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The value of technology improvements in games with externalities: A fresh look at offsetting behavior

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ABSTRACT

We model the effect of safety technology improvements in a symmetric game in which each player's payoff depends on his own precaution and the other players' average precaution. We derive conditions under which an improved technology increases or decreases players' equilibrium utilities.
For mandatory safety technologies, the direction of the welfare effect depends on whether the externality between players is positive or negative, and on whether the technology improvement is a complement or substitute for individual precaution. For safety technologies that individuals can choose whether or not to purchase, individuals expend too much on reducing the loss size but may spend either too much or too little on features that reduce an individual's loss probability.

1. Introduction

The seminal contribution of Peltzman (1975) addresses the possibility that legally mandated use of automobile safety devices such as seat belts may lead to offsetting effects in the form of reduced care in driving habits. Such an individually rational response to the lowered cost or severity of accidents can partially or even entirely offset the anticipated reductions in the overall accident and/or fatality rate. This type of phenomenon is known as offsetting behavior.

Following Peltzman (1975), numerous studies analyze whether adoption of new safety technologies leads to offsetting behavior in the context of road safety (e.g., Winston, Maheshri, Mannering (2006) and Harless and Hoffer (2003)) as well as many other areas such as workplace safety (e.g., Lanoie (1992), sports (e.g., Potter (2011) on Formula 1 racing and McCannon (2011) on basketball), food safety (e.g., Miljkovic et al. (2009)), and health (e.g., Geoffard and Philipson (1996), Fletcher et al. (2010), Philipson (2000)).

In most real world applications of offsetting behavior, an important externality is present. A driver's accident probability, for example, depends crucially on how carefully others drive, in addition to the individual's own level of care and use of technology. The likelihood of incurring an infectious disease also depends on how careful others are (or have been) in avoiding the disease since this affects the percentage of the population that is infected. However, in many empirical analyses of offsetting behavior, the externality is typically either not explicitly modeled or even recognized. In others, the externality is described in a way that suits only the particular application under study.

In order to evaluate the welfare consequences of safety technology innovations when externalities are present, we need to understand not only how each individual's equilibrium choice of precaution reacts to the technological innovation, but also how this reaction is affected by the choices made by other players who have access to the same technological innovation.

This is the purpose of this paper. In our model, we assume that the probability of an individual experiencing a loss depends both on the individual's own level of precaution and, either positively or negatively, on the average precaution level of other agents.[1] An improved safety technology generally affects agents' equilibrium levels of care — either positively or negatively, depending on whether the innovation is a substitute or complement to precaution. The welfare effect is then the sum of the direct effect of the innovation, which would arise if an individual was the only one with access to the new technology, and the indirect

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[1] By an individual's level of precaution, we mean things such as attentiveness to road hazards while driving or use of safe sex practices. These are assumed unobservable to the social planner, and create externalities for others. Our paper is essentially an application of the phenomenon of *moral hazard in teams*. See Holmstrom (1982) for a general characterization of this problem and Cooper and Ross (1985), Lanoie (1992), Pedersen (2003), and Risa (1992, 1995) for specific applications.

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effect that works through changing other individuals- equilibrium precaution levels.

Per se, offsetting behavior does not pose a normative problem. In fact, in the absence of an externality effect, offsetting behavior actually contributes positively to welfare and simply reflects people re-optimizing due to the change in the safety environment. However, if everyone's loss probability is decreasing in other agents' equilibrium level of care, and if the new safety technology reduces the equilibrium level of care, then this effect is detrimental and needs to be accounted for in welfare comparisons. Indeed, technological improvements – whether their implementation is mandatory or voluntary – can reduce welfare if there is a positive (negative) externality effect and technical progress reduces (increases) equilibrium precaution.

We also develop two specialized versions of our model that help us to relate our approach to the existing literature. The first one of these is what we call a *loss mitigation technology* (LMT). It reduces the size, but not the probability, of a loss (think of seat belts or airbags). The second one, a *probability reduction technology* (PRT), reduces the probability of a loss, but not its size if it occurs (think of rumble strips on highways that warn a driver if he is about to leave his lane and sometimes allow for corrective actions).

We show that an improved LMT always leads to a reduction in the equilibrium level of precaution, consistent with Peltzman's hypothesis. If the externality from precaution is a positive one, as is plausible in the context of traffic safety, then the offsetting behavior has negative welfare consequences. However, in applications where the externality is a negative one, such as in certain types of crime deterrence, then the offsetting behavior actually has a positive welfare effect.

Whether an improved PRT leads to offsetting behavior in the traditional sense (i.e., a reduction in individuals' precaution) or the opposite depends on how the technology affects the marginal effectiveness of precaution and can go in either direction. For example, an improved braking system may increase the marginal benefit of attentiveness for avoiding accidents which could not otherwise be avoided,[2] while rumble strips may reduce the individual's perceived value of more frequent rests while driving. The welfare effect of a PRT then depends on both the direction of the effect on precaution and on whether the externality of precaution is positive or negative.

In Section 2, we develop our unified model for analyzing the positive and normative implications of offsetting behavior. We consider both cases in which the level of safety technology is exogenously imposed or endogenously chosen. In Section 3, we address the issue of valuing discrete, exogenous changes in safety technology and compare it to the naive or engineering approach that ignores behavioral effects. In the context of specific models that reflect LMTs and PRTs, we analyze when the naive approach overestimates or underestimates the true value. Section 4 provides a discussion of our results, including how our model relates to the existing literature. Section 5 concludes and offers suggestions for further research on this topic.

2. The unified model

2.1. Setup

We now present a model that unifies many existing models of offsetting behavior. Our model is first developed for the case of exogenous (mandatory) safety technologies, such as improved crash barriers on roadways or mandatory seat belt legislation. Later, we extend the model to allow for safety technologies that are chosen and paid for by individuals, such as airbag systems.

Consider a game with a continuum of players. All players are symmetric and receive payoffs that depend on the player's own choice of activity level x, which we refer to as "precaution," the average level $\bar{x}$ chosen by the other players, and technology θ. Each player's problem therefore is

$$\max_x f(x, \bar{x}, \theta). \tag{1}$$

We assume that f is strictly concave in the first argument ($f_{11} < 0$),[3] and increasing in its third argument ($f_3 > 0$): holding all players' actions fixed, a player's payoff increases as technology improves. As to the second argument, we allow for both positive ($f_2 > 0$) and negative ($f_2 < 0$) externalities from other players' actions.

In many activities, such as automobile driving, the externality is plausibly positive, i.e., any individual's probability of incurring a bad outcome is reduced by others taking more care. However, a negative externality with respect to precaution is also a possibility. For example, an individual's own probability of being burglarized may increase (reducing utility) as a result of others increasing their level of observable precaution. This effect may follow when others make their houses less attractive to burglars (e.g., by ensuring house lights are automatically turned on and off while away), with the result that burglars shift their attention to seemingly more vulnerable properties.[4]

Note that our model is set up with uninsurable losses in mind; for example, losses could reflect lost quality adjusted life years. Furthermore, our model implicitly assumes that the individual choice of precaution cannot directly be controlled by the social planner (because this is either impossible or very costly to effect), and the level of indirect measures such as experience rating by insurers, liability through negligence rules enforced through the legal system, or imperfect monitoring such as police enforcement of traffic regulations[5] is constant with respect to the safety technology improvement. Our reason is that we wish to analyze the effect of technological change on the externality created by moral hazard and on social welfare in isolation of other issues. We recognize that, even without this direct type of externality, individual moral hazard can create a negative externality effect through an insurance pool (e.g., see Gossner and Picard, 2005). We leave aside these sorts of issues in this article, although they are all well worth exploring in future work.

2.2. Analysis

Since f is strictly concave in its first argument, the first order condition

$$\frac{\partial f}{\partial x} \equiv f_1 = 0 \tag{2}$$

is necessary and sufficient for a global optimum. An important property of the equilibrium is stability for constant technology, i.e., whether, when the other players' average action increases by 1, the individually optimal action increases by less than 1. Applying the implicit function theorem to (2) to calculate the slope of the reaction function, we assume that

$$\frac{dx}{d\bar{x}} = -\frac{f_{12}}{f_{11}} < 1 \tag{3}$$

in order to guarantee stability. Note that this includes three qualitatively different cases: in the first case, precaution by others reduces the marginal effect of individual precaution ($f_{12} < 0$ is sufficient for (3) to hold, given that $f_{11} < 0$). In the second case, $0 < f_{12} < -f_{11}$, precaution by others increases the marginal effect of individual precaution. Finally, if

[2] Of course, an improved braking system could also induce people to drive faster or less carefully.

[3] Henceforth, we will denote partial derivatives by subscripts. For example, $f_{11} \equiv \partial f^2/\partial x^2$.

[4] Whether a potential victim's precaution creates a positive or negative externality depends on whether the action is observable or unobservable to perpetrators of crime. See Ayres and Levitt (1998) and Shavell (1991).

[5] See, for example, Boyer and Dionne (1987) for an exploration of some of these measures.