has undergone a fundamental reconstruction when it comes to ownership, and the possibility to lay off laborers.

In Chapter 3, we try to investigate the trend of deforestation during the reform period and to evaluate the impact of tenure reform, economic growth and social change on China's forests. The analysis distinguishes between natural and managed forests in different property rights regimes. The findings suggest that allowing local people to manage forests boosted the incentive to plant and significantly increased the number of managed forests, but it had a less noticeable impact on natural forest cover. This suggests that managed forest and natural forests respond to different economic incentives. As incomes rise, the natural forest is first drawn down, then, when incomes rise above some level, the natural forest begins to recover. As incomes continue to rise, the managed forest eventually grows even more rapidly and offsets any continued cutting of the natural forest—with an aggregate impact of net expansion for all forests, managed and natural combined.

In order to understand the behavior of firms harvesting and processing timber and to further investigate institutional constraints causing deforestation, the last chapter is our attempt to understand the impact of manager turnover on firm performance. The paper combines firm level data from China's timber industry with information of firms' and their respective bureaus. We find that for the pooled sample with both private and state owned firms there is no significant productivity improvement following manager change. However, both regression and matching results give strong evidence that there are significant – but differentiated effects depending on ownership. In private firms there is an increase of firm performance following manager turnover, while for the state owned firms, we actually observe a detrimental effect of manager change.

The heterogeneous impact on firm productivity is due to the difference in the selection mechanisms for top managers. The chances to incur a change of manager in state owned firms is significantly driven by the change of party leader in the bureau, suggesting that political considerations dominate the economic incentive, while private owners stress the human capital of the selected candidate. The more educated candidates may be assumed to have more knowledge and younger candidates should be more able to adapt to the changing market environment and thus have significantly higher probability to be selected and appointed as managers.

The findings from this paper provide some insights concerning the importance of the way in which managers should be selected for timber firms to perform better. The change of managers in state owned firms can lead to an increase of firm productivity if the incentive for politicians is well structured and to deterioration of firm performance if the aim of politicians is to seize control and extract rents. However by selecting and appointing managers with more competence, private owners can significantly improve performance. The paper highlights the importance of the regulation, procedure and criteria of screening candidates for managers.

In summary, this thesis provides an attempt to contribute to the discussion of policies to address climate change and curb deforestation in China. We have discussed a number of policies to reach these goals. These include carbon taxes for oil importing countries, policies to promote transparency concerning companies' environmental performance and finally reforms in company management. In each of these cases we hope to have illustrated not only how important but also how difficult many of these instruments are.

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Paper I

Fossil Endgame? Strategic pricing and taxation of oil in a World of Climate change

Jiegen Wei[1]

Abstract

This paper analyses the exhaustion of oil resources, and the transition to a backstop technology as a strategic game between two blocks: the consumers and producers of oil which we simply refer to as "OPEC" and "OECD". The consumers in the OECD derive benefits from the oil but also worry about climate effects due to carbon emissions. The OECD has two instruments: it can tax fuel consumption and decide when to switch to the carbon neutral backstop technology. The tax in the OECD can serve the purpose to both reduce climate damage for Pigouvian reasons and to access some of the resource rent. OPEC on the other hand can retaliate by choosing a strategy of price discrimination selling oil cheap on domestic markets. The results show that price discrimination enables OPEC to better avoid the adverse consequences from the tax and backstop technology in OECD by consuming a larger share of the oil in their domestic market. The improvement of backstop technology can lead to larger total emissions in the early stage due to OPEC's incentive to sell oil cheaply to both markets to reduce the impact of earlier replacement of their oil by the backstop in OECD.

Keywords: *Dynamic games; Stock externalities; Carbon tax; Nonrenewable resources; Energy pricing*

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1. Introduction

The use of climate policies, such as carbon taxes to reduce emissions of carbon dioxide and thereby slow global warming have received considerable attention among policy makers and in academia. In principle, carbon taxes increase allocative efficiency by correcting the market failure caused by uncompensated emissions. In addition, politicians often like fuel taxes since they raise revenues, but they may also be concerned about political support or opposition from the consumers. The suppliers of fossil fuels tend to be against emissions taxes. They often argue that they do not help to reduce carbon emission but are merely a device for importing governments to steal the resource rent[2][3]. We know that many oil exporting countries sell petroleum products very cheaply on domestic markets and we want to formally explore the reasons for this, how their pricing policy may react to importing country taxation and what importance these strategies may have for the international negotiations concerning climate strategies.

For an exhaustible resource that generates profits, efficient resource managers would make sure that a resource rent would be reflected in the market price. Conventional wisdom suggests that this resource rent should rise exponentially, at least so in simplified and stylized economic models (Hotelling,1931). Besides, there are many studies concerning the interaction between taxation of externalities from fossil fuel and the scarcity rent related to the depletion of exhaustible resources. Recent such studies tend to combine both of these and study the interaction between pollution taxes and scarcity rents (Sinclair,1992; Ulph and Ulph,1994; Wirl, 1994; Hoel and Kverndokk, 1996). Results from these studies show that the tax may fall eventually as oil approaches depletion. For example, the first study by Sinclair (1992) concludes that constant taxes just squeeze rents and have no im-

[2] There are many proofs of this attitude for instance in the OPEC Bulletin or for instance the following quote from FORBES "Saudi King Abdullah, whose country holds the world's largest oil reserves, vowed to continue to provide enough supplies, but called on leading consumer states to cut taxes on petroleum products", http://www.forbes.com/markets/feeds/afx/2005/11/20/afx2347009.html In Bali the OPEC countries tried to argue that they should get compensation for climate policies that might reduce their income.

[3] This need not be the case for conventional oil producers though. Persson et al (2007) and Johansson et al (2008) argue that carbon dioxide taxes may increase the resource rent for conventional oil producers, since the alternatives to scarce conventional oil will be taxed at an even higher rate as a result of higher levels of carbon dioxide emissions per unit useful energy in the fuel for the the alternatives.

pact on the time-profile of extraction, expectations of falling energy taxes are what is needed to reduce extraction rates and postpone such adverse consequences that carbon emissions induce. The recent literature suggests that carbon taxes may not only serve the purpose of correcting externalities, but also can enable countries importing oil to receive at least part of the resource rent (Rubio and Escriche, 2001;Matti and Tahvonen 2004).

This paper studies a non-cooperative open-loop Nash Equilibrium carbon tax in a model with strategic importers (OECD) versus strategic exporter (OPEC). The paper focuses particularly on the *dual* pricing decisions for the domestic and OECD markets of the strategic exporters. Empirical data shows that many oil producing countries sell oil products more cheaply on the home market which implies implicitly that the oil extractors discriminate between different markets. We believe this may be an important extension since earlier studies have focused on OPEC's export market, ignoring OPEC's domestic market. Yet, the domestic market is already considerable - accounting for almost 20% of OPEC's oil and the share is expected to grow, see Gately (2007) . For Indonesia, the domestic market is close to one-half of its total oil output, and the net exports of some oil producers such as Mexico have fallen drastically because the domestic market grew so fast-which in turn was partly a result of the low domestic price.

The analysis assumes two agents, one resource-exporting cartel (nicknamed OPEC), that is in fact assumed to be the only seller of fuel to consumers, and a resource importing group of countries (OECD). Both OPEC and OECD are assumed to consume fuels produced from oil. We assume that the oil is homogeneous and unique raw material with only one possible substitute (referred to as the backstop – we are aware of the fact that this is a vast simplification removing gas, goal and many other sources). OPEC is assumed to be the sole producer and source of oil. OPEC thus faces the traditional dilemma of economizing with an exhaustible resource. The OECD, on the other hand, is concerned about maximizing welfare including environmental damages from cumulative carbon dioxide emissions. We assume that environmental quality, measured in pollution stock, causes damages that are only a concern to OECD. Naturally, this is a simplification but currently it is only (parts of) the OECD that actually is expressing a discernable concern for climate change while OPEC has, at least historically, been much against any regulation of emissions from oil. At its disposal, the OECD has a simple tax on oil. This may serve two purposes: more officially it will just tax the climate externality – but it may also seize part of OPECs scarcity rents.

If OECD taxes the oil, OPEC might react strategically by increasing the producer price to receive a larger part of the tax revenues that would otherwise remain in the oil importing countries. Beyond some point, this would however lower demand and revenues so the oil price is beyond the full control of the fuel exporting countries since the path of rent will be affected by taxes levied by OECD. Our objective is to consider the optimal design of the carbon tax in the presence of two-sided strategic interaction: the buyer side can set and coordinate taxation and understands the effect of taxes on fuel prices, and the seller side coordinating sales understands the effect of sales on taxation. We find that the tax determined by OECD is set to balance the loss of consumer surplus from consuming fuel, the tax income and the benefits of reducing carbon emissions. The optimal fuel tax includes both a Pigouvian and strategic trade-policy component. When OPEC and OECD have the same time preferences, the tax increases over time regardless of whether it is measured in absolute or relative terms. The ad valorem tax may increase in the beginning and decrease eventually if OPEC is less patient than OECD and OECD tries to stop OPEC from extracting oil too shortsightedly in the beginning and delays the oil for future consumptions.

We also analyze the optimal time path for OPEC's extraction of oil. We assume that the OECD has access and will switch to some backstop technology, such as solar or wind power once the consumer price reaches the opportunity cost of the backstop. Therefore, the optimal time path implies overall depletion at a date we call T and there is a time t* at which OECD stops importing and switches to backstop technology. We find that the larger choke price[4] in OPEC or the cheaper the backstop in OECD, the larger the difference of the timing between t* and T. Also, when a backstop technology is improved it would induce the con-

[4] The choke price is the minimum price that leads the demand in OPEC being equal to zero.

sumers in the OECD to substitute it for fossil fuel earlier, but would have an opposite effect on the timing of resource depletion in OPEC.

This in turn would imply a paradox situation when the backstop technology improves. The producer like OPEC, aware of the impact of backstop technology improvement leading to the decrease of the oil value, will be afraid that oil and gas will be replaced by the backstop technology such as solar and wind power sooner, hence sell the oil more cheaply today. The following drop in prices due to incentive to sell the oil more quickly at the present will lead to total carbon emissions to increase. This would be harmful since early emissions would lead to larger damage to the society.

As a comparison with the outcome in this game, the paper also considers a cooperative case that could be thought of as the two parties engaging together to eliminate subsidies in OPEC and deciding on a uniform world price. This would imply that domestic consumers in OPEC have to pay higher price for oil, hence OPEC can only sell smaller share of oil in domestic market and has less capability to counteract the rising tax imposed by OECD. The simulation results show that the elimination of price discrimination will lead to smaller price charged to OECD due to decreased shadow value of oil from the perspective of OPEC. The net effect from the increase of export to OECD and reduction of consumptions in OPEC will lead to later depletion of resources and a later switch to backstop technology.

In the rest of the paper, we first describe the model and analyze the interaction between OPEC and OECD. The third section analyses optimal taxation and the timing of depletion. The cooperative results are presented in the fourth section which allows us to see more clearly the effect of the strategic gaming. Most results are possible to derive analytically and we also follow up the comparative analysis with a simulation in section 5. The final section concludes.

2. The Model

So as to make the model as simple as possible we assume the world consists of two agents: one that is resource-rich but barely industrialized and the other which is poor in resources but industrialized. To be convenient, we refer to the resource rich exporter as OPEC and the resource poor importer as OECD. It is assumed that no oil is extracted within the OECD. In reality oil is not only extracted in the cartelized OPEC countries, whose coalition sometimes suffers from stability problems, but also from a range of fringe countries, such as Russia, US and Norway, however for the purposes of our analysis two agents will suffice.

There are two stocks in the model, OPECs oil deposit stock S (billion barrels) in the ground and the carbon stock E (G ton) accumulating in the global atmosphere. Since carbon is directly moved from OPECs oil deposit to the global atmosphere due to consumption in OECD and OPEC we can express the change in stocks as a function of oil consumption in OPEC and OECD, hereinafter indexed 1 and 2, respectively.

$$\dot{S} = -(x_1 + x_2) \qquad (1)$$

$$\dot{E} = \gamma(x_1 + x_2) \qquad (2)$$

where x_1 and x_2 are oil consumptions in OPEC and OECD, which together correspond to withdrawals from OPEC oil deposit stock S in (1) and adds carbon to the carbon stock E in the global atmosphere at the transfer rate $\gamma > 0$ in (2). We neglect uptake of carbon dioxide in the biosphere or the oceans since it clutters up the mathematics without adding significant insights.

The oil consumption levels x_1 and x_2 are determined by OPEC acting as a monopolist on both the OECD and OPEC markets subject to the oil demand functions (3) and (4) in OPEC and OECD, respectively. The linear demand function on the OPEC market is given by

$$x_1 = \alpha_1 - \beta_1 \cdot p_1 \qquad (3)$$

OECD is assumed to have a backstop technology, resulting in a kinked linear demand function due to the switch to backstop technology when consumer price $p_2 + \tau$ in OECD reaches $\overline{p}$ 5. Hence, the OECD demand function is described as

$$x_2 = \begin{cases} \alpha_2 - \beta_2 \cdot (p_2 + \tau) & \text{if } p_2 + \tau < \overline{p} \\ 0 & \text{if } p_2 + \tau \geq \overline{p} \end{cases} \qquad (4)$$

The backstop is a carbon-free source of energy that could be supplied at a cost equal to $\overline{p}$ and without any resource limits. This technology could be seen as an simplified

[5] We don't interpret the choke price as the opportunity cost of backstop technology because demand shocks can affect the choke price, which can't be interpreted as the improvement of backstop technology.

representation of options such as carbon neutrals fuels or electricity generated from solar, wind, nuclear or coal with carbon capture and storage. Here, we assume that $\bar{p} < \alpha_2 / \beta_2$ i.e if there is no backstop technology, OECD still will consume oil produced in OPEC at the producer price $\bar{p}$.

The demand for oil might increase due to economic expansion or decrease caused by the energy efficiency improving technology in OPEC (OECD), resulting in a change in coefficient α_1 (α_2) . Economic expansion can be modeled as an increase in α_1 (α_2), consequently spurring the demand for fossil fuel, while an improvement in energy saving technology has the opposite effect.

The policy instrument that OECD uses is a tax $\tau(t)$ on oil consumption, and decides when the switch to backstop technology takes place at *t**. Given this, there are still three possible cases: Consumers in OECD switch to the backstop and OPEC stops export to OECD before the resource is depleted. OPEC stops export to OECD after stopping domestic supply, and finally, OPEC stops export to OECD and supply to domestic market simultaneously. We assume that $\alpha_1 / \beta_1 > \bar{p}$, i.e, consumers with highest willingness to pay for oil is larger than $\bar{p}$. Hence, consumers in OECD have already switched to the backstop before OPEC consumption ends. This is a reasonable assumption if it is politically infeasible to sell oil abroad and disregard the domestic consumers who are willing to pay even higher price when politicians in OPEC want to stay in offices. Hence, we focus our analysis for the case that OPEC stops exporting before total depletion.

3. Taxation and Pricing with Price Discrimination

Given the dynamics of oil deposit and carbon stocks and the demand functions in section 2 we solve for the open-loop Nash equilibrium when OPEC can set different prices on the OPEC and OECD markets and OECD can tax oil consumption for OECD consumers. In section 3.1 the open-loop Nash taxation strategy in OECD is derived and discussed followed by the open-loop Nash pricing strategy in OPEC in section 3.2.

3.1 Taxation Strategy in OECD

The OECD social planner cares about the OECD social welfare, covering OECD consumer surplus, OECD tax revenues and OECD environmental damage from carbon emitted to global atmosphere due to oil consumption. The policy instrument that OECD can use for maximizing social welfare is a tax $\tau(t)$ on OECD oil consumption. Formally, the OECD value function is

$$V_2 = \int_0^{t*} [CS_2 + \tau(t) \cdot x_2 - \theta E] e^{-\rho_2 t} dt + \frac{\overline{CS}_2}{\rho_2} e^{-\rho_2 t^*} - \int_{t*}^{T} \theta E(t) e^{-\rho_2 t} dt - \frac{\theta E(T)}{\rho_2} e^{-\rho_2 T} \qquad (5)$$

where the term CS_2 is the OECD consumer surplus from consuming oil, τx_2 is the tax revenue, $\theta \cdot E$ is the instant damage from the stock of carbon, $\overline{CS}_2 e^{-\rho_2 t^*} / \rho_2$ is the consumer surplus from backstop technology, and finally, $\int_{t*}^{T} \theta E(t) e^{-\rho_2 t} dt + \theta E(T) e^{-\rho_2 T} / \rho_2$ is the damage caused by accumulated carbon emissions after time t* when OECD has switched to backstop technology. Using (3) and (4) and integrating the scrap value function by part, the problem for OECD is formulated as follows

$$\int_0^{t^*} [(\alpha_2 - \beta_2 \cdot (p_2 + \tau))^2 / (2\beta_2) + \tau(\alpha_2 - \beta_2 \cdot (p_2 + \tau)) - \theta \cdot E] e^{-\rho_2 t} dt + V e^{-\rho_2 t^*} / \rho_2 \qquad (6)$$

subject to the dynamics in (1) and (2) and demand functions (3) and (4), and where $V = (\alpha_2 - \beta_2 \cdot \overline{p})^2 / (2\beta_2) - \theta E(t^*) - \gamma \int_{t^*}^{T} \theta \cdot x_1 e^{-\rho_2 (t - t^*)} dt$ and $E(t^*) = E_0 + \gamma (S_0 - S_{t^*})$. Note also that after time t*, $x_2 = 0$.

Solving the problem for OECD, the tax is found to contain two terms, the Pigovian term which equals the shadow cost of carbon $-\gamma . \psi_2$, and the term denoting shadow value of resource stock λ_2. The evolution of shadow costs of carbon is

$$\psi_2(t) = \psi_2(t^*) e^{-\rho_2 (t^* - t)} - \int_t^{t^*} \theta e^{-\rho_2 (\varsigma - t)} d\varsigma \qquad (7)$$

which is equal to the current value of its marginal accumulated damage. Furthermore, the shadow value of the resource stock

$$\lambda_2(t) = \lambda_2(t^*) e^{-\rho_2 (t^* - t)} \qquad (8)$$

which is equal to the present value of resource rent at time *t** when OPEC stops exporting to OECD.

Substituting the shadow value $\lambda_2(t*)$ and $\psi_2(t^*)$ at the end of game given by transversality conditions in the appendix, we get the optimal tax levied by OECD.

$$\tau = -\psi_2 \cdot \gamma + \lambda_2 = \frac{\theta\gamma}{\rho_2} + \frac{\theta\gamma}{\rho_2} e^{-\rho_2 (t^* - t)} . \qquad (9)$$

There is a difference between the two terms on the right hand side in (9): the shadow cost of carbon ψ_2 is time independent while the shadow value of the resource stock varies with time. The later carbon is emitted into the atmosphere, the less is the present value shadow cost of carbon. It is intuitively interesting to see that when the discount rate increases, both the shadow cost of carbon and the shadow value of the resource stock will decrease. Another part of the tax, equal to the shadow value of resource stock for OECD, increases exponentially at the rate of discount rate over time which drives the demand down. Both terms tend to decrease the consumption of fossil fuel and reduce carbon emissions.

3.2 Pricing Strategies in OPEC with Price Discrimination

OPEC acts as a monopolist vis-à-vis OECD and OPEC market when maximizing OPEC social welfare which sums up to: OPEC consumer surplus and OPECs producer surpluses of extracting oil for the OPEC and OECD markets. Facing the two demand functions (3) and (4), OPEC can price differently. One of the reasons for pricing differently is that OPECs government may want to buy political support. They may expect that cheap oil will "lead to industrialization" or they may feel under pressure from local opinion (that is suspicious of its own leaders) to "share the rent" with the common man (or motorist).

The strategy for OPEC is to choose the domestic price of oil p_1, the international price of oil p_2 and the optimal timing to deplete resources T, given the taxation path imposed by OECD to maximize the following objective function

$$\int_0^T [x_1^2(p_1)/(2\beta_1) + p_1 x_1(p_1) + p_2 x_2(p_2,\tau)]e^{-\rho_1 t}dt \tag{10}$$

subject to the dynamics in (1) and (2) given (3) and (4) and nonnegative constrains of x_1 and x_2, where $x_1^2(p_1)/(2\beta_1)$ is the OPEC consumer surplus and $p_1 x_1(p_1)$ and $p_2 x_2(p_2,\tau)$ are producer surpluses from OPEC and OECD markets, respectively.

Since the minimum price leading everybody not to consume oil in domestic market is larger than the opportunity cost of backstop technologies, such as solar or wind power, OPEC will exit from OECD's market before stopping the sales in domestic market and depleting the existing oil stock. At some point of time $t^* < T$ before depletion at *T*, OPEC stops exporting to OECD and OECD switches to backstop technology.

As the sole supplier in OECD's market, OPEC will balance the benefits of additional sales and the cost from it including decreased price and the foregone value of resource available in the future. Form the appendix, the producer price in OECD can be described in the following equation

$$p_2 = \begin{cases} \frac{1}{2}(\frac{\alpha_2}{\beta_2} + \frac{\alpha_1}{\beta_1} e^{-\rho_1(T-t)} - \tau) & t \in [0, t^*] \\ \bar{p} - \tau & t \in (t^*, T] \end{cases} \quad (11)$$

The optimal price are especially influenced by two terms, first the shadow value of resource driving the price to increase over time, and the tax reducing the price received by OPEC.

Substituting the price to the demand function, the equilibrium supply in the OECD market becomes

$$x_2 = \alpha_2 - \beta_2(p_2 + \tau) = \begin{cases} \frac{1}{2}(\alpha_2 - \beta_2\tau - \frac{\alpha_1\beta_2}{\beta_1} e^{-\rho_1(T-t)}) & t \in [0, t^*] \\ 0 & t \in (t^*, T] \end{cases} \quad (12)$$

From the condition that $p_2(t^*) + \tau(t^*) = \bar{p}$, we can derive t^* when OPEC stops exporting,

$$T - t^* = \frac{1}{\rho_1}\ln(\alpha_1/\beta_1/(2\bar{p} - \alpha_2/\beta_2 - \tau)) = \frac{1}{\rho_1}\ln(\frac{\alpha_1}{\beta_1}/(2\bar{p} - \frac{\alpha_2}{\beta_2} - \frac{2\theta\gamma}{\rho_2})) \quad (13)$$

where the last formula uses the conclusion from the equation (9), i.e at $t*$ when OECD stops importing, the endogenously chosen optimum tax τ^* is equal to $2\theta\gamma/\rho_2$.

The difference of timing for exit from the two markets is determined by the choke price in OPEC and the backstop technology in OECD. The larger the choke price in OPEC or the better backstop technology in OECD, the larger the difference of the timing of exiting between the two markets. Furthermore, increases in the fuel tax will drive OPEC out of the OECD market earlier.

OPEC's incentive to extract the oil in domestic market is to balance the marginal benefits and user cost of extraction. This can also be viewed as selecting the optimal pricing path supported by the respective sales in each moment. The optimal oil price charged by OPEC in its own market p_1 equals the shadow value of oil λ_1 from OPEC's perspective which grows at the discount rate of ρ_1 until it reaches the choke price in the market at the time T

$$p_1 = \lambda_1 = \frac{\alpha_1}{\beta_1} e^{-\rho_1 (T-t)} \tag{14}$$

and the corresponding equilibrium sales can be expressed as

$$x_1 = \alpha_1 - \beta_1 p_1 = \alpha_1 (1 - e^{-\rho_1 (T-t)}) . \tag{15}$$

which is declining over time driven by the rising price.

The optimal time for OPEC to deplete the resource, can then be obtained by solving the identity equation for the exhaustible resource,i.e

$$S_0 = \int_0^T [x_1(p_1) + x_2(p_2)]dt = \int_0^T x_1(p_1)dt + \int_0^{t^*} x_2(p_2)dt \tag{16}$$

4. Pricing Strategies without Price Discrimination

In this section we put forward the question what happens if OPEC cannot price discriminate between the domestic and the OECD market, implying that the producer price on a single international market will be the same. However, OECD can still tax oil consumption for OECD consumers and therefore the OECD may face a different price path due to the change in OPEC's strategy to uniform pricing. The problem set up for OECD in (5)-(15) will remain the same with the exception that we need to change the notation p_2 to p, the international price of oil, and we will not repeat it here.

4.1 Pricing Strategy in OPEC without Price Discrimination

If OPEC loses the possibility to charge the low price which is equivalent to the elimination of the subsidy to domestic consumers, the problem for OPEC is to choose the same price p of oil, for domestic and international markets and the timing to deplete the resource to maximize the following objective function.

$$\int_0^T [x_1^2(p)/(2\beta_1) + px_1(p) + px_2(p,\tau)]e^{-\rho_1 t} dt \tag{17}$$

subject to the dynamics of oil stock (1) and carbon stock (2), nonnegative constrains of x_1 and x_2, and the constrain that the consumer price in OECD is not larger than the opportunity cost of backstop technology, i.e, $p + \tau \le \bar{p}$.

Since we have assumed that the minimum price that leads all consumers in OPEC to stop consuming, α_1 / β_1 is larger than the opportunity of backstop, $\bar{p}$, consumers in OPEC will continue consuming the oil until the resource is depleted after OECD has already switched to backstop. Still let t^* denote the time after which, the export to OECD becomes 0. After t^*, OPEC is the monopolized supplier to its own single market, hence the problem for OPEC in (37) will degenerate to maximizing the following objective function.

$$\int_{t^*}^{T} [x_1^2(p)/(2\beta_1) + px_1(p)]e^{-\rho_1 t}dt \tag{18}$$

subject to

$$\dot{S} = -x_1 = -(\alpha_1 - \beta_1 \cdot p) \text{ and } x_1 = \alpha_1 - \beta_1 \cdot p \geq 0 . \tag{19}$$

This optimization problem enables us to conclude that the price charged to domestic consumers equals the shadow value of resource, which grows exponentially at the rate of ρ_1. The price grows until it reaches the choke price and all consumers stop consuming oil, therefore the fuel price and resource rent after $t*$ can be expressed as

$$p = \lambda_1 = \frac{\alpha_1}{\beta_1} e^{-\rho_1 (T-t)} \tag{20}$$

and the respective domestic sales can be expressed as

$$x_1 = \alpha_1 - \beta_1 p_1 = \alpha_1 (1 - e^{-\rho_1 (T-t)}) . \tag{21}$$

To fully solve the problem in (17), we need to describe the pricing, extraction and taxation path when OPEC supplies both the domestic and international markets. From the appendix III, we can get the uniformly charged price

$$p = (\lambda_1 \beta_1 + \lambda_1 \beta_2 + \alpha_2 - \beta_2 \tau)/(\beta_1 + 2\beta_2) \tag{22}$$

At t*, OECD will stop consuming oil and decide to switch to backstop since the consumer price reaches the opportunity cost of backstop, and as a monopoly OPEC will start to only supply its domestic market from the price of p^*. The absence of arbitrage in the resource market implies there shouldn't be any jump in the oil. This would imply

$$p^* = \frac{\alpha_1 e^{-\rho_1 (T-t^*)}}{\beta_1} = (\lambda_1^* \beta_1 + \lambda_1^* \beta_2 + \alpha_2 - \beta_2 \tau^*)/(\beta_1 + 2\beta_2) = \overline{p} - 2\theta\gamma / \rho_2 . \tag{23}$$

The resource rent during $[0, t^*]$

$$\lambda_1 = \lambda_1^* e^{-\rho_1 (t^* - t)} = (\frac{(\beta_1 + 2\beta_2)\overline{p} - \alpha_2}{\beta_1 + \beta_2} - \frac{2\theta\gamma}{\rho_2}) e^{-\rho_1 (t^* - t)} \tag{24}$$

The difference of time can be solved from (23)

$$T - t^* = \frac{1}{\rho_1} \ln \frac{\alpha_1}{\beta_1 (\overline{p} - \tau^*)} = \frac{1}{\rho_1} \ln \frac{\alpha_1}{\beta_1 (\overline{p} - 2\theta\gamma / \rho_2)} \tag{25}$$

The difference of timing to exit from the two markets is determined by the choke price in OPEC, and the backstop technology in OECD. The larger the choke price in OPEC or the cheaper the backstop technology in OECD, the larger the difference of the timing of exit between the two markets. Furthermore, increases in the fuel tax will drive OPEC out of the market earlier.

In summary, the price charged to domestic consumers and the demand in OPEC are

$$p_1 = \begin{cases} ((\beta_1+\beta_2)\lambda_1^* e^{-\rho_1(t^*-t)} + \alpha_2 - \beta_2\tau)/(\beta_1+2\beta_2) & t\in[0,t^*] \\ \alpha_1 e^{-\rho_1(T-t)}/\beta_1 & t\in(t^*,T] \end{cases} \quad (26)$$

and

$$x_1 = \begin{cases} \alpha_1 - \beta_1((\beta_1+\beta_2)\lambda_1^* e^{-\rho_1(t^*-t)} + \alpha_2 - \beta_2\tau)/(\beta_1+2\beta_2) & t\in[0,t^*] \\ \alpha_1(1-e^{-\rho_1(T-t)}) & t\in(t^*,T] \end{cases} \quad (27)$$

The consumer price in OECD

$$p+\tau = \begin{cases} ((\beta_1+\beta_2)\lambda_1^* e^{-\rho_1(t^*-t)} + \alpha_2 + (\beta_1+\beta_2)\tau)/(\beta_1+2\beta_2) & t\in[0,t^*] \\ \overline{p} & t\in(t^*,T] \end{cases} \quad (28)$$

and the equilibrium demand in OECD's market

$$x_2 = \begin{cases} (\alpha_2 - \lambda_1^*\beta_2 e^{-\rho_1(t^*-t)} - \beta_2\tau)(\beta_1+\beta_2)/(\beta_1+2\beta_2) & t\in[0,t^*] \\ 0 & t\in(t^*,T] \end{cases} \quad (29)$$

We can solve the optimal time for OPEC to deplete the resource, when they take uniform pricing strategy, from the exhaustible condition, i.e

$$S_0 = \int_0^T [x_1+x_2]dt = \int_{t^*}^T x_1 dt + \int_0^{t^*} [x_1+x_2]dt \quad (30)$$

5. Simulation Analysis

In both cases, the resource rent and the timing of depletion and exit from the markets are jointly determined, which makes the analytical results difficult to obtain and the comparison almost impossible. We proceed by carrying out simulations of the pricing and utilization strategy under different cases and test for the sensitivity of the result to changes in the parameter values.

5.1 Oil and Carbon data

Table 1 presents the base parameters that we use for our simulation analysis. OPEC's proven conventional oil reserves were around 902.4 billion barrels in 2005 (BP, 2006). This constitutes about 75 % of the total proven conventional oil reserves. Note that this data concerns proven reserves - not the ultimately recoverable reserves that include reserves growth due to technological progress and new reserve findings. Including these would increase the extractable resource base. However, for simplicity we stick to the proven reserves. In addition, there are large amounts of unconventional oil reserves (and coal etc) which we neglect in our study.

The current atmospheric carbon stock is about 215 billion metric ton of carbon above the pre-industrial level (IPCC, 2007). Roughly each barrel of oil contains 6.1 GJ, which implies that OPEC's reserves are roughly 5500 EJ. The carbon content of oil is roughly 0.02 kg per MJ, thus the total carbon stock in the oil reserves is roughly 110 G ton carbon.

The marginal damage cost is assumed to be somewhere between US$ 10 per ton C up to maybe US$ 100 per ton C per year (Carolyn and Richard,2003, David Pearce, 2003). The shape of the damage function is highly uncertain, for simplicity we assume that the marginal damage cost is constant.

Total OPEC Reserve	S_0=905 billion barrel
Total Carbon at t_0	E_0=215 G ton
Carbon Transfer Coefficient	γ=0.122 ton/barrel
Marginal Damage of Carbon	θ=10 $/ton carbon
OPEC Demand Coefficient (billion barrel)	α_1=3.86 β_1=0.0257
OECD Demand Coefficient (billion barrel)	α_2=25.5 β_2=0.17
Cost of Backstops	$\overline{p}$ =140
Discount Rate in OPEC	$\rho_1 = 0.04$
Discount Rate in OECD	$\rho_2 = 0.04$

Several potential alternatives to conventional oil are currently discussed, ethanol, hydrogen, synthetic diesel from coal etc etc. For the moment being there is no clear winner. We assume carbon neutral hydrogen as backstop. The main reason for this is that the future cost of hydrogen has been extensively assessed and that we in the theoretical model assume a carbon neutral backstop. Optimistic prevailing estimates of what carbon neutral hydrogen may cost when the technology becomes mature are about US$ 100 to 200 per barrel oil equivalent.

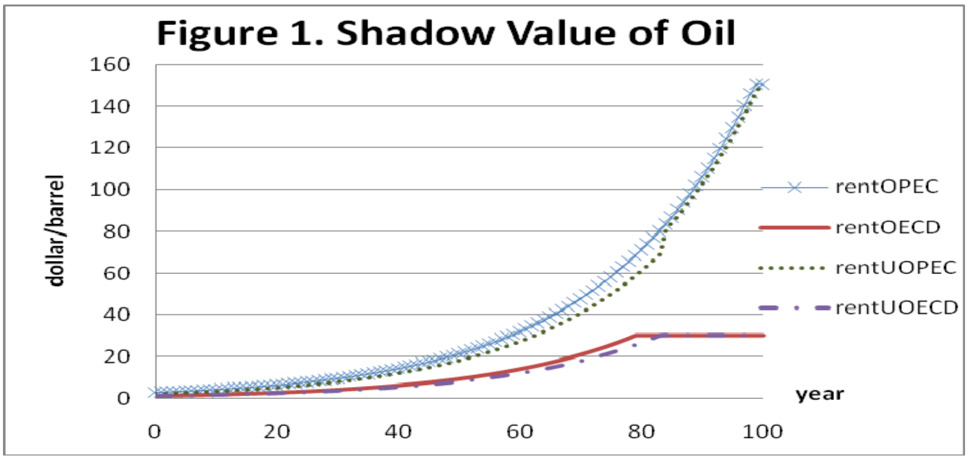
The worlds total oil consumption in 2005 was 3837 M ton, which equals roughly 170 EJ. Oil consumption in 2005 in the OPEC countries was about 15 EJ and in the OECD countries about 99 EJ (BP, 2006). The price elasticity for crude oil is assumed to be somewhere between -0.1 and -0.5, in general lower for developing countries (including the OPEC countries). If we take 2005 as base year, the oil price US$ 54.5 per barrel, i.e. about US$ 9 per GJ. We simply assume that the demand for oil would be zero at cost of US$ 150 per barrel and assume a straight line between this price/demand point the price/demand point in 2005. This would imply for OECD that the demand function would be $\beta \approx 0.17$ and $\alpha \approx 25.5$ and if we assume the competitive oil price in OPEC the demand function would look something like $\beta \approx 0.0257$ and $\alpha \approx 3.86$, where the unit is billion barrels. Of course the demand functions can be calibrated in a range of different ways, all equally arbitrary.

The base case for the parameters is shown in the table above. The results presented in the next section are obtained from varying different elements of the parameters discussed above.

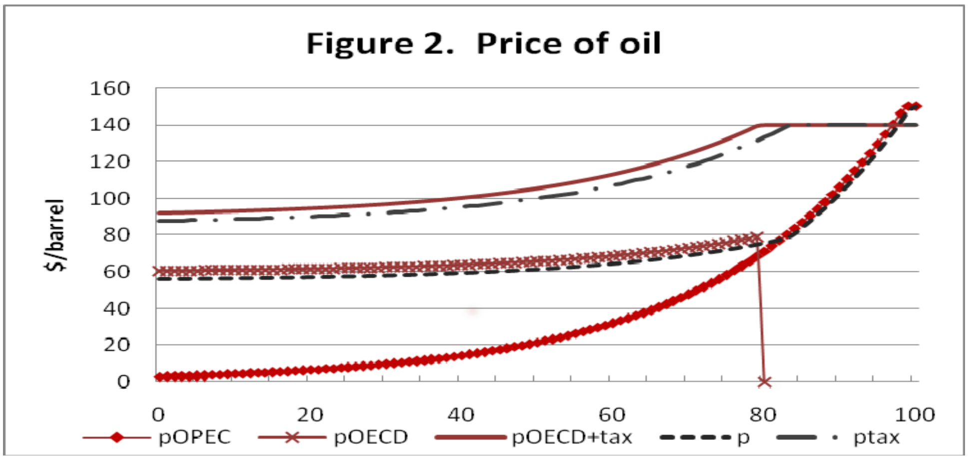
5.2 Simulating the fossil endgame.

5.2.1 Main results for the base case

Fig 1 shows the shadow value of oil in the ground for OPEC and OECD respectively. In both cases the rent starts off low and grows exponentially at the rate of time preference at relevant time intervals. It grows to a much higher level in OPEC because consumers in OPEC do not have the backstop technology and are therefore willing to pay a much higher price when the resource is close to depletion. The shadow value of oil for OPEC depends on its own strategy. If it can price discriminate against OECD, the shadow value always grows exponentially. However, if it charges the same price for domestic and foreign consumers, the rent will increase exponentially first. When OECD leaves the market and the effect of backstop and tax to deter the rise of shadow value disappears around 80 years later, the value of oil will jump by around 10$/barrel and start to increase exponentially at the same rate again afterwards until the depletion of oil. The scarcity rent of oil for OECD is the shadow value of oil underground to storage carbon, which increases exponentially at the rate of OECD's time preferences regardless of whether OPEC price discriminates.



The comparison between the solid line representing the shadow value under price discrimination strategy and the dotted or dashed line denoting the shadow value in the case of uniform pricing enables us to conclude that when OPEC loses the possibility to price discriminate, the shadow value of oil for OPEC (OECD) will decrease, which implies the total rent left for OPEC will be smaller; and the shadow value of oil for OECD will also decrease., This implies that OECD will impose a lower tax and switch to the backstop later.



The pricing and allocation of oil in both OPEC and OECD are shown in figure 2 and 3 respectively. If OPEC can price discriminate, they will charge a much lower domestic price, (implicitly a heavy subsidy, to domestic consumers). The difference of price charged to OPEC and OECD becomes smaller when OECD approaches the time to switch to the backstop technology because the shadow value of oil for OPEC will increase faster than the tax imposed by OECD. Price discrimination also means that the producer price to the OECD would be higher than the price without discrimination but this effect is smaller than the lowering of the domestic price in OPEC. This reflects both OPEC's bias toward domestic market and their response to the rising OECD tax. After OECD stops importing, the price in the domestic market rises sharply until the demand diminishes and the resource is depleted.

Figure 3. Consumption in two markets

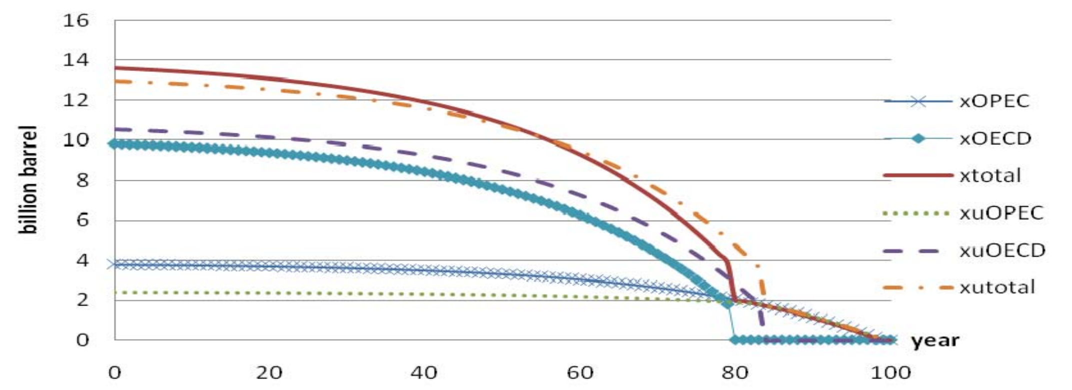


Figure 3 shows the corresponding paths for the sale of oil and the timing of resource depletion. The simulations show that domestic consumption in OPEC (which is today roughly one-fourth of total extraction) would increase quite rapidly in the future. This is especially true, when OECD stops importing oil. Price discrimination leads to a lower consumption by the OECD but this is more than compensated by a much higher oil use in OPEC so that total oil depletion is faster (and thus also accumulation of carbon in the atmosphere). The elimination of price discrimination strategy by OPEC also smoothes the path of the total consumption, in the sense that the total consumption today will decrease while in the future it will increase. The timing to switch to backstop in OECD will be delayed due to the decrease of price charged to OECD due to the uniform pricing strategy by OPEC.

Figure 4. tax

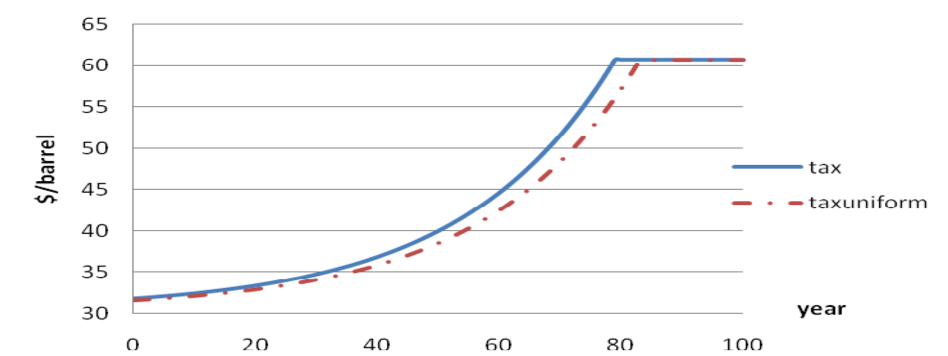


Figure 4 shows the OECD oil tax path after the change of strategy by OPEC. The tax would be lower in the absence of price discrimination because of the decrease of the incentive for OECD to conteract the smaller producer price charged by OPEC. Note however that the difference would be very small and most likely not “enough” to persuade OPEC not to discriminate.

5.2.2 The impact of cheaper backstop technology

The policies to encourage R&D in backstop technologies have been proposed as a promising tool to combat global warming and energy problems. We want to analyse the effect of an exogenous improvement in backstop technology by checking its effects in our model. We simulated the results after the opportunity cost of backstop decreases from 140 to 110$/barrel.

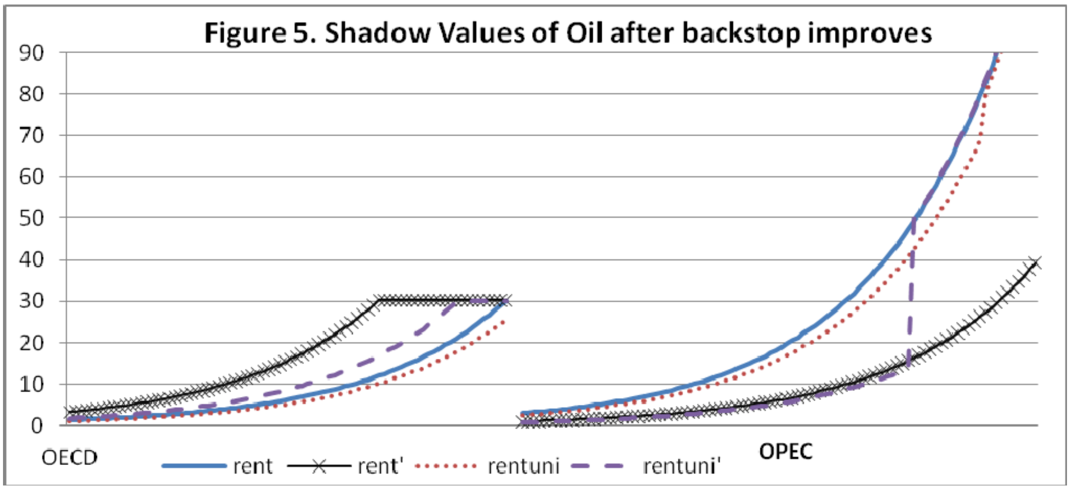
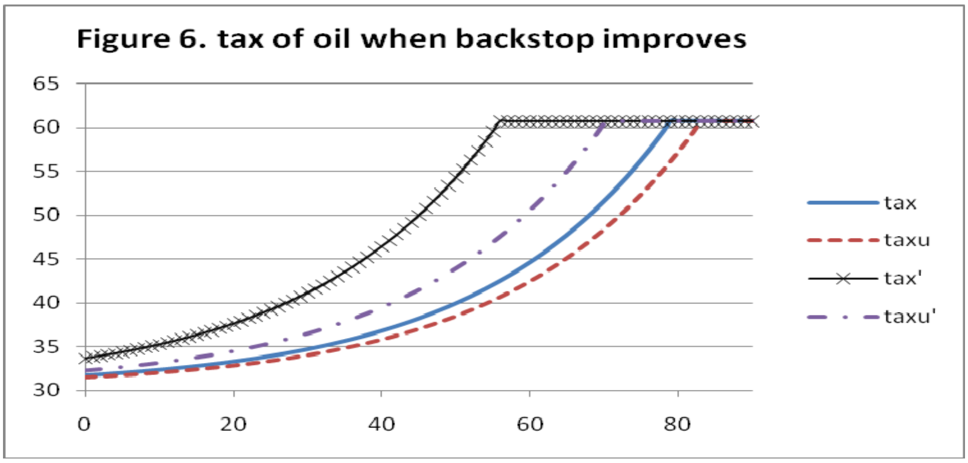


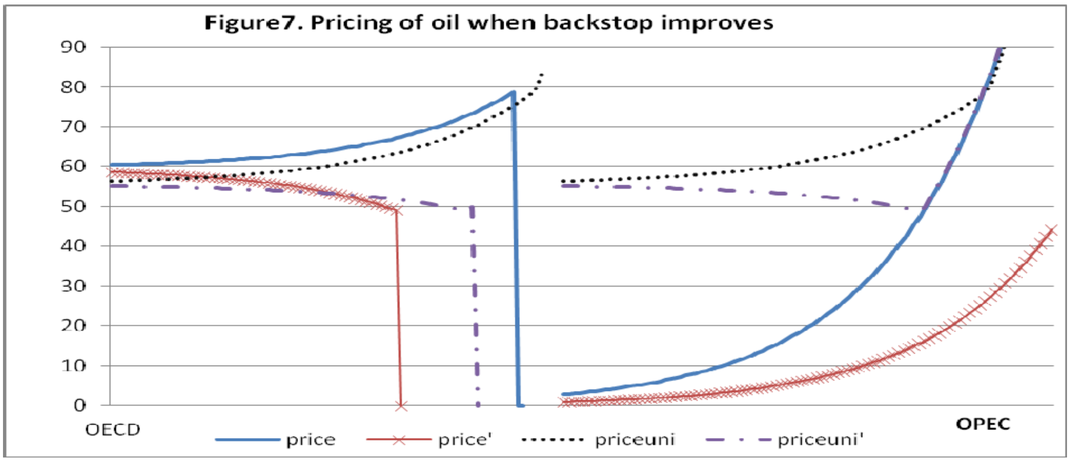
Figure 5 shows how shadow values of oil for OPEC and OECD will change with cheaper backstop technology. A change in backstop price from 140 to 110 $/bbl leads to an fall in scarcity rent for OPEC while the shadow value for the OECD of keeping oil in the ground actually increases. The loss to OPEC is intuitively obvious since they cannot make so much money in the presence of a cheaper backstop. For OECD on the other hand the importance of keeping oil in the ground rises when they do not need it so badly for energy purposes[6]. We can also observe a larger increase of shadow value for OPEC when the effect from the cheaper backstop to prevent the fast increase of scarcity rent disappears. This im-

[6] at the moment when OECD switches to backstop technology, scarcity rent always experiences a sharp increase and then increases exponentially at the rate of discount rate. The sharp increase is even larger when the opportunity cost of backstop technology is lower.

plies that the effort to improve backstop might be a useful tool for OECD to reduce the shadow value of oil in OPEC.



The impact of backstop technology on tax is different from its impact on scarcity rent as shown in figure 6. The tax on imported oil will increase with cheaper backstop technology and the gap increases over time. It will also lead to a faster switch to the backstop[7].



The producer price of oil in both OPEC and OECD is shown in figure 7. One striking consequence of a cheaper backstop is that the price of oil may fall even as the scarcity rent increases. This is because the effect from increased scarcity rent is relatively smaller than the reduction caused by the increase of tax put by OECD on the oil. Hence, the price has to fall. These combined effects may give a good motivation for countries like OECD to invest in R&D activities to counterreact the rising scarcity rent that is captured by OPEC. We can also observe that once the effect from backstop techonology in OECD on the price disappears, the price of oil sold to domestic consumers in OPEC starts rising again.

[7] This is also true in a case without price discrimination but the effect is then smaller.

The sum of tax and producer prices determines consumer prices in OECD. As the increase of tax adds to the producer price, the effect on consumer prices of a cheaper backstop is not very significant and not presented here. The main difference lies in an earlier transition to the backstop and later depletion of oil.

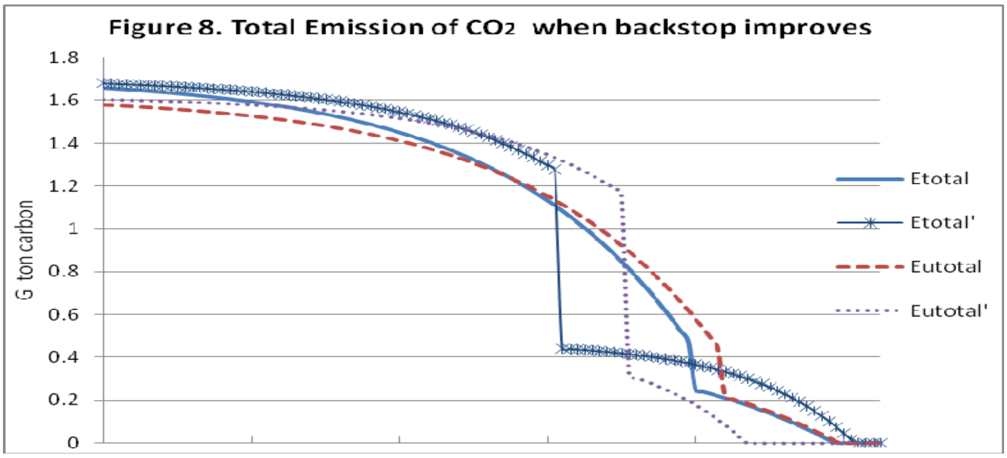


Figure 8 shows the impact of the improvement of backstop technology on the total emission of carbon dioxide. A drop in oppornity cost of backstop from 140$/barrel to 110$/barrel will lead total emissions to increase in the beginning when OPEC supplies both markets. [8] This is due to the decrease of scarcity rent which leads to larger consumption of oil. But this larger total emissions can only last for shorter time since OECD will switch to backstop earlier. After OECD leaves the market, the consumption of remaining oil left for OPEC consumers enables a sharp drop in total carbon emissions compared to the previous time period, that will continue until oil is depleted.

Our model also allows us to study for instance the effect of demand shocks. These are however fairly intuitive and we find that exogenous increases in demand (such as what we have witnessed in the last few decades in China) imply that rents will go up as will shadow values of oil and also for instance the tax that OECD finds optimal to apply (both in the case of unified pricing and even more so in the case of price discrimination). The joint effect would be that producer and consumer prices rise.

[8] "Etotal'" and "Eutotal'" represent the total emissions with and without price discrimination when the backstop improves.

6. Conclusion

This paper analyzes the problem of pricing oil by OPEC in both the domestic and OECD markets and the problem of oil taxation by an OECD that is concerned about climate damage. The extraction will lead to depletion and the consumption will lead to emission of carbon dioxide causing climate damage. OPEC won't charge the same price in OECD markets as it in its domestic market, and therefore the discrepancy between these two prices persists. The possibility to sell oil in its domestic market enables OPEC to reduce the adverse consequence they perceive from the tax imposed by OECD.

The discriminatory pricing strategy by OPEC has very important consequences. It would enable OPEC to charge a low price to domestic consumers as a rational response to counteract the OECD in case OECD seeks to appropriate resource rents through taxation. In this sense the OPEC countries could retaliate against OECD taxation and maybe attract OECD industries – thereby reclaiming rents and undoing the climate policy of the OECD. Significantly lowering the domestic price of oil products may not be a good overall industrialization strategy but it could be quite effective in attracting some industries in the petrochemical, plastics, fertilizer or other industries that use oil or energy very intensely. It would also lead the domestic market to become increasingly important as the resource stock is extracted toward depletion.

The tax by OECD is found to have two components, the strategic and pigouvian part, where both of them increase with the marginal instant damage of carbon dioxide. We find that the absolute tax on oil increases over time. However, the trend of ad valorem tax depends on the time preferences in OPEC and OECD. When OPEC has the same time preference as OECD, it always increases over time. While if the discount rate in OPEC is much larger than it in OECD, the ad valorem carbon tax decreases eventually due to OECD's motive to postpone the carbon emission induced by OPEC' myopic decision to extract resource and emit carbon earlier.

Our results from this simple model suggest the need of coordination of energy pricing and taxation policies to address climate change issues. This would imply the need to reduce OPEC's ability to reduce the effect of climate policies through substituting the sales across time and markets. The linkage of energy markets will make the tax on energy in one country reduce the rent and price of oil, hence increase the energy consumptions in other countries. The leakage of carbon in other markets without climate policies such as carbon tax will offset the reductions in carbon emission in individual countries that impose taxes. The effort towards pushing oil production countries to cancel dual pricing strategy can slow the accumulation of carbon emission and reduce the adverse effects of global warming. At a time when more and more observers are arguing in favor of harmonized carbon taxation across the World, we believe that the very special interests and situation of the oil producers merits special attention.

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Variable list

i=1,2 Index for areas, i=1 is OPEC and 2 is OECD
ρ_i the discount rate in OPEC (i=1) or OECD (2)
x_i the resource use in OPEC(1) or OECD (2)
p_i the producer price of oil in OPEC(1) or OECD (2)
$\bar{p}$ the opportunity cost of backstop technology in OECD.
μ_i Lagrangian Multiplier for x_i .
τ the tax of oil in OECD.
S the stock of oil in OPEC.
S_0 the initial stock of oil in OPEC.
S_T the stock of oil in OPEC at the end of the game.
E the stock of carbon.
ψ_i the cost of carbon in region i
λ_i the value of oil stock in region i
θ marginal damage of carbon
t^* the time when OPEC stops supplying the first market
T the time when OPEC depletes their resource stock.
γ the parameter transferring fossil fuel into CO_2.
ω the ad valorem tax on oil.

α_i β_i Parameters of the petroleum demand equation for region i

Appendix I:

From problem (1)-(6), the OECDs current-value Hamiltonian is

$$H = (\alpha_2 - \beta_2 \cdot (p_2 + \tau))^2 / (2\beta_2) + \tau(\alpha_2 - \beta_2 \cdot (p_2 + \tau)) - \theta \cdot E$$
$$- \lambda_2(\alpha_1 - \beta_1 \cdot p_1 + \alpha_2 - \beta_2 \cdot (p_2 + \tau)) + \psi_2 \cdot \gamma(\alpha_1 - \beta_1 \cdot p_1 + \alpha_2 - \beta_2 \cdot (p_2 + \tau)) \quad \text{(A.1)}$$

Using Pontryagin's maximum principle, the necessary conditions are

$$\frac{\partial H}{\partial \tau} = -\beta_2 \tau + \beta_2(\lambda_2 - \psi_2 \cdot \gamma) = 0 \quad \text{(A.2)}$$

$$\dot{\psi}_2 = \rho_2 \psi_2 + \theta \quad \text{(A.3)}$$

$$\dot{\lambda}_2 = \rho_2 \lambda_2 \quad \text{(A.4)}$$

Solving differential equation (8) and (9) yields the shadow cost of carbon

$$\psi_2(t) = \psi_2(t^*) e^{-\rho_2(t^* - t)} - \int_t^{t^*} \theta e^{-\rho_2(\varsigma - t)} d\varsigma \quad \text{(A.5)}$$

and

$$\lambda_2(t) = \lambda_2(t^*) e^{-\rho_2(t^* - t)}. \quad \text{(A.6)}$$

Transversality conditions are

$$\psi_2(t^*) = \partial V / \partial E = -\theta / \rho_2 \quad \text{(A.7)}$$

$$\lambda_2(t^*) \ge \partial V / \partial S = \theta\gamma / \rho_2, \text{ with } \lambda_2(t^*) = \theta\gamma / \rho_2 \text{ if } S(t^*) > 0 \quad \text{(A.8)}$$

$$H^* \big|_{t=t^*} = \sup_{\tau} H(x, x^*) \big|_{t=t^*} = \rho_2 V - \partial V / \partial t = -\theta \cdot E(t^*) \quad \text{(A.9)}$$

Appendix II:

The current-value Hamiltonian of the free end point problem (10) can be written as

$$H_1 = x_1^2(p_1)/(2\beta_1) + p_1 x_1(p_1) + p_2 x_2(p_2,\tau) - \lambda_1(x_1 + x_2) + \mu_1 x_1 + \mu_2 x_2 + \eta(\overline{p} - p_2 - \tau) \tag{A.10}$$

Using Pontryagin's maximum principle, the necessary conditions are

$$\frac{\partial H_1}{\partial p_1} = -\beta_1 p_1 + \lambda_1\beta_1 - \mu_1\beta_1 = 0 \tag{A.11}$$

$$\frac{\partial H_1}{\partial p_2} = -2p_2\beta_2 + \alpha_2 - \beta_2\tau + \lambda_1\beta_2 - \mu_2\beta_2 - \eta = 0 \tag{A.12}$$

$$\dot{\lambda}_1 = \rho_1\lambda_1 \tag{A.13}$$

with the Lagrangian constraints,

$$\mu_1 x_1 = 0 \ (\mu_1 = 0, \text{when } x_1 > 0; \mu_1 > 0 \ \text{ when } x_1 = 0) \tag{A.14}$$

$$\mu_2 x_2 = 0 \ (\mu_1 = 0, \text{when } x_2 > 0; \mu_1 > 0 \ \text{ when } x_2 = 0), \tag{A.15}$$

$$\eta(\overline{p} - p_2 - \tau) = 0 \ (\eta = 0, \text{when } \overline{p} - p_2 - \tau > 0; \eta > 0 \text{ when } \overline{p} - p_2 - \tau = 0) \tag{A.16}$$

and the transversality conditions are

$$\lambda_1(T)S_T = 0, \lambda_1(T) = 0 \text{ if } S_T > 0 \text{ and } \lambda_1(T) > 0 \text{ if } S_T = 0 \tag{A.17}$$

$$H_1^*\big|_{t=T} = \sup_{x_1\geq 0, x_2 \geq 0} H(x_1, x_2)\big|_{t=T} = 0 \tag{A.18}$$

The optimal prices set by OPEC in domestic and OECD markets are given by the first order conditions (A.11) and (A.12). Rearranging yields

$$p_1 = \lambda_1 - \mu_1 \tag{A.19}$$

$$p_2 = \frac{1}{2}\left(\frac{\alpha_2}{\beta_2} + \lambda_1 - \mu_2 - \frac{\eta}{\beta_2} - \tau\right) \tag{A.20}$$

The resource rent is found from solving differential equation (A.19) resulting in

$$\lambda_1 = \lambda_1(T)e^{-\rho_1(T-t)}. \tag{A.21}$$

The Lagrangian constraints (A.14), (A.15) and (A.16) are conditions of complementary slackness. As OECD consumer price $p_2 + \tau$ reaches the backstop level $\overline{p}$, OECD switches to backstop technology, and OECD demand for oil falls to zero by equation (4), and constraint (A.15) binds. Simultaneously, constraint (A.16) then also binds. One conclusion implied by the transversality condition (A.18) is that the OPEC supply to the domestic market $x_1(T)$ at the terminal time T goes to 0.

Using (A.18), we can get $x_1(T) = \alpha_1 - \beta_1\lambda_1(T) = 0$, which implies that $\lambda_1(T) = \alpha_1/\beta_1$. Hence

$$\lambda_1 = \lambda_1(T)e^{-\rho_1(T-t)} = \frac{\alpha_1}{\beta_1}e^{-\rho_1(T-t)} \tag{A.22}$$

Appendix III:

For the problem during the time in $t \in (t^*, T]$, we solve it using optimal control theory and the current value of free time Halmitonian function is written as

$$H_1 = x_1^2(p)/(2\beta_1) + px_1(p) - \lambda_1 x_1 + \mu_1 x_1 \quad \text{(A.23)}$$

The necessary conditions for an optimum are

$$\frac{\partial H_1}{\partial p} = -\beta_1 p + \lambda_1\beta_1 - \mu_1\beta_1 = 0 \quad \text{(A.24)}$$

$$\mu_1 x_1 = 0 \ (x_1 \geq 0 \text{ if } \mu_1 = 0; x_1 = 0 \text{ if } \mu_1 > 0) \quad \text{(A.25)}$$

$$\dot{\lambda}_1 = \rho_1\lambda_1, \quad \text{(A.26)}$$

$$\lambda_1(T)S_T = 0, S_T = 0 \text{ if } \lambda_1(T) > 0 \text{ and } S_T > 0 \text{ if } \lambda_1(T) = 0 \quad \text{(A.27)}$$

$$H_1^*\big|_{t=T} = \sup_{p_1 \geq 0} H_1(x_1)\big|_{t=T} = 0 \quad \text{(A.28)}$$

From (A.26), we obtain

$$\lambda_1 = \lambda_1(T)e^{-\rho_1(T-t)} \quad \text{(A.29)}$$

and (A.24), get

$$x_1 = \alpha_1 - \beta_1\lambda_1(T)e^{-\rho_1(T-t)} \quad \text{(A.30)}$$

From (A.28), we can conclude that (A.25) is binding. Hence

$$\lambda_1(T) = \alpha_1 / \beta_1. \quad \text{(A.31)}$$

Appendix IV:

For the problem during the time in $t \in [0, t^*]$, the current Hamiltonian function is

$$H_1 = x_1^2(p)/(2\beta_1) + px_1(p) + px_2(p,\tau) - \lambda_1(x_1 + x_2) + \mu_1 x_1 + \mu_2 x_2 + \eta(\bar{p} - p - \tau) \quad \text{(A.32)}$$

The necessary conditions for an optimum are

$$\frac{\partial H_1}{\partial p} = -\beta_1 p + \lambda_1\beta_1 - \mu_1\beta_1 - 2p\beta_2 + \alpha_2 - \beta_2\tau + \lambda_1\beta_2 - \mu_2\beta_2 - \eta = 0 \quad \text{(A.33)}$$

$$\dot{\lambda}_1 = \rho_1\lambda_1, \quad \text{(A.34)}$$

$$\mu_1 x_1 = 0 \ (\mu_1 = 0, \text{when } x_1 > 0; \mu_1 > 0 \ \text{ when } x_1 = 0) \quad \text{(A.35)}$$

$$\mu_2 x_2 = 0 \ (\mu_1 = 0, \text{when } x_2 > 0; \mu_1 > 0 \ \text{ when } x_2 = 0), \quad \text{(A.36)}$$

$$\eta(\bar{p} - p - \tau) = 0 \ (\eta = 0, \text{when } \bar{p} - p - \tau > 0; \eta > 0 \text{ when } \bar{p} - p - \tau = 0) \quad \text{(A.37)}$$

From (A.34), we get

$$\lambda_1 = \lambda_1(t^*)e^{-\rho_1(t^*-t)} \quad \text{(A.38)}$$

Consider the interior solution, from (A.33), we obtain

$$p = (\lambda_1\beta_1 + \lambda_1\beta_2 + \alpha_2 - \beta_2\tau)/(\beta_1 + 2\beta_2) \quad \text{(A.39)}$$

The demand for OPEC and OECD are

$$x_1 = \alpha_1 - \beta_1((\beta_1 + \beta_2)\lambda_1^* e^{-\rho_1(t^*-t)} + \alpha_2 - \beta_2\tau)/(\beta_1 + 2\beta_2) \quad \text{(A.40)}$$

and the equilibrium demand in OECD's market

$$x_2 = (\alpha_2 - \lambda_1^*\beta_2 e^{-\rho_1(t^*-t)} - \beta_2\tau)(\beta_1 + \beta_2)/(\beta_1 + 2\beta_2) \quad \text{(A.41)}$$

Appendix V:

We can also calculate the evolution of the tax in relation to product price. This is of practical interest to policy makers since it corresponds to an "ad valorem tax".

$$\omega = \frac{\tau}{\tau + p} = \frac{2\theta\gamma}{\rho_2}(1 + e^{-\rho_2(t^* - t)}) / (\frac{\alpha_2}{\beta_2} + \frac{\alpha_1}{\beta_1} e^{-\rho_1(T-t)} + \frac{\theta\gamma}{\rho_2}(1 + e^{-\rho_2(t^* - t)})) . \quad \text{(A.42)}$$

The evolution of the tax over time can be observed from its derivation with respect to time after substituting $T - t^* = \frac{1}{\rho_1}\ln(\frac{\alpha_1}{\beta_1}/(2\overline{p} - \frac{\alpha_2}{\beta_2} - \frac{2\theta\gamma}{\rho_2}))$ we get

$$\frac{\partial \omega}{\partial t} = \frac{\frac{2\theta\gamma}{\rho_2}[\frac{\alpha_2\rho_2}{\beta_2} e^{-\rho_2(t^*-t)} - (2\overline{p} - \frac{\alpha_2}{\beta_2} - \frac{2\theta\gamma}{\rho_2})\rho_1 e^{-\rho_1(t^*-t)} - (2\overline{p} - \frac{\alpha_2}{\beta_2} - \frac{2\theta\gamma}{\rho_2})(\rho_1 - \rho_2)e^{-\rho_1(t^*-t)}e^{-\rho_2(t^*-t)}]}{(\frac{\alpha_2}{\beta_2} + \frac{\alpha_1}{\beta_1}e^{-\rho_1(T-t)} + \frac{\theta\gamma}{\rho_2}(1 + e^{-\rho_2(t^*-t)}))^2}$$

(A.43)

The effect can be discussed in different scenarios. First, we consider the often assumed case in the literature when the time preference in OPEC and it in OECD are the same. Since $\overline{p}$ is the opportunity cost of backstop technology and we have assumed that $\overline{p} < \frac{\alpha_2}{\beta_2}$, the ad valorem tax increases over time. The result under this case seems to be different with the intuition suggested by Ulph (1994), that the carbon tax should definitely be falling once fossil fuels are exhausted. It is also different from the previous result that the optimal carbon tax will either be monotonically declining, or it will initially increase and eventually decline (Hoel,1996). The difference appears to be due to the fact that the analyses here explicitly takes the depletion into consideration. We do however find falling tax when assuming that the discount rate in OPEC is much higher than in the OECD, it is not obvious what results we will get. Assume the extreme situation that $\rho_1 \gg \rho_2$. Since OPEC is very myopic they want to extract more oil and sell it as early as possible. This also means the price is low but OECD will therefore counteract this with a high tax (that falls over time) to delay the time profile for carbon emissions to the atmosphere. In this scenario the ad valorem tax is falling eventually.

Paper II

On social sanctions and beliefs:
A pollution norm example

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Abstract

This paper studies the effects of reputation on compliance with social norms of behavior, and in particular, the role of information in mediating this relationship. A prevailing view in the literature states that social sanctions can support, in equilibrium, high levels of obedience to a costly norm. The reason is that social disapproval and stigmatization faced by the disobedient are highest when disobedience is the exception rather than the rule in society. In contrast, the model introduced in this paper shows that imperfect observability causes the expected social sanction to be lowest precisely when obedience is more common. The essential aspect of our analysis lies in the way beliefs are formed. Unless actions are fully observable, society finds it hard to conceive that someone is in disobedience when disobedience is rare. In this line of argumentation, the failure of an environmental norm as an internalization mechanism can be explained. The results of this paper not only draw a line between social sanctions under perfect and imperfect information structures, but also highlight the role of moral (self-imposed) sanctions, which may depend on others' behavior but not on action observability.

Key words: Social Norms, Moral Hazard, Environmental Regulation

JEL: Q52; H23; D82.

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1 Introduction

It is widely recognized that social norms are important drivers of the behaviors of individuals and organizations (Elster,1989; Kaplow and Shavel,2007; Young,2005). Actions regarded by one's social group as proper can bring rewards and have positive effects on reputation. On the other hand,breaching a social norm may lead to sanctions and losses of reputation in a society that instills feelings of shame and distress on its deviant.[1] It has been argued that social sanctions imposed on managers and owners of polluting firms can provide an internalization mechanism of external costs and damages. Cropper and Oates (1992) suggest in their survey of environmental economics that public opprobrium may explain the the Harrington Paradox (HP) in the US, i.e, firms' high levels of compliance with environmental regulation under low expected penalties(Harrington, 1988). Similarly, Elhauge (2005) argues extensively about the relevance of social sanctions for influencing managers' decisions to undertake environmental investments. Decision makers would rather incur costs of compliance than face stigmatization and losses in reputation in society.[2]

The idea that the levels of social sanctions are relatively high when disobedience is uncommon allows a high compliance state to qualify as an equilibrium; see Akerlof (1980), Bernheim (1994), and Lindbeck et al (1999). It is argued here that the potential disgrace of violating a well-established code of behavior may be significant, and that this constitute a strong deterrent. However, the social sanction approach does not necessarily give a

[1]Social norm examples studied in the economics literature include an employer's decision to pay a "fair wage" (Akerlof, 1980), an individuals' decision to actively look for a job (Clark, 2003), and to live on welfare benefits (Lindbecket et al 1999). Ostrom (1990) and Sethi and Somanthan (1996) provide discussions on the role of social norms in the management of common pool resources, and how they can prevent outcomes such as the tragedy of the commons. Some of these examples are consistent with the view that social norms often emerge as society's reaction to compensate for market failure, Arrow (1971).

[2]In a special report on business and climate change, *The Economist* (June 2nd., 2007) explains that the current shift towards cleaner energy might be due to two factors: moral(social) pressure and economic pressure: "*Businessmen, like everyone else, want to be seen to be doing the right thing, and self-interest points in the same direction.*" This paper is concerned with the social approval explanation. The economic explanation is associated with green consumerism. For theoretical analysis of markets with environmentally aware consumers, see for instance Amacher et al (2004), Bansal and Gangopadhyay (2003), and Cremer and Thisse (1999).

unique prediction of the equilibrium. Low compliance equilibria could coexist since losses of reputation are expected to be low at high levels of disobedience. Nyborg and Telle (2004) and Lay et al (2003) formalize this notion in the case where firms are expected to meet an environmental standard.

An underlying assumption that seems ubiquitous in the study of social sanctions is that of perfect observability of agents' behavior, for example in terms of their emissions and compliance status. We argue that unlike other situations where social sanctions have been used to explain economic behavior, in the industrial pollution case this assumption is not necessarily met. In fact, social sanctions are generated in different environments and firms' individual actions and compliance status are unlikely to be perfectly observable in the social circles where owners and managers interact. In some cases, awareness of the identity of polluting sources may be limited to neighboring communities and even for these it may very difficult to judge whether a given emitter is in or out of compliance with the legislation.[3]

This paper presents a theory of social sanctions with a rich informational structure. In our model, society forms (Bayesian) beliefs and expectations about the compliance status of individual firms based on two pieces of information: the general level of violation in the society, and signals that can convey some indication of firms' compliance status. Managers' beliefs and expected losses of reputation are in turn built on society's beliefs. It is farther assumed the existence of a unit mass of firms and that a single firm's action can not affect any given outcome or social equilibrium.

Three basic elements in the analysis of social interactions are introduced here: (a) Imperfect information can lead to mistakes in judgment so that losses of reputation can "wrongly" be imputed to compliant managers, whereas losses of reputation due to violation are typically reduced. (b) As mentioned earlier, when firms' actions are observable, the loss of reputation due to non-compliance is highest at high levels of compliance, thus providing support for the full compliance state to be an equilibrium. In contrast, imperfect information makes the expected loss of reputation due to violation be the lowest precisely

[3]Recently, Levin and List (2007) and Fershtman et al (2008) explain that whether a norm is activated or not depends on the characteristics of the "situation," which directly relates to the social spheres of our pollution example. While our discussion concurs with this view, we emphasize that although a norm might be activated, actions could be imperfectly observable.

when compliance is relatively high. The argument here is rather intuitive. When violations are rare, society finds it hard to conceive that anyone is in violation. (c) Accordingly, the veil of anonymity drawn over violators becomes thicker as the proportion of firms that meet the standard increases. In fact, loss of reputation due to violation is increasing in the level of violation (at high levels of compliance), as opposed to decreasing as is the case with perfect information case. Thus, a social sanction explanation of the HP heavily relies on observability of firms' actions.

Due to the way beliefs are formed in our model, the compliance incentives in the perfect and imperfect information worlds are diametrically opposed at high levels of compliance. We sometimes refer to this as a "belief curse." An important aspect of the argument is that the risk of being unveiled or caught cheating is a very different function from the loss of reputation function. As already mentioned, the potential loss of reputation (if caught) is high when compliance is high. However, the risk of being caught in a high-compliance society may paradoxically be very low since in such a society there may well be little formal control. In fact, when everyone conforms, monitoring is likely to be perceived as largely superfluous.

The framework proposed here provides insights into different situations where similar social interactions and information asymmetries come into play. It also highlights the role of moral (self-imposed) sanctions, which may depend on others' behavior but not on action observability. In this regard, this paper contributes to drawing a line between moral and social norms. While the relevance of action observability in the imposition of social sanctions has been acknowledged by some authors, see for instance Elster (1989) and Kaplow Shavel (2007), to the best of our knowledge, no explicit structure has been given to the problem.[4]

In Section 2, the model is presented and solved for both perfect and imperfect information structures. Section 3 discusses the main results and concludes the paper. Appendix A presents some partial results omitted in the body of the text and Appendix B contains the proofs of the three theorems and the lemma introduced in Section 2.

[4]This discussion in economics can be traced back to Smith (1790), where considerable attention was given to differences and similarities between social and moral motivations.

2 A model of reputation and compliance

The social norm in our model demands firms to meet a legal pollution standard. Compliance is costly but non-compliance could lead to a loss in reputation which may also be costly. In order to recreate the HP scenario we assume that regulatory costs due to non-compliance are negligible or nonexistent. As stated earlier, the main feature of social sanctions is that agents' pay-off functions not only depend on their own action but also on other agents' actions. In a setting where the number of agents that follow a norm is relatively large, social disapproval due to deviation is high. Correspondingly, if very few agents follow the norm, costs of deviation are small. Let $\alpha \in [0, 1]$ represent the fraction of firms that violate the standard. The loss in reputation function is $R(\alpha)$, where $R_\alpha < 0$. By breaking the norm violators derive pecuniary benefits represented by saved abatement expenditures a. The social benefit from meeting the pollution standard is denoted by E, which is assumed to be larger than the abatement cost a. Hence,the compliance to the norm is socially desirable.

We will only be concerned with situations where firms adopt pure strategies, either comply or violate. Let $x \in \{c, v\}$ be a firm's strategy, where c denotes compliance and v violation. A manager's utility function is then given by:

$$U(x;\alpha) = \begin{cases} -a & \text{if} \quad x = c \\ -R(\alpha) & \text{if} \quad x = v \end{cases} \tag{1}$$

An underlying assumption of the managers' utility function in equation (1) is that of perfect observability of firms behavior. The social sanction faced by managers is to a large extent given by society's beliefs concerning their firm type. Hereafter we often refer to a firm's type as its compliance status. Under perfect information society's assessment of a given firm being either type matches the firm type. Table 1 illustrates this. For instance, the bottom left corner of the table shows that the probability of a violator being identified as a compliant is 0. This in turn implies that the probability that this firm is identified as a violator is 1 (upper left corner).

In order to make our point clear we use the simple linear reputation function, $R(\alpha) = 1 - \alpha$. Furthermore, assume that there is a unit mass of firms with homogeneous fixed costs of compliance $a \in (0, 1)$ and that a single firms' actions does not affect the value

Table 1: Society's beliefs: Perfect Information

	Beliefs on firm being:	
True firm type	Compliant	Violator
Compliant	1	0
Violator	0	1

of $R(\alpha)$. This description fits that of perfect competition (or non-atomic games). In the analysis of the strategic interactions in our model the following Nash Equilibrium (NE) concept will be used. [5]

Definition 1. *Let $x(\alpha)$ be a firm's best response strategy to level of violation α, so that $U(x(\alpha);\alpha) \geq U(x;\alpha)$ for $x \in \{c, v\}$. A strategy profile α is a Nash Social Equilibrium if all firms' strategies are best response strategies. Further, a NE is Stable if there is $\bar{\epsilon}$ such that $x(\alpha) = x(\alpha \pm \epsilon)$ holds for all $\epsilon \in (0, \bar{\epsilon})$ and for all firms.*[6]

This definition presents a natural extension of NE for N-player games to a game with a continuum of players. The social equilibrium of violation α is the aggregate outcome of NE distribution of all firms. The stability condition ensures that equilibrium strategies are also best response strategies to levels of violation that slightly differ from equilibrium so that small masses of firms do not have incentives to deviate. Also, if a small mass of firms makes a mistake in equilibrium, the remaining set of firms will not change their original strategies.

Proposition 1 (Perfect Information Equilibria). *Under perfect information concerning firms compliance status, two Stable NE coexist: the full compliance equilibrium, $x(0) = c$ for all firms, and the full violation equilibrium, $x(1) = v$ for all firms. A third Non-Stable NE with partial compliance, $\alpha = 1 - a$, is also present.*[7]

[5] Schmeidler (1973) first proved existence of pure strategy equilibrium in games with a continuum of players. For a comprehensive account of this class of games see Khan and Sun (2002).

[6] Naturally, the stability condition is one sided for the extreme cases, $\alpha = 0, 1$. The best responses must, respectively, meet $x(0) = x(0 + \epsilon)$ and $x(1) = x(1 - \epsilon)$ for all $\epsilon \in (0, \bar{\epsilon})$ and for all firms.

[7] This proposition is the equivalent of Proposition 1 of Nyborg and Telle (2004)

Figure 1 illustrates the insight provided by this proposition by showing the (dis)utilities of compliance and violation for different levels of violation. Proposition 1 presents two Stable NE, namely states k and m in the figure, where all firms behave identically (or pooling equilibria). The social sanction at high levels of compliance is high enough to keep this society in full compliance, state k. Nevertheless, the compliance incentives are undermined at low levels of compliance in such a way that a violation equilibria could persist, state m. State l emerges as a possible NE but it does not meet the stability requirement.

[Figure 1 about here]

Society's attitude toward pollution in the above analysis contrasts with the traditional view used to study the industrial pollution control problem. The existence of increasing marginal damages of pollution implies that the optimal pressure imposed by society on polluting firms ought to be increasing in pollution. While we do not attempt to develop a normative theory of pollution here, it is interesting to see that under a behavioristic lens society might be more tolerant to pollution at higher levels of environmental degradation.[8] In our model, higher levels of violation are naturally associated to higher levels of pollution.

We now turn to study the imperfect information case. We assume that society has fragmentary information based on which it forms expectations about the compliance status of firms. Since beliefs are now formed with partial information, losses in reputation could be imputed to both compliant firms and violators. We assume that society knows the actual level of violation in the economy α. This in fact constitutes society's (prior) belief on the violation type. If no other information is available, α is society's most sensible estimate of the chances that any given firm, either compliant or violator, is in violation.[9] Further, although society does not observe the compliance status of firms it does receives a

[8] Under the presence of environmental and health damages associated to pollution, all levels of violation are Pareto efficient in our model. However,higher levels of compliance with the regulation will create larger social surplus.

[9] Assume compliant firms emit 0 and violating firms emit z units of pollution. Since the number of firms is normalized to unity, if they were all noncompliant total pollution would be "z". If total pollution can be observed and is measured as W then the statistic used by society to calculate the share of polluting firms is given by $\tilde{\alpha} = \frac{W}{z}$.

signal from each firm that conveys information about their type. A signal could be denoted as either a violation signal or a compliance signal. Signals are mutually exclusive and the occurrence of a compliance signal is equivalent to the non-occurrence of a violation signal. Let $\theta \in (0, 1)$ be the probability that society receives a violation signal from a compliant firm and π be the probability that such signal comes from a violator with $\pi \in [\theta, 1)$, that is society cannot be less (more) likely to receive a violation (compliance) signal from a violator than from a compliant firm. Consequently, $1 - \pi$ and $1 - \theta$ are the probabilities that a compliance signal is received from a violator and a compliant firm respectively. Note that these primitive probabilities are exogenous and firms cannot influence them.[10] Table 2 presents a cross tabulation of signals and firm types.

Table 2: Probabilities of signals

	Firm Type	
Signal	Compliant	Violator
Compliance	$1 - \theta$	1-π
Violation	θ	π

Once signals are realized society's beliefs on the expected types of firms are calculated using Bayes' rule. Specifically, society's beliefs about an individual firm being the violation type when a violation signal is received take the following form:

$$A(\alpha, \pi) = \frac{\pi}{\pi\alpha + \theta(1 - \alpha)} \ \alpha \qquad (2)$$

Without loss of insight, θ is assumed invariant throughout the analysis and was omitted in $A(\alpha, \pi)$. In fact, increases (decreases) in π can always be interpreted as decreases (increases) in θ in this type of models. Society's prior belief on the violation type, α, is updated via the ratio factor given by the first part the expression. When signals are uninformative, that is $\pi = \theta$, the updating factor equals 1 for all values of $\alpha \in [0, 1]$. With informative signals, that is $\pi > \theta$, this factor is higher than 1 for $\alpha \in [0, 1)$ and equal to 1 for $\alpha = 1$. Note that the denominator of the equation gives the total probability that society receives a violation signal from any given firm. $\pi\alpha$, is the probability that a violation signal comes from a violator, whereas $\theta(1 - \alpha)$ is the probability that a violation

[10] Society's knowledge about polluters in this model resembles that of the regulator's in a non-point source pollution problem.

signal comes from a non-violator (wrongly identified compliant firms). Thus equation (2) provides society with an estimate of the probability that a received violation signal comes from a violator after correcting for the fact that violation signals could also come from non-violators. Society's beliefs on the on the violation type when a compliance signal is received take the following form:

$$B(\alpha, \pi) = \frac{(1-\pi)}{(1-\pi)\alpha + (1-\theta)(1-\alpha)} \ \alpha \tag{3}$$

In this case the updating factor with informative signals is lower than 1 for $\alpha \in [0, 1)$ and equal to 1 for $\alpha = 1$. Now the denominator of the equation gives the total probability that society perceives a compliance signal from any given firm. $(1-\pi)\alpha$ is the probability that a compliance signal comes from a violator and $(1-\theta)(1-\alpha)$ is the probability that a compliance signal comes from a compliant firm. Thus equation (3) gives the probability that a received compliance signal comes from a violator after correcting for the fact that such signals are typically expected to come from a compliant firm. Table 3 presents a tabulation of society's beliefs under imperfect information. Unlike the perfect information case (see Table 1), compliant firms have a risk of being confused as violators and these violators could benefit from passing as complaints.

Table 3: Society's beliefs: Imperfect Information

	Beliefs on firm being:	
Signal	Compliant	Violator
Compliance	$B(\alpha, \pi)$	$1 - B(\alpha, \pi)$
Violation	$A(\alpha, \pi)$	$1 - A(\alpha, \pi)$

From the previous discussion it follows that $A(\alpha, \pi) > \alpha > B(\alpha, \pi)$ for $\alpha \in (0, 1)$ when signals are informative. The probability that a firm is in violation is higher when it emits a violation signal than when it emits a compliance signal. When there is either total violation, $\alpha = 1$, or total compliance, $\alpha = 0$, signals become irrelevant and society is fully certain about all firms types: $A(0, \pi) = B(0, \pi) = 0$ and $A(1, \pi) = A(1, \pi) = 1$. When signals are uninformative firms are completely anonymous and the level of violation, α, is the most sensible estimate of the chances that any given firm is in violation: $A(\alpha, \pi) = B(\alpha) = \alpha$. Firms make their compliance decisions taking into account their own expectations of being identified as violators. Unlike society, managers know their own types since they make the decision on the type to be adopted. Firms' unconditional expectations of being identified as violators when in compliance and violation are given by the following expressions:

$$f^v(\alpha,\pi) = \pi A(\alpha,\pi) + (1-\pi)B(\alpha,\pi) \tag{4}$$

$$f^c(\alpha,\pi) = \theta A(\alpha,\pi) + (1-\theta)B(\alpha,\pi) \tag{5}$$

Figure 2 shows the form these beliefs take under perfect and imperfect information. The solid curves represent firms' unconditional beliefs whereas the dashed curves represent society's beliefs. With uninformative signals we have that $f^c(\alpha,\pi) = f^v(\alpha,\pi) = \alpha$ (see Figure 2a). With informative signals $f_v(\alpha,\pi) > \alpha > f_c(\alpha,\pi)$ for $\alpha \in (0,1)$ (see Figure 2b). That is, signals allow compliant types to decrease the chances of being identified as violators, whereas violators see these chances increase. In fact, Appendix A indicates that $f^c_\pi(\alpha,\pi) < 0$ and $f^v_\pi(\alpha,\pi) > 0$ for $\alpha \in (0,1)$. As noted earlier, signals become irrelevant in the extreme cases so that $f^c(0,\pi) = f^v(0,\pi) = 0$ and $f^c(1,\pi) = f^v(1,\pi) = 1$.[11] In the perfect information case society's beliefs always match firms' actual behavior in such a way that only violators face losses in reputation (see Figure 2c).

[Figure 2 about here]

We started by looking at certain losses in reputation with perfect information and then turned to probabilities of violation detection with imperfect information. We are now in a position to synthesize and look at expected losses in reputation. These are now given by $f^v(\alpha,\pi)\,R(\alpha)$ for the violation type and $f^c(\alpha,\pi)\,R(\alpha)$ for the compliance type. Following the notation used in equation (1) managers' expected utility is:

$$U^E(x;\alpha,\pi) = \begin{cases} -f^c(\alpha,\pi)\,R(\alpha) - a & \text{if} \quad x = c \\ -f^v(\alpha,\pi)\,R(\alpha) & \text{if} \quad x = v \end{cases} \tag{6}$$

Ultimately, managers make decisions based on the difference in expected losses in reputation and how it relates to abatement costs. Let us denote the difference in expected

[11]Firms in violation can be unveiled with a probability $f^c < 1$ but firms in compliance may be wrongly perceived or accused of violating with probability $f^c > 0$. This is sometimes referred to as monitoring errors of type I and type II).

losses in reputation between the violation and the compliance strategies by the following function:

$$F(\alpha,\pi) = \Big[f^v(\alpha,\pi) - f^c(\alpha,\pi)\Big]R(\alpha) \tag{7}$$

When $F(\alpha,\pi) > a$, the compliance strategy dominates the violation strategy. From the properties of $f^v(\alpha,\pi)$ and $f^c(\alpha,\pi)$, it directly follows that $F_\pi > 0$ for $\alpha \in (0,1)$. That is, an increase in the accuracy of signals makes the compliance strategy more attractive. Further, $F(0,\pi) = F(1,\pi) = 0$. Lemma 1 presents other important properties of the difference in expected utilities.

Lemma 1. *When signals are informative, that is $\pi > \theta$, there exists $\hat{\alpha} \in (0, \frac{1}{2})$ such that $\hat{\alpha} = \operatorname{argmax} F(\alpha,\pi)$. Further $F_\alpha > 0$ for all $\alpha \in (0,\hat{\alpha})$, $F_\alpha = 0$ for $\alpha = \hat{\alpha}$, and $F_\alpha < 0$ for all $\alpha \in (\hat{\alpha}, 1)$.*

Starting at full compliance, as the proportion of violators α increases, signals become less coarse, thus increasing the difference in expected losses in reputation $F(\alpha,\pi)$ and managers' incentives to adopt a compliance strategy. At the same time however, a decreasing loss in reputation, $R(\alpha)$, would have the opposite effect to induce managers' to violate the regulation. This effect is reinforced and dominates at much higher levels of compliance since signals become coarse again.

Lemma 1 is not obvious from the general properties of the expected losses in reputation functions. These are concave (see Appendix A) and it is clear that the difference of two concave functions needs not be concave. Numerous simulations based on different parameter values in fact indicate that this is not the case for Equation 7. In the equilibrium analysis for the imperfect information case we use the following Bayesian Nash Equilibrium (BNE) concept.

Definition 2. *Let $x(\alpha)$ be a firm's best response strategy to level of violation α under imperfect information, so that $U^E(x(\alpha);\alpha,\pi) \geq U^E(x;\alpha,\pi)$ for $x \in \{c, v\}$. A strategy profile α is a BNE if all firms' strategies are best response strategies. Further, a BNE is Stable if there is $\bar{\epsilon}$ such that $x(\alpha) = x(\alpha \pm \epsilon)$ holds for all $\epsilon \in (0,\bar{\epsilon})$ and for all firms.*[12]

An interior BNE requires that $U^E(x(\alpha);\alpha,\pi) \geq U^E(v;\alpha,\pi)$ for the compliance types, $x(\alpha) = c$, and $U^E(x(\alpha);\alpha,\pi) \geq U^E(c;\alpha,\pi)$ for the violation types, $x(\alpha) = v$. This implies

[12] As in Proposition 1, the stability condition is one sided for the extreme cases, $\alpha = 0, 1$.

that $U^E(c;\alpha,\pi) = U^E(v;\alpha,\pi)$ or $F(\alpha,\pi) = a$. The social equilibria that may emerge under imperfect information are described in Proposition 2.

Proposition 2 (Imperfect Information Equilibria). *Under imperfect information on firms' compliance status we have that:*

- *The full violation state is a Stable BNE, that is $x(1) = v$ for all firms, whereas the full compliance state does not qualify as a BNE.*
- *Two BNE with partial compliance exist if and only if $F(\hat{\alpha}(\pi),\pi) > a$ with $\frac{dF}{d\pi} > 0$. The higher compliance equilibrium α^k is Stable while the lower compliance equilibrium α^l is Non-Stable. Further, $\alpha^k_\pi < 0$, $\alpha^k_a > 0$, $\alpha^l_\pi > 0$ and, $\alpha^l_a < 0$.*

The first part of the proposition follows directly from the Bayesian belief formation. Since beliefs are completely accurate when there is full violation, the pay-offs in the perfect and imperfect information cases are exactly the same. The full violation state is thus preserved as a stable equilibrium under imperfect information. On the other hand, an important consequence of the existence of imperfect information is the ruling out of full compliance as a possible equilibrium. Note that the expected losses in reputation due to violation are zero at full compliance under imperfect information. In a society where most people conform, people find it hard to conceive that anyone would be in disobedience.

Figures 3a, 3b and 3c help illustrate the possible emergence of partial compliance equilibria. Appendix A presents the second order condition that ensures that losses in reputation for the violation type are concave with respect to α. It starts at zero, since the risk of being unveiled is zero when no one violates. The function will rise as detection risk rises until a maximum when the effect of a decreasing $R(\alpha)$ sets in. The expected costs of compliance function is also concave (See Appendix A) and follows a similar pattern but naturally it does not fall below the costs of compliance, a. When signals are uninformative (Figure 3a) the losses in reputation faced by the two types or firms are the same. Since obedient types also incur in a compliance cost, disobedience is the only best strategy for the firm at all levels of violation. As signals become informative (Figures 3b and 3c) the expected costs of violation typically increase, while the expected costs of compliance decrease. Note that the partial compliance equilibrium emerges only when the maximum possible difference between expected losses in reputation are actually higher than abatement costs a. From the discussion above on belief formation, it is clear that at both, the full compliance and the full violation states expected utilities are not sensitive to signals: $U^E(v;0,\pi) = U^E(v;1,\pi) = 0$ and $U^E(c;0,\pi) = U^E(c;1,\pi) = -a$ since $f^c(0,\pi) = f^v(0,\pi) = R(1) = 0$.

[Figures 3a,b,c about here]

The society can have the multiple equilibrium since the risk of being unveiled or "caught" cheating is a very different function from the loss in reputation function. As already mentioned, the potential loss in reputation if caught is high when compliance is high. However the risk of being caught in a high compliance society may paradoxically be very low. The magnitude of the potential disgrace is thus high and this is supposed to be a strong deterrent but such a state of the world could also open up opportunities for cheating, particularly if monitoring and information concerning compliance is imperfect. Hence, a high compliance social equilibrium can be supported in the society. On the other hand, the potential loss in reputation will be low if compliance is low in the society. As a consequence, the probability of being caught is thus high, that will lead some firms to comply. A low non-full compliance equilibrium will coexist with a high compliance equilibrium.

Obtaining an analytical solution for the condition $F(\hat{\alpha}(\pi),\pi) > a$, introduced in Proposition 2, is virtually impossible. On the other hand by fixing $\theta = \frac{1}{2}$, a number of terms cancel out and we were able to establish an intuitive sufficient condition for the emergence of interior equilibria (the derivation is algebraically involved and is omitted here for brevity but is available from the authors). In particular, if $\pi > \frac{1}{2} + \frac{\sqrt{7a}}{2}$, two interior equilibria exist.[13] This expression has some interesting characteristics. Note that π is higher than $\theta = \frac{1}{2}$ and is increasing in abatement costs, a. Since $\pi < 1$, it can also easily be concluded that for $a > \frac{1}{7}$, no interior equilibrium can emerge.

The last part of Proposition 2 states that, as the violation signal from the violation type, π, becomes more precise the high compliance equilibrium, k, moves towards full

[13] We also established that $\pi > \frac{1}{2} + \frac{\sqrt{5a}}{2}$ is a necessary condition for the emergence of interior equilibria. The necessary and sufficient condition has thus the following form: $\pi > \frac{1}{2} + \frac{\sqrt{Na}}{2}$ with $N \in (5,7)$.

compliance, while the low compliance equilibrium l moves towards the full violation state. A similar pattern occurs if the abatement costs, a, are reduced. Figure 3c shows that the equilibrium state k has moved, in relation to the perfect information case, to the interior of $\alpha \in [0, 1]$. Note also that although equilibrium l has been preserved in its original form (Non-Stable), it now occurs at higher levels of violation.

While a high compliance equilibrium may be attainable under imperfect information, it requires a relatively low compliance costs and a relatively high level of accuracy of signals. The following proposition presents how the different equilibrium points behave as signals become extremely informative.

Proposition 3 (Almost Perfect Information Equilibria). *When information is almost perfect, and independent of costs of compliance, partial compliance equilibria α^k and α^l (Proposition 2) emerge. Further, as $\pi \to 1$ and $\theta \to 0$, we have that $\alpha^k \to 0$ and $\alpha^l \to 1 - a$. In this sense, social equilibria under perfect information are limiting situations of social equilibria under imperfect information*

Increase in the preciseness of signals drive both interior equilibria to divergent limit points. With society almost certainly receiving a violation signal from a violator and a compliance signal from a compliant, $\pi \to 1$ and $\theta \to 0$, the stable high compliance equilibrium α^k will get infinitely close to the stable full compliance under the perfect information, while the nonstable low compliance equilibrium α^k moves infinitely close to the unstable equilibrium $1 - a$ under perfect information. As shown in graphs 3a, 3b and 3c, as signals become informative expected utilities tend to resemble perfect information utilities for $\alpha \in (0, 1]$.

Finally, it should be noted that the framework proposed here is also illustrative of situations where pro-social behavior is rewarded. When the award function is given by $A(\alpha) = 1 - \alpha$, so that compliant agents experience more satisfaction when compliance is more common, the three propositions and the lemma derived above still hold. Under imperfect information, agents may experience social awards for being, correctly or mistakenly, identified as being in compliance. Although absolute utilities associated to the compliance and the violation strategies differ in the social reward problem, the difference, which is the actually driver of decision, remains unchanged.

3 Conclusions and discussion

It was shown how the internalization mechanism of an environmental externality via social sanctions imposed on polluters is eroded due to information asymmetry. When polluters actions are not fully observable, full compliance cannot be sustained in equilibrium as the expected social sanction, in the form of losses in reputations, is at its lowest at such compliance levels. The reason is that people find it hard to believe that someone is in disobedience when disobedience is rare. When information is quite accurate then we may well get an equilibrium with a fairly high level of compliance. Note that a society where social pressure is somewhat unimportant could exhibit higher obedience than a society where social disapproval does play a more important role. This is so if the latter suffers more acute information asymmetries than the former.

To a certain extent, the "classical" environmental regulator can be viewed as the one that wants to solve an information asymmetry between polluters and the judiciary (Garvie and Keeler, 1994). In fact its budget is spent in two different activities, namely monitoring and enforcement, or actual process of prosecuting firms. If provision of information to the general public is relatively cheap, as it seems to be the case with today's information technologies, the regulator could publicly disclose polluters' environmental indicators and make use of social sanctions as a substitute for conventional enforcement.

Although the discussion has focused on an industrial pollution example, the basic framework lends itself to study other situations where similar social interactions and information asymmetries are present. Direct examples may be found in the exploitation of (other) common property resources and the contribution to a public good. The "belief curse" of our model could also help understand, for instance, the persistent presence of corruption in some societies. As Bardhan (1997) puts it "*...the tenacity with which it [corruption] tends to persist in some cases easily leads to despair and resignation on the part of those who are concerned about it.*" In this context, the social norm demands public officials not to engage in corruption whereas the costs of compliance with the norm are represented by the foregone bribery benefits. Since corruption activities are carried out behind doors the most likely equilibrium in light of our model, is one in which most officials are corrupt and *society knows it* with certainty, but it does not care, i.e. the social sanction is very low. Thus countries that currently exhibit low levels of corruption appear to be likely to move to a violation state in the future. While more corrupt societies seem condemned to the current state of affairs unless dramatic changes in transparency or media exposure of public (mis)operations are put in places to drive the society out of worst equilibrium.

Individuals may have internal motives to follow a certain norm. It may also be the case that, although the individual's incentives to follow the norm depend on her peers' behavior, it does not depend on observability. In some societies, it may suffice for an individual to know that most of her peers are not corrupt to deter her from engaging in corruption. This is, in fact, the case of moral norms and this paper illustrates how valuable such norms can be.

Appendix A

Derivations are omitted but available from the authors.

$$\begin{aligned}
\frac{\partial f^v(\alpha,\pi)}{\partial\pi} &= \left(\frac{1-\pi}{1-\theta}\frac{\alpha}{1-\alpha}+1\right)^{-2} - \left(\frac{\pi}{\theta}\frac{\alpha}{1-\alpha}+1\right)^{-2} > 0 \quad \text{and} \\
\frac{\partial f^c(\alpha,\pi)}{\partial\pi} &= \frac{(1-\alpha)}{\alpha}\left[\left(\frac{1-\alpha}{\alpha}+\frac{\pi}{\theta}\right)^{-2} - \left(\frac{1-\alpha}{\alpha}+\frac{1-\pi}{1-\theta}\right)^{-2}\right] < 0 \quad \text{for } \alpha \in (0,1)
\end{aligned}$$

$$\begin{aligned}
\frac{\partial^2 f^v(\alpha,\pi)R(\alpha)}{\partial^2\alpha} &= -\left[\pi\frac{2\theta\pi^2}{1-(1-\alpha)\theta-\alpha\pi} + (1-\pi)\frac{2(1-\theta)(\pi-1)^2}{(1-\alpha)\theta+\alpha\pi}\right] < 0 \quad \text{and} \\
\frac{\partial^2 f^c(\alpha,\pi)R(\alpha)}{\partial^2\alpha} &= -\left[\theta\frac{2\theta\pi^2}{1-(1-\alpha)\theta-\alpha\pi} + (1-\theta)\frac{2(1-\theta)(\pi-1)^2}{(1-\alpha)\theta+\alpha\pi}\right] < 0 \quad \text{for } \alpha \in [0,1]
\end{aligned}$$

Appendix B

Proof Proposition 1. The proposition consists of three separate statements that are proven separately:

- $x(0) = c$ for all firms is a NE since $U(c;0) > U(v;0)$, which holds given the assumption $-a > -1$. The equilibrium is Stable since there always exists small enough ϵ such that $U(c;\epsilon) > U(v;\epsilon)$, that is $-a > -(1-\epsilon)$

- $x(1) = v$ for all firms is a NE since $U(v;1) > U(c;1)$, which holds given the assumption $0 > -a$. The equilibrium is Stable since there always exists small enough ϵ such that $U(v;1-\epsilon) > U(c;1-\epsilon)$, that is $-(1-\epsilon) > -a$

- $x(1-a) = v$ for a fraction $\alpha = 1-a$ of firms and $x(1-a) = c$ for the remaining population of firms is a NE since $U(v;1-a) \geq U(c;1-a)$ and $U(c;1-a) \geq U(v,1-a)$ hold simultaneously so that $U(c;1-a) = U(v;1-a) = a$. Suppose that a small mass of compliant firms ϵ deviate so that the new level of violation is $1-(a+\epsilon)$. Since $U(c;1-(a+\epsilon)) = -a < -[1-(\alpha+\epsilon)] = U(v;1-(a+\epsilon))$, the deviants' new best response is violation. Since this differs from their equilibrium response, that is compliance, the equilibrium is Non-Stable.

Proof Lemma 1. *Replacing equations (5) and (6) and $R(\alpha) = 1-\alpha$ into Equation (7), we obtain:*

$$F(\alpha,\pi) = (\pi-\theta)(1-\alpha)\left[\frac{1}{1+\frac{\theta}{\pi}\frac{1-\alpha}{\alpha}} - \frac{1}{1+\frac{1-\theta}{1-\pi}\frac{1-\alpha}{\alpha}}\right] \tag{8}$$

Let $m = \frac{1-\alpha}{\alpha}$ so that

$$\begin{aligned}\frac{\partial F}{\partial \alpha} &= \frac{\partial m}{\partial \alpha}\frac{\pi-\theta}{(m+1)^2}\left[\frac{1-\frac{\theta}{\pi}m^2}{\left(1+\frac{\theta}{\pi}m\right)^2} - \frac{1-\frac{1-\theta}{1-\pi}m^2}{\left(1+\frac{1-\theta}{1-\pi}m\right)^2}\right] \\ &= \frac{\partial m}{\partial \alpha}\frac{(\pi-\theta)\left(\frac{\theta}{\pi}-\frac{1-\theta}{1-\pi}\right)m}{(m+1)^2\left(1+\frac{\theta}{\pi}m\right)^2\left(1+\frac{1-\theta}{1-\pi}m\right)^2}\left[\frac{\theta}{\pi}\frac{1-\theta}{1-\pi}m^3 - \left(1+\frac{\theta}{\pi}+\frac{1-\theta}{1-\pi}\right)m-2\right]\end{aligned}$$

For $\alpha \in (0,1)$ we have that:

$$\frac{\partial m}{\partial \alpha} = -\frac{1}{\alpha^2} < 0 \quad \text{and} \quad \frac{(\pi-\theta)\left(\frac{\theta}{\pi}-\frac{1-\theta}{1-\pi}\right)m}{(m+1)^2\left(1+\frac{\theta}{\pi}m\right)^2\left(1+\frac{1-\theta}{1-\pi}m\right)^2} < 0$$

Let

$$f(m) = \frac{\theta}{\pi}\frac{1-\theta}{1-\pi}m^3 - \left(1+\frac{\theta}{\pi}+\frac{1-\theta}{1-\pi}\right)m-2$$

With informative signals, $\pi > \theta$, this function is such that

$$\begin{aligned}\lim_{m\to-\infty} f(m) &= -\infty < 0 \\ f(-1) &= -\left(\frac{1-\theta}{1-\pi}-1\right)\left(\frac{\theta}{\pi}-1\right) > 0 \\ f(1) &= \left(\frac{1-\theta}{1-\pi}-1\right)\left(\frac{\theta}{\pi}-1\right) - 3 < 0 \\ \lim_{m\to+\infty} f(m) &= +\infty > 0\end{aligned}$$

Since $f(m)$ is a continous function of m, there is one solution for $f(m) = 0$ within $(-\infty,-1)$, and one solution within $(-1,0)$. Since there are at most three solutions for the function $f(m) = 0$, we can conclude that there is only one positive solution $\hat{m} \in (1,\infty)$, that is $\hat{\alpha} \in (0,\frac{1}{2})$.

Proof Proposition 2. The two statements of the Proposition are proven separately:

- When $\alpha = 1$, society's beliefs match actual firm behavior: $f^v(1, \pi) = 1$ and $f^c(1, \pi) = 0$. This implies that $U^E(v; 1) = U(v; 1)$ and $U^E(c; 1, \pi) = U(c; 1)$. Since $U(v; 1) > U(c; 1)$, by the assumption $a > 0$, we have that $U^E(v; 1, \pi) > U^E(c; 1, \pi)$, which defines $x(1) = v$ for all firms as BNE. The equilibrium is Stable since there always exists sufficiently small ϵ for which $U^E(v; 1 - \epsilon, \pi) < U^E(c; 1 - \epsilon, \pi)$

  When $\alpha = 0$, society's beliefs also match actual firms' behavior: $f^v(0, \pi) = 0$ and $f^c(0, \pi) = 1$. This implies that $U^E(c; 0, \pi) = U(c; 0) = -c$ and $U^E(v; 0, \pi) = 0$. Since $U^E(v; 0, \pi) > U^E(c; 0)$, $x(0) = c$ for all firms is not an equilibrium.

- An interior BNE equilibrium demands that $F(\alpha, \pi) - a = 0$. According to Definition 2, at an interior equilibrium $U^E(x(\alpha); \alpha, \pi) \geq U^E(v; \alpha, \pi)$ for the compliance types, $x(\alpha) = c$, and $U^E(x(\alpha); \alpha, \pi) \geq U^E(c; \alpha, \pi)$ for the violation types, $x(\alpha) = v$. This implies that $U^E(c; \alpha, \pi) = U^E(v; \alpha, \pi)$ or $F(\alpha, \pi) = a$.

  When $\alpha = 0$, we have that $F(\alpha, \pi) - a = -a < 0$. Thus, if there is α such that $F(\alpha, \pi) - a > 0$ there exists at least one α for which $F(\alpha, \pi) - a = 0$ (by the Bolzano's Theorem). Lemma 1 states that $F_\alpha > 0$ for $\alpha \in (0, \hat{\alpha})$, thus if $F(\hat{\alpha}, \pi) - a > 0$ there exists one and only one $\alpha^k \in (0, \hat{\alpha})$ such that $F(\alpha^k, \pi) - a = 0$, which is the condition for a BNE. Similarly, we know that when $\alpha = 1$, $F(\alpha, \pi) - a = -a < 0$. From Lemma 1, $F_\alpha < 0$ for $\alpha \in (\hat{\alpha}, 1)$. Thus, when $F(\hat{\alpha}, \pi) > a$ there exists one and only one BNE, $\alpha^l \in (\hat{\alpha}, 1)$.

  $F(\alpha, \pi) \in (0, 1)$ for $\alpha \in (0, 1)$ since $0 > f^v > f^c > 1$ and $R(\alpha) = 1 - \alpha \in (0, 1)$. Since $a \in (0, 1)$ there always exists small enough a such that $F(\hat{\alpha}(\pi), \pi) > a$. $\frac{\partial F}{\partial \pi} > 0$ for $\alpha \in (0, 1)$ (Appendix A) implies that $\frac{dF}{d\pi} > 0$ by the Envelope Theorem.

  To prove stability note that $F_\alpha(\alpha^k) > 0$ implies that for small enough ϵ, $F(\alpha^k + \epsilon) - a > 0$ and $F(\alpha^k - \epsilon) - a < 0$. That is $U^E(c, \alpha^k + \epsilon) > U^E(v, \alpha^k + \epsilon)$ and $U^E(v, \alpha^k - \epsilon) < U^E(c, \alpha^k - \epsilon)$. If a small mass of compliant firms deviate the new violation level is $\alpha^k + \epsilon$. As shown above, their new best response is the same as the original equilibrium strategy, that is compliance. If a small mass ϵ of violators deviate the new violation level is $\alpha^k - \epsilon$. From the expressions above, it is clear that the deviants' new best response does not differ from their equilibrium response, that is violation. Hence, α^k is a Stable BNE. $F_\alpha(\alpha^l) < 0$ implies that for small ϵ, $U^E(v, \alpha^l + \epsilon) > U^E(c, \alpha^l + \epsilon)$ and $U^E(v, \alpha^l - \epsilon) < U^E(c, \alpha^l - \epsilon)$. Using the same line of reasoning we used to analize α^K, it is clear that small masses of compliant firms or violators have incentives to deviate at α^l so that it does not qualify as a Stable BNE.

Total differentiation of the condition for interior equilibrium, $F(\alpha, \pi) - a = 0$, with respect to π and a gives $\alpha_\pi = -\frac{F_\pi}{F_\alpha}$ and $\alpha_a = \frac{1}{F_\alpha}$. Since $F_\pi > 0$, $F_\alpha > 0$ at α^k and $F_\alpha < 0$ at α^l we have that $\alpha^k_\pi < 0$, $\alpha^k_a > 0$, $\alpha^l_\pi > 0$ and, $\alpha^l_a < 0$.

Proof Proposition 3. From equation 8, we have that for $\alpha \in (0, 1)$, $\lim_{(\theta,\pi)\to(0,1)} F(\alpha, \theta, \pi) = \lim_{\theta\to 0}(1-\theta)(1-\alpha)(\frac{\alpha}{\alpha+\theta(1-\alpha)} - 0) = 1-\alpha$. This implies that $\hat{\alpha}(\theta, \pi) = \text{argmax}\, F(\alpha, \theta, \pi) \to 0$. Thus, as signals become extremely informative, the condition for emergence of interior equilibria k and l, $F(\hat{\alpha}(\theta, \pi), \theta, \pi) > a$ (Proposition 2), is met: Note that $1 - \hat{\alpha}(\theta, \pi) \to 1$ while $a \in (0, 1)$. Further, since $\alpha^k \in (0, \hat{\alpha}(\theta, \pi))$, it must also be case that $\alpha^k \to 0$. According to Definition 2, at interior equilibrium l, $F(\alpha^l, \theta, \pi) - a = 0$. From the discussion above, it follows that $\lim_{(\theta,\pi)\to(0,1)} F(\alpha^l, \theta, \pi) - a = 1 - \alpha^l - a = 0$. Hence, $\alpha^l \to 1 - a$ for this equality to hold.

Figure 1: Perfect information equilibria

(● Stable ● Non-Stable)

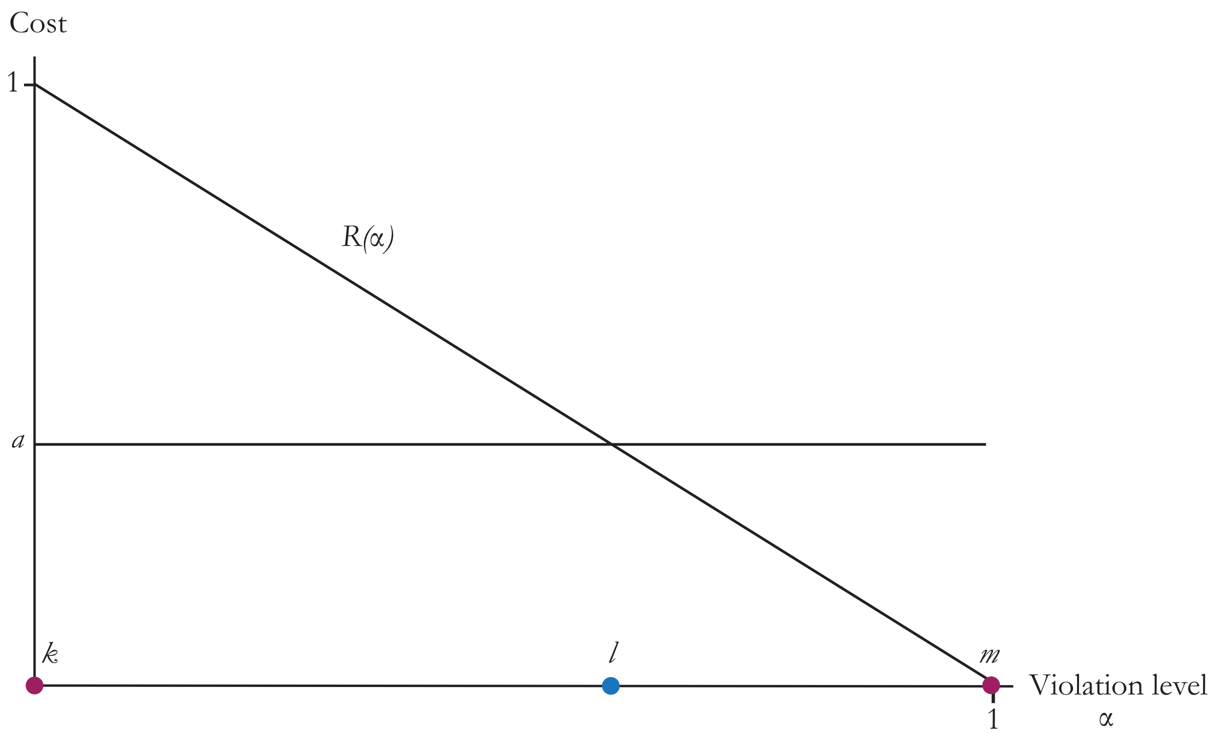


Figure 2: Beliefs under imperfect and perfect information

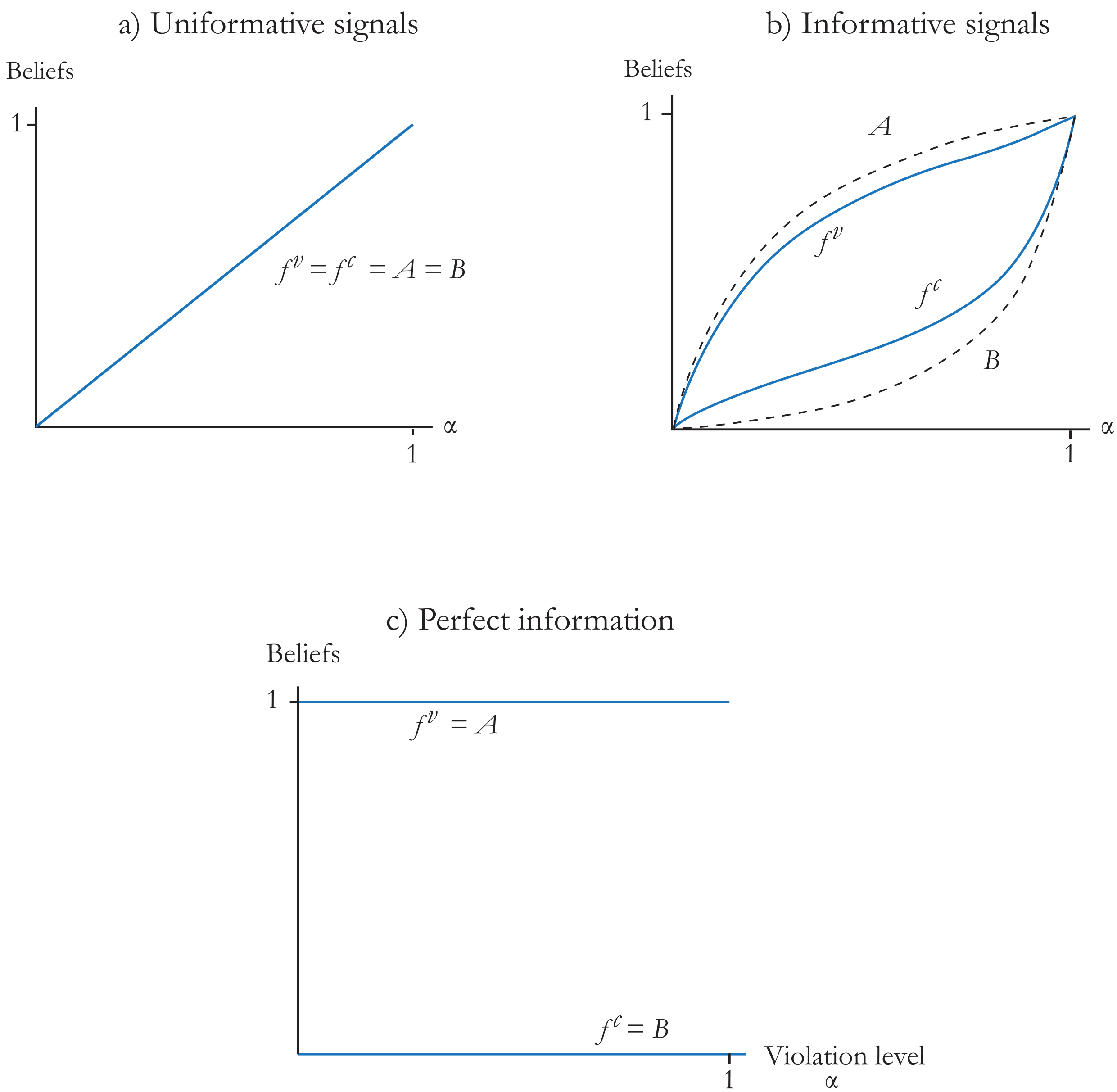


Figure 3a: Imperfect information equilibria

with uniformative signals, $\pi = \theta$

(● Stable ● Non-Stable)

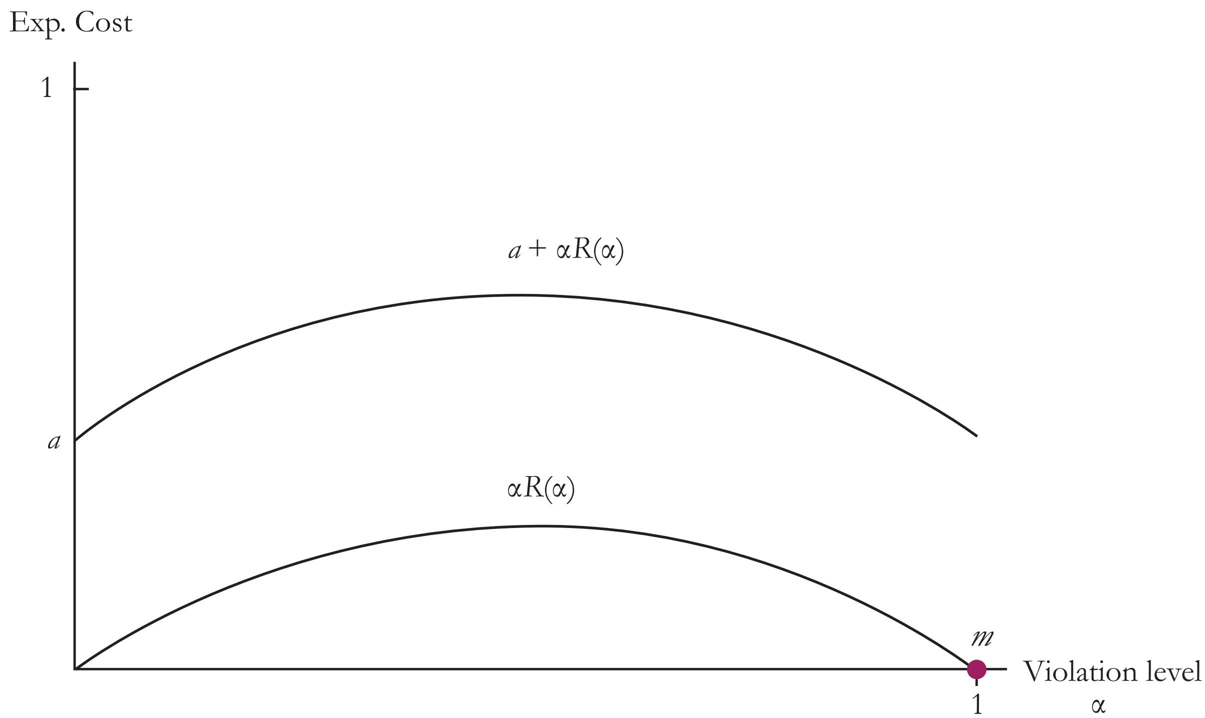


Figure 3b: Imperfect information equilibria with informative signals, $\pi > \theta$
(● Stable ● Non-Stable)

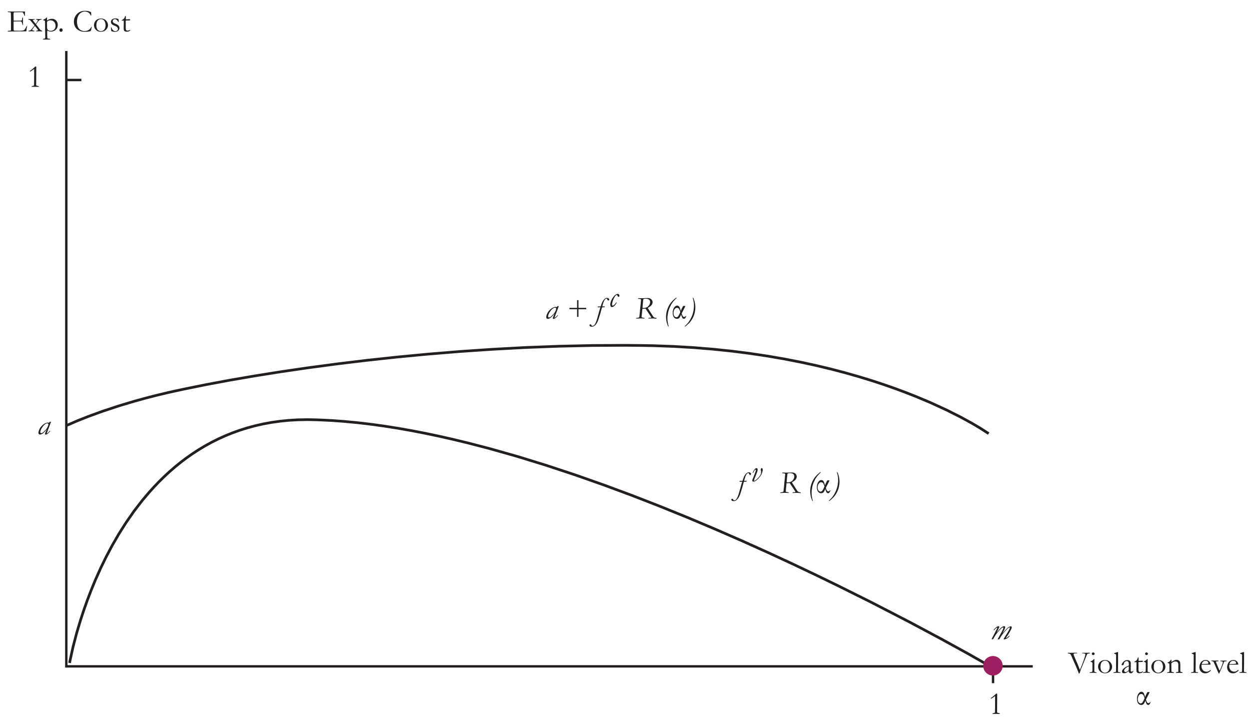
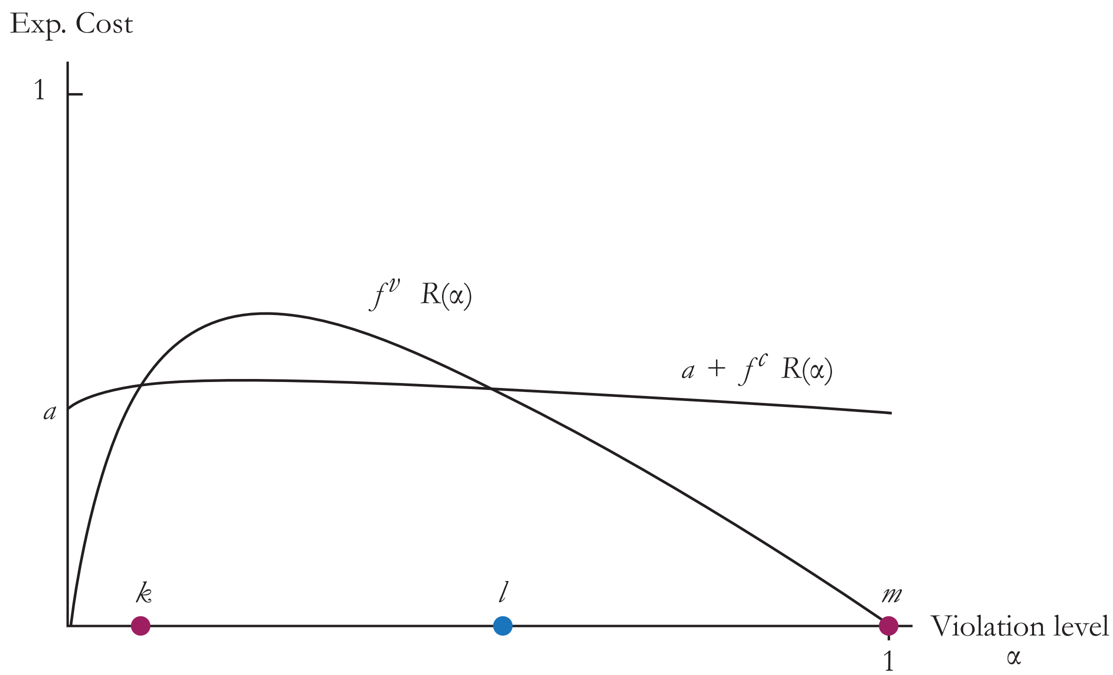


Figure 3c: Imperfect information equilibria with very informative signals, $\pi >> \theta$ (● Stable ● Non-Stable)



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Paper III

Economic Growth and the Natural Environment: The Example of China and its Forests since 1978

William F. Hyde, Jiegen Wei, and Jintao Xu*

Abstract

China's rapid growth over almost 30 years and its consistent forest data across 28 provinces provide an unusual opportunity to examine some frequently discussed questions about macroeconomic and population impacts on the forest. The data support a theoretical argument for separating forests into four components, managed and natural forests administered by either state or private agents. Our regressions suggest 1) cautious optimism for a restrictive dual to Malthusian arguments about population; that is, declining rural populations may go hand-in-hand with forest recovery; and 2) more confident support for a variation of the environmental Kuznets curve for forests. That is, as incomes rise, the natural forest is first drawn down then, when incomes rise above some level, the natural forest begins to recover. As incomes continue to rise, the managed forest eventually grows even more rapidly and offsets any continuing draw on the natural forest—with an aggregate impact of net expansion for all forests, managed and natural combined. The question that must arise is whether these environmentally satisfying results for China would be prove to be global—if comparable forest data were available elsewhere.

Keywords: forests, China, Malthus, Kuznets, population, income growth

JEL:Q23, Q28, P28

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1. Introduction

The discussion of the effects of aggregate growth on the natural environment has a long history and it continues to receive attention among economists. Two arguments deserve special note. The first maintains that early economic growth in the overall economy is tied to a decline in the natural environment but further growth beyond some level is correlated with environmental recovery. The second argues that population growth leads to environmental decline. The discussion has spawned numerous assessments. [See Dasgupta et al. (2002) and Copeland and Taylor (2004) for reviews of the first argument and Malthus (1798) and many successors (e.g., Meadows et al**.** 1972) for examples of the second.] Nevertheless, few have drawn convincing conclusions regarding the effects of either economic growth or population growth on the forest environment—although forests account for an immense 29.6 percent of all global land area (FAO 2001). Good measures of the effects of aggregate growth on the forest are crucial to the global policy dialogue because two other critical issues, biodiversity and climate change, so central to all discussion of global policy and because forests are key resources in any attempt to address either—as forests contain most of the remaining unidentified global biodiversity and forest growth is a fundamental component in any attempt to affect the global carbon balance and mitigate climate change.

The objective of this paper is to revisit the questions of macroeconomic and population effects on the forest. We will use data from China and we will separate forests into their managed and natural, and state-owned and non-state, components in an attempt to find convincing economic and statistical results. Most assessments of forests and those other assessments that make use of forest data overlook these distinctions. Indeed, the official forest data for most countries do not make these distinctions. Our discussion and our analytical results will demonstrate their importance.

Official measures of what constitutes a forest vary from country to country by as much as four orders of magnitude.[1] Therefore, consistently measured data from one large and diverse country such as China are an advantage for our assessment. China's rapid

[1] The minimum area for forest classification in Papua New Guinea is 10,000 times that for the Czech Republic (Lund 2000, as reorganized and cited in Hyde (2005).

economic growth since the introduction of its economic reforms in 1978 adds to this advantage, creating an unusually broad range of both forest and economic data for one nation or even one region of the world. Moreover, China is an interesting example because its economic growth and its forests are especially important in the policy dialogue about climate change. For example, the United States has given China's exemption (as a less-developed country) from the forest cover requirements of the Kyoto Protocol as one reason it chooses to remain the lone significant non-signator to that international agreement.

The distinctions between managed and natural, and state-owned and non-state, forests are important to any economic characterization of those resources. Managed forests are responsive to market conditions while many natural forests are remote and removed from the market effects. Private forests, similarly, are generally responsive to economic conditions while state-owned forests are often managed according to other, administrative and non-market, criteria. We will argue that these distinctions, supported by the remarkable array of China's data, encourage three convincing observations with respect to growth and the environment.

- First, beyond some level of economic development, income growth is, indeed, associated with growth in managed forests, but natural forest cover may decline.
- Second, beyond some greater level of economic development, income growth may also be associated with recovery of the natural forest environment. However, the institutions of public management instruct caution with these generalizations. The effect of these institutions on the natural forest can be as important as the effect of economic growth, yet their effect is not always positive.
- Third, regarding the Malthusian hypothesis: it is important to distinguish the rural population from the aggregate population. As rural population density generally declines with economic growth, this decline has a beneficial effect on both the managed and the natural components of the forest.

We posit that these three observations for China are general for many other countries as well. We suspect that they are global for forestry, and we suspect that they may have counterparts for other renewable natural environments—if those too are examined within the context of similar distinctions in resources and in the institutions that manage them.

The first section of our paper summarizes China's experience with market reform and economic growth since 1978. The second section introduces the economic basis for our distinctions between managed and natural forests and between state and non-state ownerships, and then summarizes China's recent history with respect to these characteristic forest categories. The analytical body of the paper follows, first, with a discussion of our model and, then with our econometric results. A final section summarizes and suggests policy implications and the potential global generality of our results.

2. China's Market Reforms and Economic Growth

China entered its period of market reforms in 1978 with reforms in agricultural property rights in Fengyang County in Anhui Province. The decentralization of property rights and an upward adjustment in government procurement prices were the fundamental elements of the early reforms. Property rights for land and agricultural capital were transferred from collectives to individual households and unified government procurement prices for crops were, first, adjusted upward and, eventually in 1985, eliminated in favor of market transactions. These reforms took different forms in different counties and provinces but, by 1984, the majority of agricultural households across the country had long-term "household responsibility" contracts for both land and the capital implements of agricultural production. Land productivity increased 225 percent and the productivity of agricultural labor increased 172 percent in a period of only six years.[2]

Two additional rounds of market reforms followed. New rural wealth became a source of funding for the development of rural township and village enterprises (TVEs). Initially, the TVEs were responsible to local authorities under contracts similar to those in agriculture. The TVEs grew rapidly, absorbing underemployed labor from agriculture at an annual rate of 15 percent. Their share of rural production increased from 26 percent in 1984

[2] See Hyde et al. (2003) for a chronology of China's market reforms with emphasis on the agriculture and forest sectors.

to 45 percent in 1992—by which time the TVEs had become almost completely market-oriented. They accounted for one-half of the increase in China's per capita income during the 1980s. The first signs of change in China's previously egalitarian distribution of income also appeared during this period. Nearly all households benefited but they did not all benefit uniformly. Households in urban and eastern coastal regions tended to benefit more.

Industrial and financial reforms got their start in the late 1980s, and they too emphasized the contracted transfer of responsibilities that had been so successful in agriculture. The central authorities maintained control over most of the capital investments of the largely urban state-owned enterprises (SOEs), but they transferred discretion for variable inputs and for output levels to the enterprise managers. The productivity of the full manufacturing sector increased as a result, at an annual rate of more than 15 percent between 1980 and 1990.

A third round of reforms began in 1991 when the central government allowed the sale of some SOEs. Seventy percent of small SOEs were privatized by 1997. Beginning in 1995, the central authorities allowed managers of the remaining SOEs to release redundant employees and, by 1998, one-fifth of all employees of SOEs (seven million workers) had been released. Many found employment in the rapidly expanding private sector. Meanwhile, the government simplified the tax system, decreased the number of civil servants, and liberalized international trade. Household incomes continued to grow and savings, the fuel for further investment, grew to a phenomenal 62 percent of gross domestic product (GDP) in 1998.

In sum, China's market reforms have been a source of remarkable growth over the last quarter century. Nevertheless, despite the reforms, central authority retains a major role in China's economy today and, of special interest to us in this paper, in its forest sector in particular.

Table 1 summarizes the growth in per capita income and also in agricultural production, a crucial measure for a population that was approximately 80 percent rural in

1978 and which remains about 60 percent rural today. The value of agricultural production increased 13 times over (from 112 billion to 1,487 billion yuan in year 2003 values) while the land area under cultivation increased less than 2 percent (from 150.1 to 152.4 million ha.). (The land area under cultivation has actually declined 2-3 percent since 2000, while agricultural production has continued to increase.) Per capita annual rural income grew almost 600 percent (from 442 to 2,622 yuan) from 1978 to 2003, but it did not keep up with urban income which grew an even greater 745 percent (from 1,137 to 8,472 yuan).

These are national averages, however, and they mask important regional differences. Table 1 also shows the regional extremes. The difference in per capita rural incomes between the highest and lowest income provinces (Beijing and Shanxi, respectively) was 225 percent in 1978.[3] By year 2003, this difference had risen to 425 percent (Shanghai had the highest per capita income and Ningxia had the lowest by this time). Perhaps these differences are not surprising for a country that is the world's largest in terms of population and third largest in land area, a country that ranges from densely populated coastal cities with the best modern infrastructure in the east, to sparsely populated continental plateaus 5,200 km to the west, a country that ranges from both the tropics of Hainan and also the high himal of Tibet in the south 5,500 km north and northeast to the grasslands and deserts of Inner Mongolia and the near boreal forests of Heilongjiang.

Regional income disparities have become a major policy concern in modern China. Per capita gross domestic product in the southwest, for example, is only 44 percent of that in the eastern coastal areas. Income disparities are one important justification for the 12-year, 96.5 billion yuan (US$ 12 billion) Western Regional Development Program begun in 1998. For us in this paper, however, China's income growth is a source of intertemporal variation and its regional disparities are a source of cross-sectional variation. Variation among observations is a desirable quality in any statistical analysis.

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[3] China is administered as 32 provinces and autonomous regions. The autonomous regions are Beijing, Shanghai, Tibet, and Inner Mongolia. The first two contain the large urban areas of the same name and also the surrounding agricultural lands and forests.

3. Forestry: General Distinctions and China's Recent Experience

China's forests display comparable, if less extreme, variation since 1978. We'll review this variation but, first, consider two important distinctions in forest classification, the distinction between managed and natural forests and the distinction between forests managed by private households and institutions and those managed by state agencies.

3.1 General Distinctions

Managed forests respond to market forces—otherwise managers would not expend financial resources to manage them. Natural forests, by definition, have been left to grow according to the forces of nature and without substantial human input. Natural forests may have been harvested in the past and they may be harvested again, but their reestablishment subsequent to harvesting is left to natural regeneration the subsequent second growth forest remains unmanaged. Natural forests must be of generally lower commercial value than the more market-responsive managed forests. Some remote natural forests have no commercial value and demonstrate no response whatsoever to the usual market forces.

This distinction anticipates a geographic continuum defined by access to active markets, a continuum from agricultural activities to managed forests to natural forests. Some lower-valued agricultural activities compete with managed forests for land at their mutual margin. Beyond this margin, the intensity of forest management declines gradually until even limited management is no longer economically rewarding. Beyond this point, many forests are open access resources and their growth is entirely a function of natural processes.

For the second distinction (between administrative agents), we can anticipate that private landholders are market responsive, particularly on their managed forests. Their (generally smaller) holdings of natural forests are extensions of their managed forests, extensions that may respond to moderate increases in local market prices. For some landholders, these private natural forests are seen as emergency reserves.

The second set of institutions, state forest agencies, manages many lands that, at the time these agents assumed responsibility, had little commercial value. Some of these lands may have commercial value now, but many state forest agencies, nevertheless, manage their commercial forests according to social and political criteria that are at variance with economic criteria. For example, Canada's provinces arguably subsidize their commercial forests and some believe that a full financial accounting would show that the timber operations of the US National Forest System have suffered net losses each year of their existence (Barlow et al. 1980, 1980a, Wolfe 1989). In China, the management objective for state-owned forests has been to provide sufficient timber to maintain employment in the mills. Financial criteria have not been important until recently and, as a result, the standing volume of state-owned timber has been drawn down sharply. Many of these forests can no longer support either the mills or their own forest workers (Zhang 2001).

Of course, other state forestlands in China and elsewhere, whether of commercial value or not, are managed for non-market values (e.g., parks, watershed management, and natural reserves). Still others are simply remote areas under state stewardship.

These two distinctions (managed or natural forest and state or private administration) anticipate the description of forest lands contained in figure 1 where the vertical axis measures land value net of all costs except the cost of obtaining and maintaining property rights. The horizontal axis reflects ever decreasing access to the geographic center of commercial activity. Agricultural land values are greatest near the commercial center. They decline with decreasing commercial access. [This follows von Thunen's (1826) original description of economic geography. See Samuelson (1983) for a general review and Hyde (2005) for a summary forestry discussion.] Agricultural land value exceeds forest land value near the commercial center but agricultural value declines more rapidly than forest value until managed forestry eventually competes with agriculture at a point like A. Both agricultural and forest product prices affect land management at this point and forest product prices have both short- and long-term effects inducing both immediate extraction and also longer-term investment in forest management.

The costs of obtaining and enforcing property rights to either agricultural or forest land increase as access decreases—until even the costs of insuring minimal rights to the land eventually exceed the value of land used in either agriculture or forestry at a point like B. Land with positive agricultural or forest value beyond point B becomes an open access resource that is degraded out to a point like C where forest product prices alone affect land use and the only market response to them is one of short-term resource extraction. Beyond point C the opportunity cost of the extraction activity itself exceeds any value in the extracted natural product. In some poor countries the degraded open access area between points B and C can be very large. India, for example, has 75.5 million hectares of officially designated wasteland and another 24 million hectares of degraded grazing land, but only 64.1 million hectares of forestland (NRSA 1995, FAO 2001)**.** Finally, the remote lands beyond point C in figure 1 remain in the natural state of a mature forest. Of course, some of these open access forests beyond point B and even beyond point C are sources of important non-market values.

The formulation in figure 1 is clearer for the private sector. The critical points B and C are not as apparent for those state agencies that a) manage some timber according to non-financial criteria and also b) actively protect the rights to some non-market resources beyond points B and C. Nevertheless, the budgets of all state agencies are limited and as they are, they limit the extent of those agencies' abilities to vary from the financial criteria that define these two points.

One additional factor, the opportunity cost of labor, has a crucial effect on these two critical points. Since labor opportunities tend to improve as an economy grows, we can anticipate that the impacts of general economic growth and development will proceed through their effect on wages and income to alter the levels of both managed and natural forests. That is, as labor opportunity improves and, therefore, wages and incomes rise, some rural workers are drawn away from subsistence and even local commercial use of the forest. They can no longer afford to venture as far into the natural forest in pursuit of its resources. The right tail of the forest value function in figure 1 shifts left or inward (dashed line), and points B and particularly C also shift inward. Some natural forest beyond point C becomes recovering secondary natural forest as a result.

We can observe the effect of economic development in the United States over the last 120 years as income levels have risen and the U.S. forest inventory has improved sharply. The state of New Hampshire, for example, was 50 percent forested in the early twentieth century. It is almost 90 percent forested today (USDA Forest Service 2005). Forest cover in France has doubled over the course of the last two centuries (Payton and Colnard 2002). Forest cover increased six-fold in India's Punjab during its period of remarkable economic growth between 1960 and the mid-1990s—as crop area doubled, crop yields tripled and per capita income also doubled (Singh 1994). Surely, we expect a similar pattern in China as improved property rights have been a feature of China's market reforms and its economic development over the last quarter century, a period in which China has afforested or reforested more than 20 million hectares. China now has more than 47 million hectares of forest plantation, approximately one-quarter of the world's total (FAO 2001).

These distinctions between managed and natural forests and state and private administration, as well as the impact of improved labor opportunity are global. They are also crucial to an understanding of the pattern of forest development in China since its initial market reforms in 1978.

3.2 China's Recent Experience

Modern China initially confiscated feudal agricultural and forest land in the late 1940s and early 1950s. This early policy changed, however, as the government began building a planned economic system. The era of cooperatives and people's communes in mountainous and forest areas began in 1958. In effect, two systems of ownership were established, state-owned forestland under the management of the state-owned forest enterprises (SOFEs—integrated forest bureaus and independent forest farms) and collective forests. A quarter century of decline in the forest base followed before the first agricultural reforms in 1978. By this time, the standing forest volume on the collective lands had declined to an average of 50 m^3/hectare—in comparison with a global average of 100 m^3/hectare (FAO 2001).[4]

[4] See Xu and Hyde (2005) for a more extensive review.

The reforms that began in agriculture spread rapidly to other sectors. In forestry, households gained land use rights to collective forestlands (a “contract responsibility system” comparable to the “household responsibility system” in agriculture) as the third component of the “three fix” policy: stabilizing the rights and ownerships of forests and mountains, identifying the boundaries of household plots, and establishing a forest production responsibility system. Change was rapid. By 1984, 30 million hectares or 60 percent of the land area in collective forests had been transferred to 57 million individual households and many households began drawing on their own resources to reforest the new lands they managed (Yin and Newman 1997, Liu and Edmunds 2003). Yin and Newman calculated that household investments were responsible for a 20 percent increase in timber production as early as 1984 in one heavily deforested region.

Four additional factors had important effects on forestry during the subsequent period from 1985 to 2000: auctions of wasteland, the liberalization of the unified procurement pricing system for timber, general economic growth, and trade liberalization. The government began auctioning barren forestlands (the “four wastelands”) for afforestation in 1993 and it allowed private actors to compete in these auctions. By 1996, 3.7 million hectares had passed into private hands under this arrangement. The practice of selling forestland through public auctions has subsequently extended to lands with juvenile and mature stands of timber.

The unified procurement pricing system was gradually relaxed until planned government procurement was less than ten percent of all timber sales by the mid-1990s (Zhang et al. 1994, Waggener 1998). Nevertheless, government regulations on timber harvest levels and shipments remain strong and timber markets are still underdeveloped in some regions to this day.

General economic growth, rather than any specialized forest policy, was responsible for some of the growth in forest management in this period. This is not surprising. The forest sector accounts for only one percent of China’s GDP. The pattern of growth in the paper industry illustrates this effect. The demand for paper is closely tied to GDP but it tends to grow faster than per capita income in most economies. Paper production grew at a 13 percent annual rate in China after 1984, a rate in excess of the 8-10 percent rate of annual growth in GDP. As a result, the industry's demand for wood fiber grew and that created a price incentive to expand forest management (Xu et al. 2003).

Two recent empirical assessments confirm the importance of growth in aggregate demand—after accounting for one semantic modification. That is, China officially labels all managed forests "plantations". The first step in forest management, in China or anywhere else, is to include a measured area of forest in a central plan. However, some form of managed reforestation, often planting itself, is usually the first physical activity in the forest. Therefore, for our purposes in this paper, and for China, "plantations" and "managed forests" are essentially the same. Zhang et al. (2000) determined that a one percent increase in per capita GDP explained a 0.59 percent increase in plantation area in one province (Hainan) and Rozelle et al. (2003) determined that a one percent increase in the light industry share of China's full economy was correlated with a 0.13 percent increase in total forest land. This 0.13 percent may actually underestimate the impact on plantations and overestimate of the impact on natural forests because an additional share of plantation forest was necessary to make up for any harvesting that occurred on the natural forests.

On the other hand, trade liberalization absorbed some of the increasing demand for woody raw material, and the new restrictions on logging beginning in 1998 assured that log imports would become even more important. Log imports nearly tripled (from 4.8 million m^3 to 13.6 million m^3) between 1999 and 2001 and they have continued to grow since then (China Customs Office 1999-2001, Sun et al. 2003).

Tracing government investment and the performance of the SOFEs is more difficult. The available data are not as complete. Government investment in silviculture did increase, and at an annual rate of 7.9 percent between 1979 and 1997. Much of this investment reflects expenditures on a few very large public investments—in 1979 when the Three North Forest Protection Project (the Green Great Wall) was established, after 1987 when a 1.14 million ha. fire in northeast China was followed with great effort and cost to reforest, and between 1996 and 2001 when several large ecological disasters (the floods of the Yangtze and Songhua River basins in 1998 and the dust storms in northern China in 2000-2001) induced the government decisions to restrict timber harvests from natural forests in some regions and to reforest and protect the upper watersheds.

China's industrial and financial reforms have spread only slowly to its forest industry and reforms in the SOFEs are still mostly experimental.[5] The SOFEs are a primary government concern in 2008; however, as 80 percent of them had exhausted their mature timber by the mid-1990s and more than half of them are in financial arrears. Meanwhile, the demands on the state-owned forests for wood as a raw material, for fuel, and for environmental and recreational services continue to grow.

Table 2 summarizes the impact of the last quarter century of market reform and aggregate economic growth on China's forests. It maintains our distinctions between managed (or plantation) and natural, private and state forests. Of course, in China the "private" forests are not private in the western European fee simple sense. Rather, they are collectively-owned forests whose long-term land use rights have been transferred to private households. Our paper will maintain consistency with China's terminology and identify these as collective forests. The first row of cells records the forest area and standing forest volume within each of our four categories for the first, and then the sixth and most recent, of China's periodic forest inventories (conducted between 1977 and 1981 and between 1999 and 2003, respectively). The second and third rows of cells provide the same information for the two most productive forest regions. The northeast is the traditional industrial forest region. The SOFEs that account for more than 60 percent of its total forest resource dominate in this region. The collectives and the farm forests that have performed so very well during this period of rapid economic growth dominate in the south/south central region.

The table shows that, in national aggregate, both area and volume measures of the forest grew between the first and sixth national forest inventories for both managed and natural forests and for both collective and state administration. As expected, managed forests

[5] See Zhang (2001) for a discussion of these experiments.

grew more rapidly (in both volume and area) than natural forests, and collective forests (both managed and natural) grew much more rapidly than state-owned forests. The managed component of the collective forests increased to more than three times its former area and more than seven times its former volume. Natural forests increased by approximately 60 percent in both volume and area—as there was some decline in uneconomic harvest activities on those forests. Some state-owned forests reverted to the collectives and some were, and still are, inaccessible. Therefore, the opportunity for growth in the state-owned forests was less than for the collective forests. Nevertheless, volume doubled on the managed component of the state-owned forests and the natural forest area and volume of these forests each increased by approximately 10 percent.

Similar comparative experience with forest growth is also broadly true within the two crucial commercial forest regions of northeastern and south-south central China, with managed forest volumes on the collective forests in these regions displaying the greatest increases and natural forests under state administration displaying the least.

4. Model and Empirical Assessment

This next section returns to our fundamental question: the effects of economic and population growth on the environment or, specifically in our case, the effects of the aggregate economy and population on the forest and, particularly, on China's forests. We will call on the preceding discussion to anticipate the functional relationship, then comment on our data and, finally, review the regression results.

4.1 Regression Model and Data

We will follow a multivariate regression approach. Specifically:

$$F_{it} = \alpha_0 + \alpha_1 Inc_{it} + \alpha_2 Pop_{it} + \alpha_3 Refm_{it} + \alpha_4 Pr_{it} + \varepsilon_{it}$$

(1) where F_{it} is a measure of the forest stock in province i at time t, Pop_{it} is a measure of population, Inc_{it} is a measure of income, $Refm_{it}$ measures the process of land tenure reform, Pr_{it} contains market price information, and the ε_{it} are randomly distributed errors. The α_i are parameters to be estimated.

The coefficients on the first two independent variables address the aggregate economic growth and Malthusian questions that are central to this paper. The third coefficient separates out the tenure effect that is basic to China's rapid growth since 1978. The fourth coefficient is the standard economic price term. Failure to obtain expected results for this final coefficient would raise doubt about all other findings no matter how reasonable they might seem otherwise. Our assessment will independently follow this general form for two sets of regressions, one for the managed component of China's forests and one for the natural component.

4.2 Dependent Variable

China's National Forestry Census summarizes forest stock in terms of both area (hectares of forest cover) and volume (cubic meters). Its collection of these data is based on a sampling and direct estimation procedure similar to that used for forest surveys in most developed countries. The survey results do not pass through the government hierarchy and they are used only for assessing the status of the country's forests—and not for evaluating the performance of local officials. Therefore, data consistency and misreporting, often a concern for those who use China's data, are probably not a serious problem.

To date, China has completed six rounds of periodic forest inventories, one every five years since the first inventory conducted between 1978 and 1981 (summarized in Table 2). These data are complete for the 28 most forested of China's 32 provinces and autonomous regions (China National Forest Bureau 1976, 1981, 1988, 1993, 1998, 2003). We divided these forest area and volume data by the total land area of each province in order to normalize for differences in province size.

Data from the first forest inventory do not distinguish between managed and natural forests. As a result we are left with complete data for five of the six forest inventory periods and 28 provinces or autonomous regions—for a total of 140 pooled observations for managed forests. The Shanghai autonomous region did not record any natural forests for the final three inventories. Therefore, 137 pooled observations are available for the natural forest regressions. The time period is consistent with China's rapid development since the beginning of market reforms and, therefore is appropriate for our assessment of the effects of markets and economic growth on the forest.

Beginning with the fifth forest inventory (1994-8), the National Forestry Census modified the definition of forest used in its survey from 30 percent ground cover to 20 percent cover. This should increase the official measures of forest cover and volume and the increase should be most notable in remote areas where the forest cover is minimal and there are few competing land uses. We will introduce a dummy variable associated with the fifth and sixth inventories to control for the effect of this change in definition of the measures of forest cover and forest volume.

4.3 Independent Variables

Income: Higher levels of per capita income go hand-in-hand with greater demands for consumption goods—such as the commercial products of both the managed forest and the exploitable frontier of the natural forest. Greater demand leads to expansion in the managed forest and more production from it. Greater demand also leads to increased harvests from, and a reduction in, the natural forest. However, as incomes rise, so do wages and higher wages mean better opportunities away from the forest for those who previously depended on the open access natural forest for a portion of their livelihood. Therefore, the expected sign on the income variable in the managed forest regressions is positive but the expected the sign in the natural forest regressions is uncertain.

Growth in the demand for consumable forest products is generally less rapid at higher income levels. Furthermore, at higher per capita income levels, non-market demands on the resource also tend to increase and they work to protect the forest from some of the increasing consumptive demand. Therefore, we will introduce a second order income term. The sign on this term should be opposite to the first order sign for all regressions. The coefficient on this second order income term will enable us to identify the turning point associated with an environmental Kuznets curve for forests.

Population: The Malthusian hypothesis encourages the view that larger populations are destructive of the environment. Our intuition is that population density, specifically the density of the rural population and not absolute population level, is what matters for the forest environment. The entire population, urban and rural, consumes a variety of marketed forest products, but this consumption is captured in a measure of aggregate economic performance. It is largely the rural population, with its component of low opportunity cost and often subsistence demands that degrades the forest. Therefore, the important measure of population for our purposes is the rural population density (the ratio of rural population to total land area of each province).

Property rights: Improved property rights (or tenure) are an inducement for longer-term forest management. As production on the managed forest increases, the relative level of reliance on the natural forest for extractive products decreases.

We measured property rights in forests as the increasing household-managed share of a province's total forest. Yin and Newman (1997) use the same measure. Lin (1992) uses a similar measure in his classic assessment of the effects of market reforms on China's agricultural sector. This share largely originates with increasing allocations from the collective forest. Therefore, the expected sign for the tenure coefficient in the collective managed forest regression is positive. Improved tenure may also have a positive impact on the smaller and more marginal category of collective natural forests as improvements in land tenure included some transfer of these latter forests to the households. A smaller share of state-owned forest was transferred as well to individual household management (as part of the "three fix" program), also resulting in an increase in our measure of property rights. Therefore, the state forests lost area and volume in the process of improving household tenure and the expected sign of the tenure coefficient on the state forest regressions is negative.

Prices: Two sets of prices should be relevant, the prices of the agricultural products that compete for land with managed forestry and the prices of forest products themselves.

Grazing by domestic livestock is generally the lowest-valued use of agricultural land. Therefore, grazing is often the agricultural competitor with managed forestry. As livestock prices rise, agriculture may compete more successfully with the intensive margin of forest management. It is unclear whether rising livestock prices also induce China's livestock industry to extend its operations into previously open access natural forest in regions where forest product prices are too low to justify managed forester and where grazing, perhaps, compete with other uses of the natural forest.[6]

An increase in the price of commercial forest products induces an immediate increase in harvests from both managed and natural forests. The volume and area of both managed and natural forests decline as a result. However, more sustained forest product price increases also induce reinvestment in managed forests. We expect that they have no effect on the natural forest. We examined several possible price lags for forest products. The one-year lag performed best. Yin and Newman (1997) also observe that a one-year lag predicted well.

Tables 1 and 2 show the national trends in per capita income and in forest survey data, as well as the extremes for those regions and provinces that are most important for forestry. Table 3 provides summary national data for the remaining independent variables as well as comparable data for two key provinces, Heilongjiang in the northeast where state-owned forestry dominates and Hunan in the predominantly collective south central part of the country.[7] It is clear that the sample data display wide geographic dispersion, and that all but the population data display substantial intertemporal variation.

5. Empirical Results

These data permit us to estimate the regressions for both forest volume and forest cover for each of four categories of the dependent variable, managed and natural forests each separated according to collective and state administration—a total of eight regressions. Ours

[6] We also considered a grain price index for this variable. The livestock price index performed better—probably because grazing tends to be a lower-valued use of agricultural land and, therefore, a closer substitute for managed forest land. Regression results available from the authors.
[7] These three tables substitute for the single table of descriptive statistics included in many empirical analyses.

are fixed effect, double log, regressions. The former means that our regressions control for exogenous differences between provinces, and the latter means that the estimated coefficients are elasticities.

5.1 Results: Collective Forest Lands

Consider the collective households first. Four regressions predict forest area and forest volume for, first, managed, and then, natural forests. The first column of table 4 identifies the independent variables. Subsequent columns identify the expected signs and record the results for each regression, including the estimated coefficient (elasticity) and the t-value and statistical significance for each variable. The equation F statistics and R^2s for all four regressions are satisfactory.

For the managed forest, the signs on all eight coefficients in the forest area regression follow expectations and three coefficients are statistically significant. Seven of eight signs in the forest volume regression follow expectations and four are statistically significant. We expect these to be the most reliably predicted of all regressions because decisions for these managed forestlands most closely follow predictable market incentives.

For the natural forests managed by collective households, six of seven signs in the area regression follow expectations (although three expectations are uncertain), but only the sign on tenure is significant. All seven signs in the volume regression follow expectations and the coefficient on tenure continues to be significant.

In sum, decision making for the collective forestlands very largely followed expectations since the introduction of market reforms—and once we made our own important distinction between managed and natural forests. Improved household land tenure had a large and significant effect on both managed and natural forests. This result is consistent with the prior literature for both forestry and agriculture in China. Also, as anticipated, increased rural population density is associated with decline in both managed and natural forests. Greater per capita incomes led to greater demand for the products of the forest, more forest management, and less natural forest as some of the latter was, perhaps, converted to managed or plantation forest. Per capita income had the most elastic of all productive responses for both forest area and forest volume. However, this effect declined as incomes continued to rise. It will be interesting to observe whether these income terms exhibited similar effects on the state-owned natural forests which tend to be less accessible for market exploitation and, often, more attractive for environmental preservation. Finally, the timber and livestock price effects also followed expectations, although their coefficients were not statistically significant and the responses to changes in these variables were generally not as elastic as for the other predictive variables.

5.2 Results: State-owned Forestlands.

The regressions for managed forests administered by the state did not perform as well. We know that, in countries around the world, even timber harvest operations on these forests are often determined by administrative rather than market criteria and we know that, in China, the management decisions for these forests have been guided by the need to support mill employment, rather than by financial criteria. Many state forest bureaus and state forest farms have continued to operate only with the exogenous budgetary support of the central government. Therefore, it is not surprising that state-owned *managed* forests do not predictably respond to the economic variables in our regression.

As an alternative to our economic variables, central government budget allocations for silvicultural management might be a useful predictor of state forest management. Silvicultural budget data are available for a limited period covering the second to the fourth forest inventories for many provinces. Independent regressions incorporating this new variable were more satisfying in all respects.[8] However, the limited number of observations, limited period of time, and the absence of any basis for understanding adjustments in these government budgets encourage caution in reporting these results. We conclude only that decision making on state-owned/managed component of all forest lands is more complex and less predictable than decision making for either component of the collective forests.[9]

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[8] Regressions available from the authors.

[9] The focus of this paper on the effects of aggregate economic and broad demographic factors restricts further attempts to assess other determinants of behavior on the state-owned forests at this time.

The regressions for state-owned *natural* forests presented in table 5 are more satisfying. Signs on five of the seven coefficients follow expectations in the area regression and all five are statistically significant. All seven signs in the volume regression follow expectations and three are statistically significant. The equation F and R^2s are also satisfactory.

To summarize, population density had an indeterminate effect on the generally less accessible state-owned natural forests. In any event, these forests are too inaccessible for us to have predicted any substantial population effect. Improved household tenure also has an indeterminate effect. Improved tenure may have drawn land away from some managed state forests but it apparently had little effect on more remote natural forests. The change in forest definition for the most recent two inventories had a significant effect only on this one category of forest, apparently adding lower grade and less accessible lands and volume to the state-owned natural forest base.

The standard economic variables performed as predicted. Rising timber prices led to significant increases in timber harvests for these natural forests and, as a result, decreases in the natural forest area. (Logging restrictions on state lands since 1998 may have temporarily limited this effect.) Rising livestock prices may have induced some infringement on the natural forest, particularly in western China where grazing often remains an open access activity. However, rising incomes had the largest effect by far, and the effect was positive. These regressions argue that China has added substantially to its state-owned natural forests at the same time its per capita income has risen dramatically. Perhaps some timber harvest activities have shifted away from natural forests and to more productive managed forests, as Rozelle et al. (2003) suggest. Certainly China has added substantially to its protected natural reserves (86.4 million hectares or 8.6 percent of its land area since 1982) and much of the addition must have been in the form of recovering natural forest (SEPA 1998, FAO 2001). Additional forest area that was previously either managed or open access and degraded must also be recovering naturally.

5.3 Net Effects: The Aggregate of Collective and State-Owned Experience

Table 6 reports summary regressions for the aggregate of all collective and state managed forests and for all collective and state natural forests. The explanatory power of these regressions is not as great as those in tables 4 and 5 but it is easier to obtain aggregate conclusions regarding the Malthusian and Kuznets hypotheses for them than from less aggregate assemblies of data. We selected the area regressions for these summaries because the area regressions in tables 4 and 5 generally performed slightly better than the volume regressions. All eight signs for the new managed forest regression follow our expectations and two (income and tenure) are significant.[10] All seven signs for the new natural forest regression follow expectations and one (timber price) is significant. Once more, the equation F statistics and R^2s are satisfactory.

The predictable market effects observed in the collective regression (table 4) dominate the summary managed forest regression. First, the small coefficient on population provides a minimum of cautious support for the Malthusian hypothesis that an increasing population is associated with a declining resource. In fact, the (opposite) declining population perspective may be a better way to consider this effect. That is, as the rural population density begins to decline, as it has in some parts of China, the decline may be accompanied by increases in the managed forest resource. At least this is a possibility worthy of consideration. If this is an accurate appraisal of the population effect of China, the question that arises is whether we could predict a similar population-managed forest relationship elsewhere in the world if and as other rural populations also begin to decline.

Second, our additional coefficients show that improved land tenure was an indisputable incentive for longer-term forest management. The timber price coefficient shows that rising timber prices worked to increase timber harvests but also to encourage longer-term forest management, and the livestock price coefficient shows that livestock grazing was a substitute use of some managed forest land.

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[10] These general managed forest observations are consistent with those of Demurger and Yang (2006) for the recently afforested subset of all managed forest area in China. Demurger and Yang observe that afforested land is a negative function of agricultural prices and rural population density and a positive function of the level of rural assets.

Third, the significant first order income term displays the most elastic response of any independent variable. It shows that increasing per capita incomes had a positive effect on total land area devoted to managed forests. This positive income effect is triple the magnitude of the negative population effect—although the second order income term shows that this effect did decline for higher income levels. A share of this effect is due, no doubt, to recent investment by the central government in several immense forest recovery programs. However, this public investment, at best, can account for only 40 percent of the total area afforested since 1978. The remaining 60 percent is due to non-public participation. Therefore, we can conclude that rising per capita incomes have had an undeniable positive effect, increasing the demand for forest products and, thereby, inducing an increase in the land area under forest management.

The summary natural forest regression reflects a mix of the effects observed in the disaggregated collective and state administered natural forest regressions. Increasing rural population density had a small and insignificantly positive effect on the natural forest. The price terms show the merit of separately describing effects on managed and natural forests. Rising timber prices induced harvesting from the natural forest, but they had no long-term effect on the natural forest in this or any other regression we examined. We did not expect livestock prices to have a substantial effect on natural forests, and they do not. Finally, rising per capita income had a small and decreasingly negative effect on the natural forest.

Aside from the general conclusion of the theoretical and empirical merit of separating the forest into managed and natural components, the income terms may be most interesting. They seem to suggest that rising incomes cause some drawdown of the natural forest, but this decline subsides with further increases in income. Meanwhile, rising incomes have a much stronger positive effect on the land area devoted to managed forests. While this latter effect also declines with rising incomes, the net effect—across the income range observed in China over the last quarter century—has been strongly positive and total forest area has increased as a result.

These income observations, taken together, seem to support the contention of an environmental Kuznets' curve for forestry. The turning point for natural forest cover occurred at an income level of 563 yuan, although this income level might have been a little higher if China had not changed the level of minimal cover in its official forest definition. This means that the decline in natural forest area probably ended in the mid-1980s. The turning point for expanding managed forest cover occurs at a per capita rural income level of 12,198 yuan. Since average per capita rural income for all China was only 2,622 yuan in 2003 (table 1), we can expect that China's managed forests will continue to expand for many years. Indeed, these two conclusions are consistent with our personal reflections on the data and our impressions from years of travel to the field. Natural forest cover did decline through the early 1980s, but we have not observed additional decline in recent years anywhere in our travels throughout the country, and there is some evidence of recovery in secondary growth natural forests. On the other hand, there is evidence of increasing managed forest cover in almost all provinces today.

6. Conclusions

We are left with two broad conclusions, one regarding the best way to describe forests for management and policy analysis and one regarding macroeconomic effects on the forest.

For the first, forests are best described in two parts, managed and natural. We hypothesize that the former responds to both short- and long-term forest product price incentives and, at its intensive margin, to competitive agricultural prices. Natural forests are more remote or less accessible to the market and that is the primary reason they remain in a natural state. Natural forests respond only to short-term price signals and only to those from the market for forest products. The Chinese data support this hypothesis but we anticipate that it is a valid hypothesis for forest measurement and for forest management and policy in other countries as well.

More generally, we must also wonder whether our resource distinctions between managed and natural, state and non-state management are valid for other biological resources. In particular, would these distinctions improve our understanding of commercial fish stocks such as salmon or trout or some shellfish, which include both wild and managed components, subject to both state and private administration, or even our understanding of the few large game species whose stocks fall into similar management and ownership categories?

For the second broad conclusion, the more general economic environment has two identifiable effects on these forests, one for which we have only very limited support and one for which China's evidence is most convincing. First, declining rural population density may be associated with an increase in land devoted for forest management. This is the cautious and optimistic dual to Malthusian warnings of the dire consequences of general population growth. Is it possible that the rural-to-urban migration we observe around the world could have a beneficial effect on forest area and, therefore, at least one beneficial environmental effect?

Finally, economic growth and development, as measured by per capita rural income, has a substantial effect on both managed and natural forests. This observation should not surprise us. Forestry contributes less than one percent of China's gross domestic product and more than five percent to the GDP of only one country in the world (Finland at 7.6 percent, FAO 2001). Surely forestry's small share of the full national economy suggests that the national economy has a greater effect on forestry than forestry has on the full economy. Our regressions tell us that China initially drew down its natural forest cover in the 1970s but, since the mid-1980s, income growth (and with it, increasing consumer demand for marketed forest products, increasing demand for forest-based environmental services, and decreasing subsistence demands on the forest) has been by far the greatest force behind managed forest growth and the substitution of forest management for the products of the (no-longer-declining) natural forest. Furthermore, we can anticipate that a broad range of additional income growth will continue to have a strong favorable effect on forest management and aggregate forest cover. We suspect that similar research for other countries around the world would yield similar encouraging results.

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Table 1 Summary Statistics: Income and Agricultural Production

	National averages/totals	Highest province	Lowest province
Per capita income: 1978[1]			
Rural (yuan)	442	774 (Beijing)	331 (Shanxi)
Urban (yuan)	1,137	1,853 (Shanghai)	637 (Anhui)
Per capita income: 2003			
Rural (yuan)	2,622	6,653 (Shanghai)	1,564 (Guizhou)
Urban (yuan)	8,472	14,867 (Shanghai)	6,530 (Ningxia)
Agriculture: 1978[1]			
Production (billion yuan)	112.00	28.191 (Jiangsu)	0.513 (Tibet)
Cropland (million ha.)	150.10	11.844 (Sichuan)	unknown (Tibet)
Production/hectare (yuan/ha.)	744.15		
Agriculture: 2003			
Production (billion yuan)	1,487.0	59.900 (Shandong)	2.53 (Tibet)
Cropland (million ha.)	152.4	13.684 (Henan)	0.14 (Beijing)
Production/hectare (yuan/ha.)	9,756.0		

[1] Converted to year 2003 values using China's CPI

Sources (China Statistics Bureau 2000, 2004a).

Note: ha. = hectare

Figure 1: The Forest Landscape

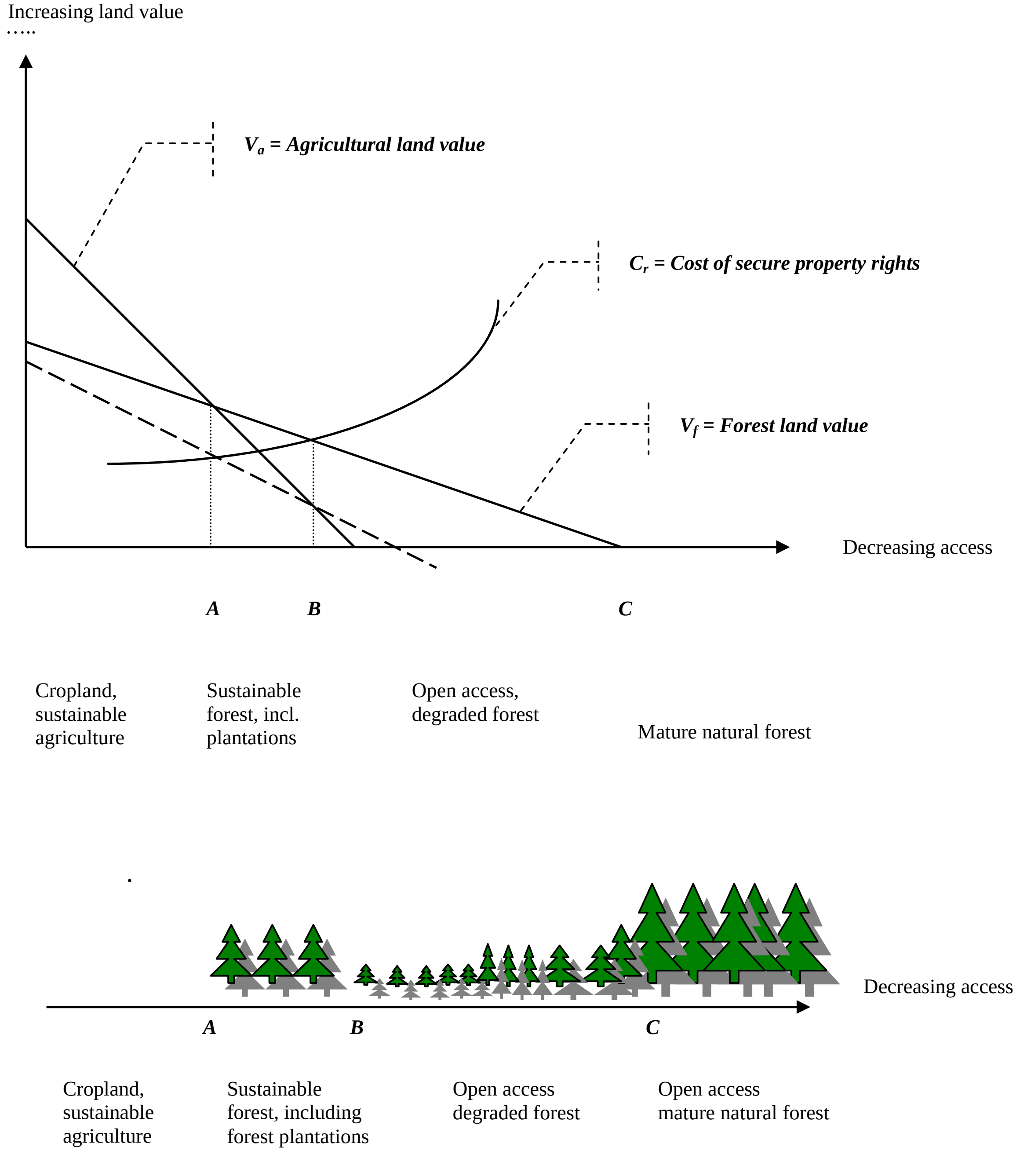

Table 2: Summary Statistics: Forests

	First Forest Inventory (1977-1981)		*Sixth Forest Inventory (1999-2003)*	
	Collective	*State-owned*	*Collective*	*State-owned*
All China				
Managed Volume	134.10	119.50	1020.00 (661%)	467.00 (249%)
(plantation) Area	7.95	4.74	24.27 (205%)	7.68 (62%)
m^3/ha	16.87	29.80	42.03 (149%)	60.79 (104%)
Natural Volume	1665.36	5139.09	2650.00 (59%)	5620.00 (9%)
Area	30.41	47.28	49.51 (63%)	51.98 (10%)
m^3/ha	29.80	109.00	53.52 (89%)	108.11 (-1%)
Northeast Region[1]				
Managed Volume	13.87	50.14	83.20 (500%)	165.03 (229%)
(plantation) Area	0.85	1.53	1.94 (128%)	2.68 (75%)
m^3/ha	15.61	32.77	42.89 (175%)	61.58 (87%)
Natural Volume	75.32	2060.00	149.38 (98%)	1970.00 (-4%)
Area	2.48	19.83	2.40 (-3%)	21.25 (7%)
m^3/ha	52.24	103.88	62.24 (19%)	92.71 (-11%)
South and South Central Regions[2]				
Managed Volume	103.89	24.55	637.01 (513%)	182.17 (642%)
(plantation) Area	5.41	0.98	14.12 (161%)	2.53 (158%)
m^3/ha	19.20	25.05	45.11 (135%)	72.00 (188%)
Natural Volume	1093.66	195.30	1240.00 (13%)	194.73 (-0%)
Area	18.86	2.90	28.38 (44%)	2.16 (-26%)
m^3/ha	57.99	67.34	43.69 (-25%)	90.15 (34%)

All areas in million ha. All volumes in million m^3. Measures in parentheses are percentage changes between the first and sixth forest inventories.

[1] Heilongjiang, Jilin, and Inner Mongolia

[2] Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hubei, Hunan, Jiangxi, and Zhejiang

Source: State Forestry Administration (1981, 1988, 1993, 1998, 2003)

Table 3 Additional Summary Statistics

	1981	1988	1993	1998	2003
All China					
Rural population density*	98	103	107	108	102
Tenure**	0.425	0.486	0.500	0.541	0.553
Timber price (an index)	126.95	408.56	443.32	543.75	522.0885
Timber price lagged one year	100	298.87	399.02	537.84	528.965
Livestock price (an index)	101.10	224.13	269.48	431.34	361.2655
Northeast region, Heilongjiang					
Rural population density*	44	44	45	44	43
Tenure**	0.001	0.0642	0.0388	0.0673	0.0741
Timber price	126.94	331.15	358.6	431.67	433.2
Timber price lagged one year	100	248.42	344.81	404.56	431.9
Livestock price	101.1	228.49	320	500.15	462.8
South and south central regions, Hunan					
Rural population density *	222	237	245	245	201
Tenure**	0.881	0.921	0.93	0.937	0.943
Timber price	125.9	596.49	602.13	626.43	581.26
Timber price lagged one year	100	368.66	571.28	638.56	579.52
Livestock price	101.1	231.39	307.59	516.94	525.2

* Rural population density calculated as agricultural population/total land area.

** Tenure calculated as (household contracted forest area/total forest area)

Sources: China Statistics Bureau (1999, 2004), State Forestry Administration (1981, 1988, 1993, 1998, 2003), China National Price Bureau (1998), China Statistics Bureau, Rural Comprehensive Survey Team. (1982, 1989, 1994, 1999, 2004).

Table 4: Fixed effect regression results for collective forests

		Managed (plantation) Forest				Natural Forest		
		cover		*volume*		*cover*		*volume*
ln (rural pop/area)	-	-0.671	-	-1.738	-	-1.111	-	-2.346
		(0.98)		(1.68)*		(0.89)		(1.25)
ln (rural income/cap)	+	3.004	+	4.862	?	-1.201	?	0.52
		(2.93)***		(3.13)***		(0.62)		(0.18)
ln (rural income/cap)^2	-	-0.195	-	-0.327	?	0.114	?	-0.007
		(2.80)***		(3.10)***		(0.88)		(0.03)
ln (tenure)	+	1.48	+	1.421	+	1.008	+	0.96
		(16.25)***		(10.30)***		(6.24)***		(3.95)***
ln (timber price)	-	-0.076	-	-0.036	-	-0.245	-	-0.004
		(0.23)		(0.07)		(1.06)		(0.01)
ln (timber price lag)	+	0.098	+	0.169				
		(0.28)		(0.32)				
ln (price livestock)	-	-0.054	-	0.378	?	-0.288	?	-0.852
		(0.18)		(0.81)		(0.48)		(0.95)
definition change	+	0.144	+	0.167	+	-0.022	+	0.438
		(0.93)		(0.71)		(0.08)		(1.01)
constant		-17.032		-27.966		-2.278		-8.711
		(3.17)***		(3.43)***		(0.24)		(0.60)
observations		140		140		137		137
number of provinces		28		28		28		28
R-squared		0.87		0.86		0.37		0.23
F(8,104)		86. 12		78. 41				
F(7,102)						8. 48		4. 42

Absolute value of t statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5: Fixed effect regression results for state-owned natural forests

		Natural forest		
		cover		*volume*
ln (rural pop/area)	-	0.290	-	-1.103
		(0.61)		(1.08)
ln (rural income/cap)	?	2.33	?	5.442
		(0.947)**		(1.69)***
ln (rural income/cap)^2	?	-0.171	?	-0.372
		(0.06)***		(0.11)***
ln (tenure)	-	0.023	-	-0.143
		(0.08)		(0.14)
ln (timber price)	-	-0.317	-	-0.235
		(0.11)***		(0.20)
ln (price livestock)	-	-0.195	-	-0.609
		(0.29)*		(0.52)
definition change	+	0.489	+	0.526
		(0.14)***		(0.25)*
constant		-8.067		-19.882
		(4.68)*		(8.36)**
observations		137		137
number of provinces		28		28
R-squared		0.27		0.16
F(7,102)		5.45		2.70

Table 6: Summary fixed effect regression results for the combination of collective and state-owned forests

		Managed (plantation) forest cover		*Natural forest cover*
ln (rural pop/area)	-	-0.578	-	0.153
		(1.11)		(0.40)
ln (rural income/cap)	+	1.449	?	-0.038
		(1.85)*		(0.06)
ln (rural income/cap)^2	-	-0.077	+	0.003
		(1.44)		(0.08)
ln (tenure)	+?	0.162	-?	-0.004
		(2.32)**		(0.08)
ln (timber price)	-	-0.034	-	-0.161
		(0.14)		(2.28)**
ln (timber price lag)	+	0.009		
		(0.04)		
ln (price livestock)	-	-0.111	?	0.193
		(0.47)		(1.06)
definition change	+	0.053	+	0.14
		(0.44)		(1.59)
constant		-11.589		-2.305
		(2.82)***		(0.78)
observations		140		137
number of provinces		28		28
R-squared		0.70		0.38
F(8,104)		30.96		
F(7,102)				9.03

Absolute value of t statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Paper IV

Candidate Selection, Manager Turnover and Firm Productivity:

Evidence from China's timber industry

Jiegen Wei[1]

Abstract

This paper uses firm level data matched with information from the forest bureau in China's timber industry to evaluate the impact of manager turnover on firm productivity. We find that due to differences in selecting and screening manager candidates, the impacts of manager change on firm productivity are heterogeneous across ownership types. In state-owned firms, manager change is mainly driven by bureau leaders who may want to control the rent from firms and hence appoint new managers who are loyal to them. Consequently, deterioration of firm productivity can be observed following a change. For private firms, it is found that manager selection is based on the human capital of candidates. Therefore, firm productivity tends to improve after a change. The results from both a regression analysis and a matching approach provide similar evidence.

Keywords: manager turnover; ownership; selection of manager; firm productivity.

JEL: P34; P26; G34; P28.

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1. Introduction

Selecting qualified candidates to leadership and management positions is fundamentally important for both firms and nations that want to flourish (Besley, 2005). Many studies in the corporate finance literature show that manager change commonly follows poor performance (Warner et al., 1988; Weisbach, 1988; Morck et al., 1989) and that firm performance increases following manager turnover (Denis and Denis, 1995; Denis et al., 1997). These results indicate that boards and outside hostile bidders function well to remove unqualified managers in industrialized countries, especially in the US. Others find that firms that select new CEOs from among those with personal relations (by blood or through marriage) with the departing CEO, with a founder, or with a large shareholder, tend to under-perform relative to those that select CEOs based on merit (Francisco, 2006). That firms that select a CEO who is related to the previous CEO perform worse has also been observed in Danish firms (Morten, Kasper, Francisco, and Daniel, 2007). The impact of a change in leadership on countries' economic growth illustrates this phenomenon. Recent studies show that unpredictable changes in a country's leadership due to its leader's accidental or illness-related death can trigger changes in measures such as the gross domestic product (GDP) (Jones and Olken, 2004).

According to recent literature, the success or failure of privatization and reform in transition economies may depend on the manner in which the managerial labor market operates and the way owners screen and select top managers. Empirical evidence from central Europe shows that firm productivity improves only with the arrival of outside owners (Frydman et al., 1999). Other studies point to the importance of new managers in Russia and the Czech Republic (Barberis et al., 1996; Claessens and Djankov, 1999). Along the same lines, in their influential analysis of China's state-owned enterprise, Groves et al. (1995) find similar evidence that firm performance improves when a new manager is hired, while there are no improvements in firms administered by their original managers.

This paper aims to explain how the selection of managers in private and state-owned firms might differ due to differences in the principals' incentives and to explore the consequences of these differences for productivity. State-owned enterprises (SOEs) are often controlled by politicians who are more interested in their own goals than firm profits or productivity. It is commonly observed that politicians use SOEs to pursue their political goals, such as to gain political support from employees, or to seek monetary benefits or transfers through corrupt use of control (Shleifer and Vishny, 1994). The money earned enables politicians to further strengthen their control over the firms – often by appointing loyal CEOs. Under these circumstances, it is highly possible that firms may actually perform worse following CEO turnover. Private owners are more immune to political goals due to shareholders' appetite for profits and less interference from politicians. Hence, they are keener on displacing unqualified managers and getting competent ones in order to improve firm performance.

The present empirical analysis of the impact of manager change on firm productivity is based on a recent survey of firms in China's timber industry. This sector provides enough diversity and thereby an opportunity to perform such an exercise. On the one hand, it is a dynamic industry with ordinary private firms as in other market economies. On the other hand, there are a substantial number of state-owned firms under the control of forest bureau politicians.

The results illustrate that ownership structure affects the manner in which managers are selected, which, in turn, has a profound effect on firm productivity. In contrast to previously reported evidence that the auctioning-off approach to select able managers in the 1980s increased firm performance and productivity (Groves et al., 1995), we find neither significant improvement nor deterioration of productivity following manager change when we look at the population of firms as a whole. However, the aggregate picture masks the important differences in impact that can be seen after sub-classifying firms based on ownership. In terms of state-owned firms, if the approach to select and appoint managers does not aim to improve firm performance but rather is based on political favoritism, we would expect to find that firms that have changed manager tend to be significantly less productive than those that have not.

We find that there are differences in the underlying causes of manager change between state-owned and private firms. Personnel change in state-owned enterprises serves as a tool for government bureaucrats to control resources, and a change of leadership in the bureau therefore tends to lead to significant changes in the management teams of state-owned firms. The significant negative impact of manager turnover in state-owned firms on firm productivity is confirmed in both regression and matching results. In terms of private firms, the selection and screening process is mainly based on the candidates' human capital. Therefore, not surprisingly, an increase in firm productivity is commonly observed following a manager change compared to those private firms that have not changed the manager, and this can be interpreted as a causal effect of manager change.

This paper is closely related to the literature evaluating the impact of reform on firm productivity. The results from these analyses are very mixed. In Eastern Europe, some authors show that privatization has had little effect on firm performance (Estrin and Rosevear, 1999). Others find that performance increases only in firms with a specific type of private owner (Frydman et al., 1999). These are in contrast to the analyses of Chinese state-owned enterprises (SOES). Most studies on China find significant improvements in firm productivity arising from reforms such as autonomy, introduction of incentive packages, liberalization of product and factor markets, and selection of new top managers, though not necessarily from privatization (Jinhai, Xiaoxuan, and Bigsten, 1998; Groves et al.,1995).

This study will proceed as follows. Section 2 gives a brief summary of the related literature and a detailed introduction of the institutional background for our analysis. Section 3 presents the model of interest and the identification strategy. Section 4 gives detailed information on the data and measurements. Sections 5 and 6 report the main results from the regression analysis and a matching approach, respectively. The last section concludes the paper and provides a short discussion on policy implications.

2. Institutional background and related literature:

2.1 The effect of manager change in private firms

Manager change is a tool used by boards of private firms to effectively monitor executives in an attempt to fulfill performance-improvement goals. If future benefits are expected to rise with a new manager, then termination of a contract between the firm and the incumbent manager should lead to an increase in share price and in shareholder wealth. Accordingly, based on US data, Johnson et al. (1985) find that sudden death of an executive may lead to an increase in the share price of his or her company. On the contrary, Warner et al. (1988) find no evidence that turnover affects stock returns of US publicly listed firms. Weisbach (1988) shows that excess returns are always positive and larger when the CEO is not of retirement age. Dividing the sample by board composition, the effects of turnover are more positive for outside-controlled and mixed boards and close to zero for insider-dominated boards. Denis and Denis (1995) report that forced resignations and retirements are often followed by restructuring activities, leading to significant improvements in terms of stock returns and operating income growth.

2.2 Interaction between manager change and ownership

Ownership matters because it affects the incentives to and objectives of shareholders. The objectives of public owners are usually considered to be less profit-oriented than those of private owners. In state-owned firms, politicians may for example create excessive number of employment opportunities on the firm as a way to buy votes (Shleifer and Vishny, 1994). A private owner tends to provide proper incentives to the manager. A change in the allocation of ownership rights from politicians to private owners shifts the objectives of the principals, which changes the incentives provided to the manager and protects him or her from the negative influence of politicians. Privatization can also deny access to information that a malevolent government could use abusively (Shapiro and Willig, 1990) or can provide a mechanism for a benevolent government to credibly commit not to intervene in daily operations of firms, which can distort managerial incentives (Schmidt, 1996).

There is substantial evidence of the positive effect of privatization on incentives and turnover. Studies documenting the evidence include: from Mexico, La Porta and López-De-Silanes (1999), and a cross section of both developing and developed countries by D'Souza and Megginson (1999). Cragg and Dyck (1999) claim that top management turnover is closely associated with type of ownership, and find in British data that turnover and firing rates are higher in privatized firms. This supports the assumption that privatization can improve firm performance if the new owners make turnover more likely by linking continued employment to performance, and thus raise both incentives and the turnover rate. Evidence from transition economies shows that if shares are directly connected to managers and workers within the firm, then outside investors are hardly able to change the manager due to resistance from the insiders afraid of losing their interests (Blanchard and Aghion, 1996). Therefore, the impact of changes in either manager or ownership on firm productivity is generally contingent upon each other.

The evidence from transition countries also shows that manager change improves firm performance under certain circumstances. In China, Groves et al. (1995) find in their sample of managers selected by politicians that for the large majority of firms, it was most likely that more capable managers were appointed and an improvement in performance was observed in firms that hired a new manager; no improvement was detected when the incumbent manager was reappointed. These authors believe that the reason why politicians in the 1980s chose capable managers was the downgrading of the role of the party and increased regional competition. Barberis et al. (1996) find similar results from Russian shops, indicating that hiring a new manager with new skills increases the likelihood of restructuring, but that the provision of better incentives to incumbent managers does not improve the prospects of a firm. In the Czech Republic, Claessens and Djankov (1999) find unambiguous evidence of improved profitability and productivity following appointment of new managers.

2.3 Institutional environment of the Chinese timber industry

The Chinese timber industry varies enormously in sophistication since China has experienced fundamental changes over the last several decades in not only government priorities and preferences but also in institutions and policies regarding forestry management. Timber production for the state sector used to be the main goal, and was conducted primarily by state forest bureaus, which are huge and complicated state-owned enterprises often serving as key economic and political actors in the regions where they operate. With troops and other workers sent to the remote natural forest areas, mainly in the northeast and southwest of China in the 1950s following nationalization, the Chinese government set up bureaus to harvest natural forests and meet the demand from other industrial sectors. There are a total of 155 forestry bureaus in China that manage hundreds of thousands of hectares. Of these, 135 operate timber harvest and transportation, while the remaining 20 focus mainly on replanting. In addition to having administrative functions as forest authorities, the state-owned forestry bureaus also operate as corporate enterprises.

The forestry bureaus manage hundreds of processing mills that employed more than one million workers in the 1980s and 1990s (State Forest Administration, various years).[2] The larger mills are often part of the so-called integrated wood industries, which may comprise one or several saw mills and a host of small-scale ancillary plants – each unit representing an ad hoc addition to an original sawmill. Most of the time when the ancillary plants (designed to use the sawmill waste) have grown too big to be supplied by the original mill and there is no space to enlarge the existing mill, an additional sawmill or plant is created.

2.3.1 The evolution of control

In the 1980s, local governments began to change enterprise governance by

[2] This is counting only the 135 state forest bureaus concerned with timber harvesting.

introducing various "managerial responsibility systems" to depoliticize the firms. Under the new systems, some managerial positions in SOEs were auctioned off as a means to select competitive candidates. New managers were delegated power to make many decisions, and managers as well as workers were given financial incentives – primarily bonuses – tied to enterprise performance. In most cases, bonuses were tied to the sum of profits, reflecting the local governments' interest in maximizing the value of the enterprises and in aligning the interests of managers and workers with their objectives. Indeed, these policies contributed to the success of state-owned enterprises in the 1980s. Most studies have found significant improvements in firm performance and productivity in this period (Groves et al., 1995).

However, the success story didn't last long, and auctioning of top management positions has become an exception rather than a rule. After the Tiananmen Square event, the Party Organization Department's ultimate control over personnel selection and dismissals has remained untouched, and in fact even reinforced. This has since become a fundamental principle of China's political and economic organizations known as "the Party controlling personnel (Dang Guan Renshi)."

The selection of managers by Party Organization Departments and bureaus results in a number of problems that keep the objectives of firms from being profit driven (Yingyi Qian, 1996; You Ji, 1998). First, since the appointment of managers is essentially the same as the selection of government officials, the process is politically complicated and not transparent, and the selection criteria are not always based on economic performance but instead frequently on "political correctness." This seriously undermines the possibility of attracting the right type of managers and adversely affects managerial incentives. Second, there is no reason to believe that people from the Party Organization Departments have the ability and incentives to choose the most effective candidate for managerial positions, since they may have their own objectives and favor candidates with personal ties to them. The appointment and dismissal process could be a useful channel for them to gain political influence over and control of enterprises.

The common agency problem is pervasive and the residual claim is unclear in state-owned enterprises. The operation of state-owned mills is influenced by various government departments and the rights of control over them are ill defined. By screening and appointing managers who are loyal to them, the politician in the party or the bureaus can control them, and extract rent from their resources and mills. Local governments have at different times been allowed to retain some of the earnings from enterprises within their jurisdictions. However, they have often managed to exceed their allowances through uncompensated use of enterprise resources. Therefore, it is not surprising to observe that the turnover of bureau leaders can lead to subsequent change in the managerial teams of mills in the respective constituencies.

3. Empirical model and identification strategy

We thus have a multi-tiered principal-agent structure. At the firm level, managers are responsible for their plants, but the selection of them is made at higher levels of the hierarchy and we therefore need to consider characteristics at the level of the forest bureaus. Our aim in this paper is to evaluate the causal relationship between manager change and firm productivity, while manager change in turn is determined by the matching process between managers and either politicians or private owners. The structural equation of interest is described as:

$$y_{it} = \alpha_0 + \alpha_1 * d_{it} + \alpha_2 * firmcharacteristics_{it} + \alpha_3 * managercharacteristics_{it} + \varepsilon_{it}, \quad (1)$$

where the dependent variable y_i measures firm performance, d_i denotes whether there is a change of manager in the given year, *firm characteristics* includes firm size and registered ownership status, and *manager characteristics* contains information regarding manager age, education, experience, and political responsibility.

One potential problem concerning the use of the OLS approach to estimate equation (1) is that bureau leaders may want to appoint a specific type of manager while private owners may want to appoint a more able manager with better past performance, which could cause biases. We suggest two solutions. We assume that the change in and seniority of leadership in the forest bureau is beyond the influence of the individual state-owned firms and are important in explaining manager selection and the control of firms. Therefore, information about the turnover and seniority of officials such as directors and party secretaries, and the budget situation in the forest bureaus, can provide exogenous variation to explain manager turnover. We will use information about the bureau as instrumental variables and report the results from a two stage least squares (2SLS). Another strategy is to use the increasingly popular matching approach to identify causal effects for observational data. We compare the productivity of firms that have changed their managers with that of comparable firms that have not changed managers based on the propensity score estimated from the regression of manager change on the information about bureau leadership and budget, and a set of characteristics of firms and candidates.

A reduced-form matching equation to determine the selection of managers is needed to control for the role of personnel control at the bureau level. We explore the performance- related hypothesis of turnover and the possible political matching mechanism between managers and the leadership in their respective bureaus. The econometric model of manager turnover is:

$$\begin{aligned} d_{it} = \beta_0 + \beta_1 * firmcharacteristics_{it} + \beta_2 * bureaubudget_{jt} \\ + \beta_3 * managercharacteristics_{it} + \beta_4 * bureauleader_{jt} + \eta_{it} \end{aligned} \quad (2)$$

where we include similar firm and manager characteristics to consider the possibility that the screening of candidates depends on a firm’s or a manager’s observed characteristics. Additional variables are information at the bureau level covering bureau budget information and the change in and seniority of the director and party secretary in the respective bureau.

4. Data and variables

4.1 Data

The data used in this paper is from a 2005 survey that covers forest areas in Heilongjiang, Jilin, and the eastern part of Inner Mongolia, which are among the richest and most important forest areas in China. There are 35 million hectares of forest and a total standing stock volume of 2.8 billion cubic meters, accounting for 70% of the area and 65% of the volume of all state-owned forest areas in China (Lei, 2001). These resources are geographically divided among seven large forestry bureaus directly controlled by the Chinese national forest bureau and managed by 75 lower-level bureaus.

The survey collects information about lower-level forestry bureaus within all seven large bureaus,[3] and about firms within the respective local bureaus. To ensure that the sample is representative, local bureaus are stratified into three groups based on size, where within each group a local bureau is randomly selected. Three local bureaus are selected in each of the seven central bureaus, with the exception of the Yichun forestry bureau in Heilongjiang Province where six local bureaus are selected to account for the larger number of local bureaus. In total, fifteen, six, and three lower level forestry bureaus were selected from Heilongjiang, Jilin, and Inner Mongolia, respectively. The detailed questionnaire included detailed information about local bureaus' financial status, leadership, activities, and ongoing projects.

Table 1 The sample and privatization over space and time

Area	Bureaus	Firms		
		Total	Private	
			Number	Percentage
Heilongjiang	15	85	38	45%
Jilin	6	35	8	23%
Inner Mon	3	15	1	7%
Total	24	135	47	35%

The survey also collects information on processing mills. Ten mills are randomly selected from each of the chosen local bureaus, and the survey finally includes 206

[3] The survey did not cover Daxing'anling forestry bureau in Heilongjiang Province.

processing mills.[4] The survey asked accountants to fill out a set of financial accounting and input-output data in 2004 and 2000, and where applicable information for the privatized firms regarding the year of privatization. Detailed questions about the history of change with respect to managers are also included in the survey. Information about background and locations, ownership patterns, production scale, and managerial characteristics was also recorded by enumerators through personal interviews. Among the 206 mills, 71 were registered after 2000 (especially in 2002 and 2003), are in a start-up phase, or are not yet operating at full capacity, and we therefore exclude these observations in our analysis.

4.2 Measurement and variables

We measure firm performance by total factor productivity (TFP).[5] To avoid the difficulty of choosing the weights for different inputs in the parametric approach, TFP in our analysis is estimated with the nonparametric Data Envelope Analysis method (DEA). Since processing mills produce different final products, some aggregation and grouping of inputs and outputs is necessary. Various products that are manufactured from mills and sold are converted into real values. All inputs are classified into raw material input, energy input, labor and capital input, and are converted into real money terms using 2004 prices, except labor which is measured through number of employees. All observations are pooled and firm productivity is measured as the distance to the most efficient firms.

As for our ownership variables, the definition of a privatized firm is controversial. For example, Brown, Earle, and Telegdy (2006) regard firms with a strict majority of shares held by private individuals as private, while Estrin and Rosevers(1999) consider a firm to be privatized as long as it has any number of private shares. Our survey collected data about firm type, i.e., whether the firm is state-owned, collective, or domestic private, has foreign private shareholdings or is a joint venture between different shareholders.

[4] Data on 240 sample mills were supposed to be collected according to the sampling scheme. However, due to limited numbers of firms in some local bureaus, the survey team couldn't obtain ten firms in all local bureaus. In addition, some observations had to be dropped due to incomplete data.

[5] Other performance variables like profitability might appear to serve our interest better. However, profits might be misreported to avoid corporate tax and we therefore focus on total factor productivity which is more immune to such problems.

The involvement of foreign capital is seldom observed in China's timber industry and there is only one firm in our sample that is foreign private owned. There are 21 joint ventures between private and state owners, and one between private owners and collectives. In all these cases, we find that the private owners hold a controlling majority, and we thus categorize them as "private." As shown in Table 2, 35% of 135 firms are registered as private firms before 2000.

Table 2. Descriptive statistics

Description	Obs	Mean	Std. Dev.	Min	Max
Log (TFP)	260	-0.827	0.725	-3.817	0
Manager turnover within last year, yes=1	260	0.238	0.427	0	1
Private, yes=1	260	0.346	0.477	0	1
Log(net asset)	260	6.539	2.271	-1.038	12.03
Has the manager been an official? yes=1	260	0.715	0.452	0	1
Has the manager been a party leader? yes=1	260	0.227	0.420	0	1
Age	260	37.9	6.42	22	62
College education, yes=1	260	0.246	0.432	0	1
Share of fees from firms in bureau's budget	260	0.451	0.291	0.030	1
Is the director also the party leader? yes=1	260	0.335	0.473	0	1
Turnover of the director last year? yes=1	260	0.419	0.494	0	1
Tenure of the director (years)	260	3.573	1.880	1	8
Turnover of the party leader last year? yes=1	260	0.458	0.499	0	1
Tenure of the party leader (years)	260	3.281	2.176	1	8

We also include some information on firm characteristics and manager attributes. Some studies find that firm size has a significant effect on firm performance; we therefore include net assets to measure firm size (Xianming, 2000). Magager experience as a government official or party leader is important, and information regarding this is therefore contained in the regression. We also include additional variables such as age and whether the current manager is a college graduate to explore the reason why a new manager was appointed.

Attributes of local bureau leaders are included to explain the selection and appointment of new managers. In a bureau, the director is in charge of daily operations and the party secretary is responsible for the decision to select new managers. We therefore include information on both the director and party secretary regarding, e.g., whether they were appointed last year, number of years in office, and whether the director also holds the position of party secretary.

Summary statistics are reported in Table 2. Twenty-four percent of the firms had experienced a change of manager. Most of the managers, around 72%, had a career in the government and 23% had even been party leaders. Most managers are very young; the average age is 38 years.

Since this paper focuses on the impact of manager turnover on firm productivity, we make a cross tabtulation of firm productivity according to whether the firm incurred a change of manager and ownership status. The results of this are presented in Table 3. There are no major differences in manager turnover between the different ownership forms, and the percentage of firms with a change of manager is close to 24% in both private and sate-owned

Table 3 Firm productivity in state-owned and private firms that changed manager

	Total		No Change		With a Change		Difference
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Number	Mean	Number	Mean	Number	Mean	Mean
State-owned	170	-0.753	130	-0.706	40	-0.905	0.199
		(0.05)	(76.5%)	(0.06)	(23.5%)	(0.10)	(0.12)
Private	90	-0.966	68	-1.041	22	-0.734	-0.307
		(0.09)	(75.6%)	(0.10)	(24.2%)	(0.16)	(0.20)
All firms	260	-0.827	198	-0.821	62	-0.844	0.023
		(0.04)	(76.2%)	(0.05)	(23.8%)	(0.09)	(0.11)

Standard errors in parentheses in Columns (2),(4),(6), and (7)
Percentages in parentheses in Columns (3) and (5)

firms. However, the effect of manager turnover on productivity varies greatly depending on ownership: For state-owned firms, the average productivity of firms with a new manager is 20% lower, while for private firms, the average productivity increased by 31%. These descriptive statistics show that the impact of manager turnover on firm productivity depends significantly on who controls the firm. In the next two sections, we will employ regressions and the matching approach to probe into some plausible causal inference.

5. Regression results

5.1 Selection of manager

We first estimate the manager turnover equation. The dependent variable is a dummy indicating whether there was a change of manager in that year, with 1 meaning there was a change of manager. Table 4, Column (1) reports the probit results from the regression of manager turnover on a set of variables for the whole sample. The mechanisms of manager selection are possibly different between private and state-owned firms, suggesting that ownership is one important aspect of heterogeneity in our sample. In order to capture these potential differences, we split the sample into two subsamples, one for each type of ownership, and estimate the model separately for each subsample. The results for private and state-owned firms are reported in Column (2) and (3) respectively.

Looking at the whole sample, not many variables are significant. One exception is the impact of change of bureau director. Since directors are in charge of daily bureau operations, it appears that they tend to avoid manager change. This may be due to that they value stability and want to keep subordinates who are familiar with their working procedures and rules and regulations. Hence, in a bureau where there has been a recent change of director, the likelihood of manager turnover is significantly lower. The negative impact of director seniority on manager turnover also supports this argument.

We test whether the impact of the independent variables on manager changes is heterogeneous between the private and state owned firms, and reject that the impact is the same at the 10% level. After splitting the whole sample into state-owned and private firms and re-estimating the model, two interesting patterns emerge. First, both change of director/party leader and director seniority have significant impacts on the decision whether to select and reappoint a new manager in state-owned firms. Second, the manager selection in private firms is significantly affected by the age and education of the candidate manager but not by leadership change in the bureau. The former suggests that manager change in state-owned firms is largely driven by a political process, where the screening and selection of a manager doesn't depend much on his/her human capital but rather on the desire of state officials to control firms (this is especially true for the party leader who is responsible for personnel control). For example, if a bureau has experienced a recent change of its party leader, we see significantly higher rates of subsequent manager change. The higher the seniority of the party leader, the more likely

Table 4. Selection and turnover of managers

	Probit model dependent variable: whether there is a change of manager		
	(1)	(2)	(3)
Independent variables	All firms	Private	State-owned
Log(net asset)	0.0141	-0.0319	0.0269
	(0.0388)	(0.0975)	(0.0431)
Has the manager been a government official? yes=1	-0.181 (0.209)	-0.274 (0.330)	-0.236 (0.291)
Has the manager been	-0.122	-0.561	-0.0415
a party leader? yes=1	(0.211)	(0.417)	(0.260)
Age of manager	0.0205	0.0500*	0.00349
	(0.0141)	(0.0268)	(0.0183)
Is the manager a college	0.320	0.619*	0.187
graduate? yes=1	(0.206)	(0.366)	(0.260)
Share of fees collected	0.448	0.776	0.328
from all firms in bureau's budget	(0.323)	(0.604)	(0.411)
Is the bureau director also	0.187	-0.0452	0.303
the party leader? yes=1	(0.195)	(0.340)	(0.260)
Director turnover within	-0.463*	-0.126	-0.953**
the last year? yes=1	(0.269)	(0.462)	(0.430)
Tenure of bureau director	-0.0688	0.322**	-0.267**
	(0.0791)	(0.141)	(0.122)
Party leader turnover	0.370	0.0351	0.792**
within the last year? yes=1	(0.250)	(0.444)	(0.333)
Tenure of party leader in	0.0368	-0.127	0.134
the bureau	(0.0665)	(0.121)	(0.0898)
Constant	-1.651***	-3.266***	-0.613
	(0.624)	(1.077)	(0.902)
Observations	260	90	170
X^2	14	17	13

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

it is that a new manager will be appointed. Centralization of power, measured by a variable indicating whether a director also holds the position of party leader, increases the likelihood of displacing the old manager. If a bureau's budget to a large degree depends on fees collected from firms, it may be more afraid of losing control of them. This may lead bureau leaders to change managers more often to avoid the problem of insider control that may arise if managers stay too long in their positions.

The selection of managers in private firms appears to operate on quite a different basis and depends mainly on the human capital of the manager. Since private owners care about profits, the objective for them is to find the manager who is best suited to improve firm performance and profits. The observation that more educated or experienced candidates are more likely to be recruited by private owners as new managers is therefore hardly surprising. The probability of management turnover is higher among young managers, which is consistent with Jensen and Murphy's (1990) finding that it is harder to replace older managers when they are close to retirement.

When considering the effect of our control variables, we find that political screening, represented by the variable for past experience as a party leader or government official, plays a less important role and does not provide a significant explanation for the decision to choose a manager. Neither firm size appears to be a significant explanatory factor.

5.2 Manager turnover and firm productivity

We are now ready to estimate the effect on profits found in the main structural equation (1) - especially the coefficient of manager turnover. Table 5 presents the results from various specifications and estimation methods. Columns (1)-(4) present the OLS estimation with and without firm dummies.

As can be seen, the impact of manager turnover on firm productivity varies a lot across Columns (1)-(4). We do not find a significant improvement of firm productivity following manager change in Column (1), i.e., the OLS estimation assuming a homogeneous impact of manager change for all firms. Once we account for the possibility of a heterogeneous treatment effect and re-estimate the equation using OLS after including the interaction term between ownership and manager change, both manager turnover and the interaction term become significant at the 5% level as shown in Column (2). When state-owned firms appoint a new manager, total factor productivity significantly decreases by 23 %, but when privately owned firms do, there is a 25% increase. The results in Columns (1) and (2) are driven mainly by the cross-sectional pattern of the data, and do not account for the heterogeneity across different firms. Columns (3) and (4) present the results from the regression using the variation within firms. As shown, there are some significant changes. Nevertheless, it is fairly robust that in OLS estimation, we always find a negative relationship between firm productivity and manager turnover when we look at all firms, and this is mainly driven by state-owned firms. If we account for heterogeneity of the impact, firm productivity is always negatively associated with manager turnover in state-owned firms, while the association is positive in private firms.

Table 5. Manager turnover and firm productivity

	Dependent variables: log(firm total factor productivity)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Independent variables	OLS	OLS	OLS	OLS	IV	IV	IV	IV
Managerial change, yes=1	-0.0618	-0.227**	-0.016	-0.129	-1.817*	-0.914*	-1.086	-0.818***
	(0.097)	(0.109)	(0.076)	(0.086)	(0.981)	(0.539)	(0.815)	(0. 370)
Interaction between manager		0.474**		0.302**		0.134		1.254***
change and private firms		(0.208)		(0.152)		(0.861)		(0. 442)
Private firm, yes=1	-0.195*	-0.312**			-0.144	-0.205		
	(0.106)	(0.122)			(0.144)	(0.238)		
Log(net asset)	-0.0314*	-0.0307*	0.0068	0.0192	-0.0316	-0.0313	0.079	0.091
	(0.017)	(0.017)	(0.090)	(0.086)	(0.029)	(0.022)	(0.095)	(0. 058)
Has the manager been a	-0.064	-0.0687	0.391**	0.330*	-0.153	-0.106	-0.364	-0.216
governmental official? Yes=1	(0.112)	(0.110)	(0.180)	(0.170)	(0.159)	(0.117)	(0.402)	(0.206)
Has the manager been a party	-0.11	-0.0949	-0.444	-0.399	-0.151	-0.125	0.008	-0.073
leader? Yes=1	(0.094)	(0.094)	(0.284)	(0.284)	(0.157)	(0.121)	(0.324)	(0.209)
Age of the manager	0.00422	0.00364	-0.0371***	-0.0346***	0.0177	0.0102	0.007	0.004
	(0.007)	(0.006)	(0.011)	(0.011)	(0.013)	(0.009)	(0.012)	(0.009)
Is the manager a college	0.450***	0.441***	-0.273	-0.261	0.623***	0.527***	-0.138	-0.101
graduate? Yes=1	(0.093)	(0.093)	(0.363)	(0.351)	(0.181)	(0.125)	(0.231)	(0.208)
Dummy for firms and time	No	No	Yes	yes	no	No	yes	Yes
Instrument relevance test (p value)					7.5(0.27)	16.1(0.14)	3.7(0.71)	10.6(0.45)
Weak instrument test					1.34	1.38	0.30	0.44
Sargan over id test (p value)					2.9(0.72)	10.5(0.39)	4.4(0.49)	11.5(0.32)
Observations	260	260	260	260	260	260	260	260
R-squared	0.088	0.106	0.812	0.816	0.086	0.123	0.779	0.574

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

5.2.1 The endogeneity of screening manager candidates:

The estimators from the OLS results might not provide statistically correct causal relationships if they suffer from endogeneity problems. Several issues might lead to bias. First, owners generally screen candidates based on their past performance, or unobserved characteristics. The hired candidate's unobserved ability and experience will affect the performance of the firm, suggesting that OLS estimators underestimate the impact of manager change. Another cause of bias may come from unobserved shocks to firms; a firm might experience difficulties in, say, credit markets, and this negative shock on firm performance might lead to a change of manager. This would lead our OLS estimates to be downward biased. We test the endogeneity of manager turnover by reporting Durbin-Wu-Hausman statistics of 7.035, implying a significant rejection of the exogeneity hypothesis at the 1% level. To cope with the endogeneity issue, we use information on bureau leadership as instrumental variables for the change of manager, and re-estimate the equation using 2SLS.[6]

If both manager change in state-owned firms and bureau leadership are determined or influenced by the superior bureau, or the superior Party Organization Department that can affect firm performance, then variables on bureau leadership are not valid instruments. We provide indirect evidence to test the validity of our instruments by reporting the over-identification test at the bottom of the table. If we reject the over-identifying restriction, we can infer that at least one of the instruments violates the exclusive restriction. All the Sargan tests reported in Table 5 suggest that our instrumental variables affect firm performance through the selection of manager.

The results from using instrumental variables are presented in Columns (5)-(8). Again, we find a similar qualitative impact since the sign of impact does not differ from in the OLS estimations. However, we do observe a noticeable increase in the magnitude of the impact, suggesting that the OLS estimates are downward biased. As shown in Column (8),

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[6] The interaction term between ownership status and the dummy indicating manager change is instrumented by the interaction of ownership status and information about the bureau.

firm productivity significantly decreases by 81% following a change of manager in state-owned firms, while for private firms we observe a significant 44% improvement. A new manager's human capital is important to firms in order to achieve better performance. At the same time, an old manager generally has more experience. However, he/she is presumably less able to increase his/her knowledge to adapt to the fast changing realities of an economy like the Chinese one. Perhaps this explains why we observe that the younger the manager, the better the firm performs. It is also important for a manager to have college education, since in several specifications we observe that firms managed by more educated managers perform significantly better.

Table 5 also reports the test of the relevance of our instruments. The results show that our instruments suffer from "the weak instruments" problem. We resort to the matching approach in the next section as a way to compare the results and search for systematic patterns.

5.2.2 The timing of manager change

Although Table 5 provides evidence that the impact of manager change in the previous year on firm productivity is different between state-owned and private firms. There are two potential concerns with the use of manager change in the previous year as a treatment variable. First, the impact of manager change may need time to take effect; consequently, the use of manager change in the previous year may suffer from bias. Second, we might capture differences in performance due to a differential timing of manager turnover even though we have included the time trend in one of our specifications. We therefore use manager change in the year before the previous year as a treatment variable to examine its impact; the results are presented in Table 6.

Table 6 reports the results of the basic specification in Columns (1)-(4). We re-estimate the impact of manager change with and without the interaction term between ownership and manager change by using OLS, and as in the specification in Table 5, we also include the results with time and firm dummies in the regression. We find that the results are quite similar to those in Table 5. Firm performance does not change significantly without the interaction term. After including the interaction term, we can conclude that private firms perform significantly better while state-owned firms under-perform once a new manager is appointed.

We also use bureau information as instruments to explain the change of managers in the year before last and report the 2SLS results in Columns (5)-(8). Columns (5) and (6) present the results **without** time and firm dummies, with and without an interaction term between ownership and manager change, respectively, and Columns (7) and (8) show the same results, but **with** time and firm dummies.

In summary, the main conclusion that the impact of manager change on firm performance is significantly contingent on type of ownership does not change. However, we observe that the magnitude of the impact is relatively larger for the results in Column (8). If a new manager is appointed, firm productivity decreases by around 100 percentage points in state-owned firms, while it increases by around 60 percentage points in private firms.

Table 6. Firm productivity and manager turnover in the year before last

	Dependent variables: log(firm total factor productivity)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Independent variables	OLS	OLS	OLS	OLS	IV	IV	IV	IV
Managerial change, yes=1	-0.0482	-0.291**	-0.0432	-0.106	-1.592**	-0.780*	-0.658**	-1.024***
	(0.108)	(0.119)	(0.089)	(0.095)	(0.769)	(0.446)	(0.316)	(0.381)
Interaction between manager		0.711***		0.183		0.177		1.651***
change and private firms		(0.214)		(0.199)		(0.941)		(0.424)
Private firm, yes=1	-0.197*	-0.321***			-0.19	-0.225		
	(0.107)	(0.116)			(0.126)	(0.194)		
Log(net asset)	-0.0312*	-0.0320*	0.0325	0.0399	-0.0245	-0.0285	0.0569	0.116*
	(0.017)	(0.017)	(0.089)	(0.087)	(0.026)	(0.021)	(0.071)	(0.061)
Has the manager been a	-0.063	-0.057	0.105	0.0874	-0.133	-0.0918	-0.0746	-0.173
government official? yes=1	(0.112)	(0.109)	(0.103)	(0.101)	(0.140)	(0.112)	(0.146)	(0.177)
Has the manager been a party	-0.106	-0.0864	-0.337*	-0.311	-0.0172	-0.0625	-0.114	0.0454
leader? yes=1	(0.095)	(0.093)	(0.182)	(0.188)	(0.146)	(0.116)	(0.185)	(0.226)
Age of the manager	0.00386	0.00433	0.00353	0.00378	0.00755	0.00558	0.00386	0.00594
	(0.007)	(0.006)	(0.011)	(0.011)	(0.009)	(0.008)	(0.010)	(0.011)
Is the manager a college	0.448***	0.437***	-0.0682	-0.0595	0.580***	0.503***	-0.048	0.0239
graduate? yes=1	(0.093)	(0.093)	(0.317)	(0.319)	(0.153)	(0.119)	(0.228)	(0.247)
Dummy for firms and time	No	no	Yes	Yes	no	No	yes	Yes
Instrument relevance test(p value)					9.6 (0.14)	15.2(0.17)	10.9(0.09)	26.1(0.01)
Weak instrument test					1.57	1.25	0.95	1.09
Sargan over id test (p value)					3.1(0.69)	13.2(0.21)	7.6(0.18)	6.4(0.78)
Observations	260	260	260	260	260	260	260	260
R-squared	0.087	0.12	0.846	0.847	0.075	0.042	0.791	0.758

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

6 A matching approach to deal with possible endogeneity

The interpretation of the regression results as a causal relationship builds on the claim that since an individual firm does not have any influence on a change of bureau leader, the information about the bureau provides strong explanatory power for manager change. As shown in the last section, we find that the 2SLS estimator suffers from a "weak instruments" problem. Therefore, we use a matching approach to evaluate the causal impact of manager change on firm productivity as a comparison or robustness check on the regression analysis. The propensity score matching estimation method is becoming an increasingly popular means to evaluate labor market intervention program impacts based on observational data, and is considered to be quite reliable (Dehajia and Wahba,1999 and 2002).

6.1 The approach and estimation strategy

Let y_{1i} and y_{0i} denote firm productivity if there is and is not a change of manager in firm *i*, respectively. The parameter of interest is to estimate the average treatment effect on the treated subjects, i.e, the impact of manager turnover on the firm with a change:

$$ATT = E(y_{1i} - y_{0i} \mid X_i, d_i = 1)\,. \qquad (3)$$

The econometric issue here is that we can not observe $E(y_{0i} \mid X_i, d_i = 1)$, i.e, the counterfactual firm productivity for firm *i* with a change of manager if there had been no change, and we therefore have to construct a proper estimator.

Suppose we can find a set of variables denoted X_i, such that $(y_{1i}, y_{0i}) \perp d_i \mid X_i$, i.e., (y_{1i}, y_{0i}) and d_i are independent conditional on X_i. Then according to Rosenbaum and Rubin(1983), we have:

$$E(y_{1i} - y_{0i} \mid X_i, d_i = 1) = E(y_{1i} - y_{0i} \mid P(X_i))\,, \qquad (4)$$

where $P(X_i)$ is the propensity score, or expected probability, of incurring a change of manager, $P(d_i = 1)$.

Using the sample, the consistent sample estimation of (4) can be expressed as:

$$\widehat{ATT} = \sum_{i \in M_1} (y_i - \sum\nolimits_{j \in M_0} w(p_i, p_j) y_j)\,, \qquad (5)$$

where M_1 and M_0 are the groups of firms that have had and have not had a change of manager respectively, p_i is the estimated propensity score for firm *i* and $w(p_i, p_j)$ is the weight.

We first run a probit regression of manager turnover on the same set of variables as in Table 2 for the whole sample,[7] and then calculate the propensity score based on the estimated coefficients. A kernel method is used to calculate the weight for the control group. This weight is smaller the farther this group's propensity score is from that of the treatment group. The weight function y_j for a firm j in the control group for the treated firm i is expressed as:

$$w(p_i, p_j) = \frac{K[(p_i - p_j)/h]}{\sum_{k \in M_0} K[(p_i - p_k)/h]}, \qquad (6)$$

where $K(p)$ is the Gaussian normal function and h is the bandwidth parameter.

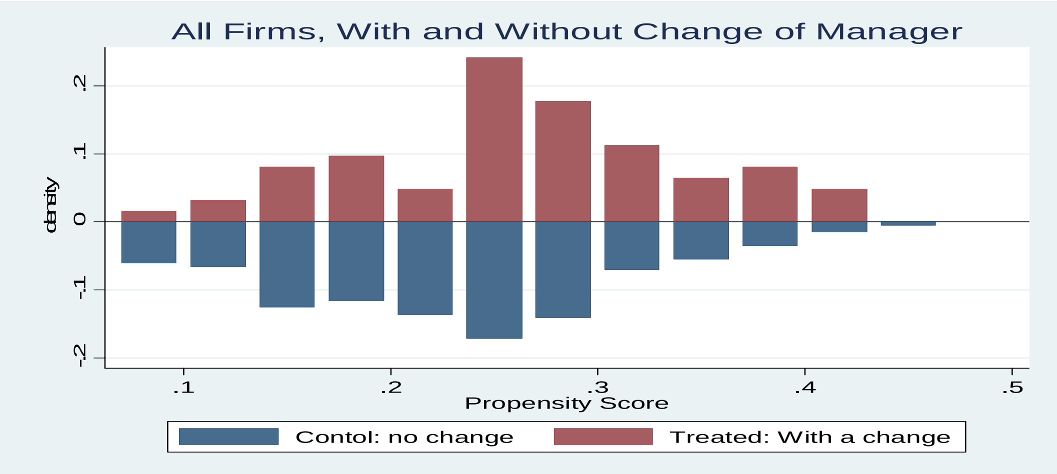
6.2 Sensitivity and balancing test

The propensity score matching method provides a reliable and robust estimator for the effect of manager change if, conditional on the propensity score, the potential outcomes y_{1i} and y_{0i} are independent of the incidence of turnover. Under the assumption of independence conditional on observables, the variables in estimating the turnover should be balanced between the treatment and control groups. Lack of balance points to a possible misspecification of the propensity score estimation. Hence, as emphasized by Rosenbaum and Rubin (1983) and Dehejia and Wahba (2002), it is important to verify that this balancing condition is satisfied by the data. We perform a number of balancing tests suggested in recent literature (Dehejia, 2005; Smith and Todd, 2005).

To give an intuitive investigation of the propensity score, we stratify the estimated propensity score within a stratum for treated and comparison units and the distribution of them are plotted in Figure 1. As can be observed, except in the strata with the lowest and

[7] We also calculate the propensity score based on the separate estimated coefficients on the two classified subsamples, i.e., the private and state-owned firms, and use the propensity score to inference the counterfactual based on the same procedure as for the whole sample, but the conclusion doesn't change.

highest scores, where the figure shows that the treatment and the control groups do not have common support, the scores for the treated and the control groups are quite close and without significant difference.



The first balancing test examines the standardized bias for all variables used in the propensity score estimation. The standardized bias for a variable is defined as the difference in mean score between the firms with change of manager and the matched firms scaled by the standard. The smaller the difference, the more balanced the treatment and comparison groups will be in terms of the variable under consideration. We calculate the t-statistics between the treatment and matched comparison and perform a test of the null

Table 7. Balancing test across matching variables from kernel matching

	Mean			%reduct	t-test	
Variable	Treated	Control	%bias	|bias|	t	(p>|t|)
Log(net asset)	6.60	6.56	1.9	51.7	0.1	(0.92)
Private firm	0.35	0.36	-1.7	29.2	-0.09	(0.93)
Has the manager been an official?	0.69	0.69	0.5	91.6	0.03	(0.98)
Has the manager been a party leader ?	0.23	0.22	2.1	-494.2	0.12	(0.91)
Age	38.92	38.57	5.5	74.5	0.3	(0.76)
College	0.31	0.30	1.9	89.4	0.1	(0.92)
Director and party leader?	0.35	0.38	-4.3	23.4	-0.23	(0.82)
Change of director?	0.35	0.38	-4.6	73.3	-0.26	(0.80)
Tenure of director	3.45	3.48	-1.4	84.2	-0.08	(0.94)
Change of party leader?	0.50	0.51	-2.7	75.6	-0.15	(0.88)
Tenure of party leader	2.98	3.06	-3.5	81.2	-0.2	(0.85)

hypothesis of no significant differences. The results are presented in Table 7. As can be observed, the bias reduction in the propensity score following matching is substantial, and the difference between the two groups become small. The formal t-test accepts the null hypothesis that there is no difference in the propensity score for each individual variable, suggesting that the propensity score for each individual variable is balanced across the sample.

The balancing test above calculates the cross-sample difference in each variable in the probit model separately. It might be the case that those differences can be jointly significant. To rule out this misspecification, we divide the propensity score into quarters and report two statistics: Hotelling's T-squared statistic to test the equality of the mean score in each interval, and the Kolmogorov-Smirnov statistic to test the equality of the distribution of scores. The results are presented in Table 8. Each test rejects its respective null hypothesis, i.e., no difference in propensity score mean and no difference in distribution of the propensity score in each interval. Both tests support our assumption that the propensity score is balanced between treatment and control groups.

Table 8. Balancing test over different quantiles of the propensity score

	Hotelling test		Kol-Smirnov test	
quarter	T-sq statistics	p-value	KS statistics	p-value
First	1.05	0.31	0.27	0.64
Second	1.91	0.17	0.29	0.35
Third	0.42	0.52	0.29	0.22
Fourth	0.17	0.68	0.13	0.96

6.3 The matching result

The comparison and treatment groups of firms are comparable under the condition that the propensity scores are balanced. Table 9 presents the matching estimates according to equation (6) with bandwidth 0.06. The difference between the treated group and the control group can be interpreted as the causal impact of manager change on firm productivity, and the figures in the table can be explained as percentage changes in firm productivity. The top half of the table reports the estimate without imposing common support. Since using the observation without common support in either the control or the treatment group would cause the estimated impact to be biased (Heckman et al., 1997), we impose common support restrictions, where 12 firms (less than 5% of the total number) are dropped, to calculate the treatment effect again. The results of this are reported in the bottom half of Table 9. Our explanation focuses mainly on the results with common support.

Table 9. The matching estimates

Sample	Change	No change	Difference	St. Er.
No common support				
All	-0.844	-0.811	-0.033	0.103
Private	-0.734	-1.017	0.282	0.192
State	-0.905	-0.664	-0.241	0.119**
Common support				
All	-0.891	-0.808	-0.083	0.113
Private	-0.648	-1.004	0.356	0.207*
State	-0.991	-0.663	-0.328	0.131**

The impact of manager turnover on firm productivity depends largely on the analyzed sample. If all firms are pooled together, we do find firm productivity decreases following manager change. However, the effect is not significant. Once we classify the whole sample into two subgroups and compare the difference in firm productivity between the treated group and the control group, the estimates reveal the different effects of manager turnover on firm productivity between state-owned and private firms. Firm productivity increases significantly by 36% after the private owner appoints a new manager. On the contrary, if a party leader puts his/her favorite candidate in a managerial position, then the productivity of that state-owned firm is expected to decrease significantly by 33%.

7. Conclusion and discussion

This paper provides an empirical analysis of how the type of ownership, i.e., state-owned vs. private, affects the impact of manager turnover on firm productivity in China. In order to give a plausible causal explanation, in the regression approach we use information about the leadership in the bureaus as instruments to provide excluded exogenous variation to explain the change of manager in the firm. We also use the propensity score matching approach to identify the causal effect and examine the impact of manager change on firm productivity.

Our results suggest that there is substantial heterogeneity in the effect of manager turnover on productivity, and that this heterogeneity depends on the ownership status of a firm. The matching results from the pooled sample suggest that there is no significant productivity improvement following manager change. However, both regression and matching results give strong evidence that an increase in firm performance following manager turnover only occurs in private firms, while in state-owned firms we actually observe a detrimental effect. These results are driven by the different mechanisms of selecting and screening manager candidates. The chance that a state-owned firm changes its manager is significantly driven by a change of party leader in the bureau, suggesting that political considerations dominate the economic incentives, while private owners instead stress the human capital of the selected candidate. Since more educated candidates may be assumed to have more knowledge and younger candidates should be better able to adapt to the ever changing market environment, these two groups of candidates should have a significantly higher probability of being appointed as new managers.

Even though the analysis only focuses on China's timber industry, which limits our ability to generalize the conclusion to other industries, our findings still provide some insights concerning the importance of the way in which managers should be selected in order for firms to perform better. Manager change in state-owned firms can lead to increased firm productivity if the incentives to politicians are well-structured (Groves et al., 1995), but also to deteriorated firm performance if the aim of politicians is to seize control and extract rent. The privatization of firms alone does not necessarily imply an improvement in firm performance if current incapable managers can't be displaced (Barberis et al., 1996). However, by selecting and appointing managers with more competence, private owners can significantly improve performance. In order to understand the myths of success and failure of state-owned enterprise, the regulation, process, and criteria of candidate screening, and how these are enforced, are crucial aspects for further studies to address.

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