PRODUCERS AND PREDATORS

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ABSTRACT

This paper explores a series of general-equilibrium models in which people can choose to be either producers or predators, and in which producers can allocate their resources either to production or to guarding their production against predators. The analysis shows how the ratio of predators to producers and the social cost of predation depend on the technology of predation, on the interpersonal distribution of productive resources, and in a fundamental way on whether the decision to allocate resources to guarding against predators is made individually or collectively.

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> In the time of Jesus, his fellow villagers in Nazareth made their living by growing grapes, olives and grain on terraces cut into the limestone hills. At harvest time, all 300 villagers - Jesus likely included - would stomp grapes to extract juice, and *huddle in watchtowers at night to guard their produce against thieves.* These images emerge from the excavation of the only pristine farmland left in the center of Nazareth...(Karen Laub, Associated Press dispatch, December 23, 1997, italics added)

Traditionally, general-equilibrium analysis has taken property rights as given and has been concerned with the allocation of resources among productive activities and the distribution of the resulting product through markets. But, history tells us that this formulation of the economic problem is incomplete because it assumes that ownership claims to productive inputs and outputs are perfectly secure, and it neglects the allocation of scarce resources to appropriative activities. In all, or almost all, societies, both past and present, some people eschew productive activities and allocate their time and effort instead to predatory activities like theft and robbery. In addition, the threat of predation causes producers, like the ancient villagers of Nazareth, to allocate scarce resources to guarding against predators. The wasted resources of predators plus the resources allocated by producers to guarding against predators comprise the social cost of predation.

Why are some people productive, whereas other people are predators, who produce nothing, but live by appropriating the product of the producers? This paper explores a series of four general-equilibrium models in which people can choose to be either producers or predators, and in which producers can allocate their resources either to production or to guarding what they produce.[1] These models assume that each person chooses to be a producer or a predator according to whether predation or production would yield him or her

[1]This abstract analysis assumes that all activities can be classified either as being predatory, or as being directly productive, or as being a way to guard against predators. In fact, although some activities, such as burglary and robbery, are unambiguously predatory, and some activities, such as college teaching, are

more consumption.[2]

A first pair of models assumes that all people have the same productive opportunities. This basic framework shows how the ratio of predators to producers as well as the social cost of predation depend on the technology of predation. A second pair of models extends this basic framework by assuming that some people are well endowed with productive resources and other people are poorly endowed with productive resources. In this extended framework we see how the interpersonal distribution of productive resources can affect both the ratio of predators to producers as well as the social cost of predation.

Guarding against predators includes all actions that are costly but have the effect of decreasing the ability of predators to appropriate the product of producers. Examples of ways of guarding against predators include the locating of production in inconvenient but secure places, the production of things that are harder for predators to appropriate, the installation of locks, the building of walls, the hiring of private security guards, and the organizing of a police force. For simplicity, the models in the present paper focus only the

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unambiguously productive, and some activities, such as installing locks, are unambiguously ways to guard against predators, there are activities, such as litigating, that are not easily classified. I leave the reader free to classify specific activities according to his or her own inclination. But, I point out that predation is not synonymous with crime. Although many predatory activities, like burglary and robbery, are criminal, many criminal activities, like illegal gambling and drug dealing, are productive and not predatory.

In a brief and long neglected contribution Trygve Haavelmo (1954, pages 91-98) provided a canonical general-equilibrium model of the allocation of resources among productive and appropriative activities. Over the years a number of authors have reinvented Haavelmo's formalization of this problem and have extended the analysis in a variety of ways. For example, Dan Usher (1987) developed a pioneering general-equilibrium model in which people decide whether to be producers or predators and in which producers also decide how much time and effort to put into guarding against predators.

[2]In Grossman and Kim (1998b), we study an alternative model in which only some people, whom we define to be amoral, are potential predators. The other people, whom we define to be moral, always choose to be producers, no matter how lucrative predation is relative to production. In contrast, the models analysed in the present paper implicitly assume that everybody is amoral.

total amount of resources allocated to guarding, abstracting from different ways of guarding.[3]

A decision to allocate resources to guarding against predators can be made either individually — that is, by single producers or by small subsets of producers — or collectively — that is, by a coordinated decision of all of the producers. Importantly, an individual producer or small subset of producers in choosing the amount of guarding takes the choices of other people to be predators or producers as given. In contrast, a collective choice of the amount of guarding can take into account the deterrent effect of guarding on the fraction of people who choose to be predators. The possibility of deterrence becomes relevant if producers can enforce their collective choice of the amount of guarding and can prevent individual producers from free-riding on the efforts of others to guard against predation. The collective choice of the amount of guarding also must be irreversible.[4]

Within each pair of models the paper considers both the case in which producers (or small subsets of producers) individually choose the amount of resources to allocate to guarding

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[3]Although the models do not explicitly consider the apprehension and punishment of predators, they could be extended to allow for apprehension and punishment. The apprehension and punishment of predators would not directly decrease the ability of predators to appropriate the product of producers, but apprehension and punishment by decreasing the expected utility of predators would make the choice to be a predator less attractive.

[4]To be more concrete, we can think of government as being the agent to whom producers assign the task of enforcing a collective choice of the amount of guarding, with taxation being the means of enforcement. In this context inability to enforce an irreversible collective choice of the amount of guarding reflects limited ability either to collect taxes or to allocate them for this purpose. Casual observation suggests that Western European countries and some East Asian countries provide examples of collective choice of the amount of guarding against predators, whereas other countries, mainly in South America, Africa, and Asia, and, perhaps, some places in the United States, provide examples in which at the margin producers individually choose the amount of guarding. This paper does not attempt to explain differences among countries in the ability to enforce collective choices. The work of William Easterly and Ross Levine (1997) and Alberto Alesina, Reza Baqir, and Easterly (1997) suggests that difficulties in providing public goods are attributable, at least in part, to political polarization caused by ethnic diversity.

and the case in which producers collectively choose the amount of guarding. The analysis of these two cases shows how the ratio of predators to producers as well as the social cost of predation depend in a fundamental way on whether the decision to allocate resources to guarding against predators is made individually or collectively.

1. BASIC ANALYTICAL FRAMEWORK

Assume initially that each person has an identical endowment of Ω units of resources. Given this endowment, each person has to choose whether to be a predator or a producer. Each person makes this choice individually, taking as given his or her potential consumption as a producer or as a predator. Let r denote the nonnegative fraction of people who choose to be predators and let $R \equiv \frac{r}{1-r}$ denote the ratio of predators to producers.[5]

If a person chooses to be a producer, then he or she has to decide how to allocate his or her resources between production of consumables and guarding against predators. As discussed above, this choice can be made either individually or collectively. Let G denote the ratio of the resources that each producer allocates to guarding against predators to the resources that he or she allocates to the production.

To simplify the analysis of the choice between being a predator and a producer, assume that a unit of resources can produce one unit of consumables. The number of units of consumables that a producer actually produces equals the product of his or her resources and the fraction of his or her resources that he or she allocates to production. Thus, a producer produces $\frac{\Omega}{1+G}$ units of consumables.

[5]For simplicity, the analysis assumes that people must specialize in either production or predation. If people were able to divide their time between production and predation, then we would have to analyse the fraction of their time that they allocate to predation. Further, to focus on the effects of predation, the analysis assumes that individual productive activities are independent and abstracts from trade in either productive inputs or consumables.

A producer appropriates the nonnegative fraction p of the consumables that he or she produces, and predators appropriate the nonnegative fraction $1 - p$. Assume that p depends negatively on the ratio of predators to producers, R, and positively on the ratio of resources allocated to guarding against predators to resources allocated to the production of consumables, G. Specifically,

$$p = \frac{1}{1 + \theta R/G}, \quad \theta \geq 0. \tag{1}$$

In equation (1), the nonnegative parameter θ, determines the effectiveness of predators in appropriating consumables for given values of R and G. The larger is θ the better is the technology of predation.[6]

Let C denote the consumption of a producer. After allowing for the fraction of resources allocated to guarding against predators and for the fraction of consumables appropriated by predators, we have

$$C = \frac{p\Omega}{1 + G}. \tag{2}$$

Let D denote the consumption of a predator.[7] Assuming that each predator obtains an

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[6]Equation (1) is a generic black box that conceals the process of predation, just as the standard generic production function conceals the process of production. For example, the relation between appropriative inputs and the appropriative outcome described by equation (1) could involve either the use of force or a peaceful settlement under the threat of force, although, strictly speaking, given complete information and the absence of stochastic factors, this analysis does not provide an internal explanation for costly violence. Dagobert Brito and Michael Intriligator (1985) address the question of whether appropriative conflict is resolved with or without violence and destruction, and emphasize the importance of incomplete information as a cause of violence. Also, equation (1) assumes, for simplicity, that for each producer p depends only on R and on his or her own amount of guarding. It would be easy to extend the model to allow p to depend either positively or negatively on the amount of resources that other producers allocate to guarding.

[7]For simplicity, the analysis assumes that predators only prey on producers. Predators do not prey on other predators. The analysis also abstracts from the possible destruction of consumables as the result of predation. The models in Grossman and Kim (1995, 1996) show how destruction is easily incorporated into the analysis.

equal share of the total amount of consumables that predators appropriate, we have

$$(3) \qquad D = \frac{1-p}{R}\frac{\Omega}{1+G}.$$

If R equals zero, then the analysis takes the value of D to be $\lim_{R\to 0} D$, which, using equation (1), equals $\frac{\theta}{G}\frac{\Omega}{1+G}$.

2. THE RATIO OF PREDATORS TO PRODUCERS

To decide whether to be a producer or a predator, each person compares the values of C and D. In taking as given his potential consumption as a producer or as a predator, each person in effect takes as given the choices by other people to be producers or predators, as reflected in R, and the choice by producers to allocate productive resources between production and guarding against predators, as reflected in G. By substituting equation (1) into equations (2) and (3), we can calculate that C is larger than, equal to, or smaller than D as G is larger than, equal to, or smaller than θ. Thus, in this basic framework the choices to be a producer or a predator are such that

$$(4) \qquad R = \begin{cases} \infty & \text{for } G < \theta \\ x \in [0,\infty] & \text{for } G = \theta \\ 0 & \text{for } G > \theta. \end{cases}$$

Equation (4) says that, if G were smaller than θ, then every person would choose to be a predator, that, if G equals θ, then every person is indifferent between being a producer or a predator, and that, if G were larger than θ, then every person would choose to be a producer. In Figure 1 the L shaped locus represents equation (4).

Assume initially that producers or small subsets of producers individually choose the amount of resources to allocate to guarding. In this case each producer chooses G to maximize C, taking R as given. To analyse this choice problem we substitute equation

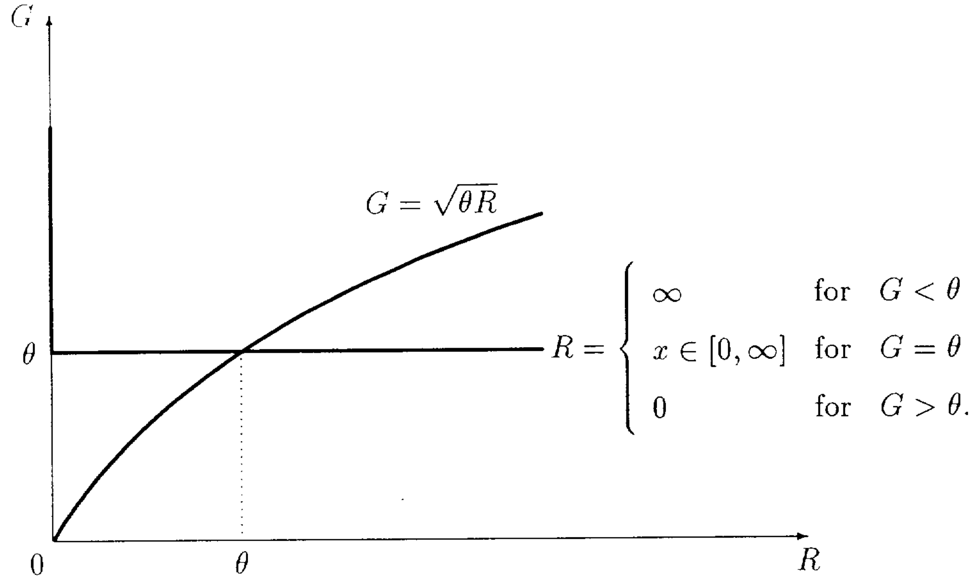

Figure 1: $R = \theta$

(1) into equation (2) and calculate the value of G that satisfies the condition $dC/dG = 0$. This condition implies that each producer chooses G such that

$$G = \sqrt{\theta R}. \tag{5}$$

In Figure 1 the concave locus represents equation (5).

Solving equations (4) and (5) simultaneously, we find that, with identical endowments and individual choice of the amount of guarding, the equilibrium configuration of choices, as shown Figure 1, is

$$R = G = \theta. \tag{6}$$

Equation (6) says that in equilibrium both the ratio of resources allocated to guarding against predators to resources allocated to the production of consumables and the ratio of predators to producers are equal to θ. A ratio of predators to producers equal to θ is just sufficient to cause producers to choose G equal to θ, which leaves each person indifferent between being a producer and a predator. Equation (6) implies that $r = g = \frac{\theta}{1+\theta}$.[8]

Substituting equation (6) into equation (1), we find that in equilibrium the fraction of consumables that producers appropriate is

$$p = \frac{1}{1+\theta}. \tag{7}$$

Substituting for p from equation (7) and for G from equation (6) into equations (2) and (3), we obtain

$$C = D = \frac{\Omega}{(1+\theta)^2}. \tag{8}$$

Equation (8) says that in equilibrium every person has the same consumption. More importantly, equation (8) reveals the social cost of predation. Specifically, if θ is positive,

[8]Although this model can determine the ratio of predators to producers, it cannot determine which people choose to be predators.

then consumption is less than the potential production of consumables, which is Ω. This shortfall of consumption results because the fraction $\frac{\theta}{1+\theta}$ of people choose to be predators and because producers allocate the fraction $\frac{\theta}{1+\theta}$ of their resources to guarding against predators. Equation (8) also implies that consumption is a decreasing function of θ. This result obtains because the more effective are predators in appropriating consumables the more people choose to be predators and the more resources producers allocate to guarding against predators.

3. COLLECTIVE CHOICE OF THE AMOUNT OF GUARDING

With individual choice of the amount of guarding each producer took the choices of other people to be producers or predators as given. This section considers the alternative of collective choice of the amount of guarding. An irreversible collective choice of G differs from an individual choice of G in that an irreversible collective choice takes into account both the effect of G on p for a given ratio of predators to producers and the effect of G on the choices of the people to be producers or predators.[9]

Substituting equation (1), which determines the effect of G on p for a given R, and equation (4), which determines the effect of G on R, into equation (2), we find that producers maximize C by collectively choosing

$$G = (1+\epsilon)\theta, \tag{9}$$

[9] Because the analysis assumes that for each producer p depends only on R and on his or her own amount of guarding, the potential gain from collective choice of the amount of guarding involves only the strategic advantage from taking into account the effect of G on R. If p also depended either positively or negatively on the amount of resources that other producers allocate to guarding, then a collective choice of the amount of guarding also could take these technological externalities into account. Another possible complication from which the analysis abstracts is that some ways of guarding that can only be chosen collectively could be more efficient than other ways of guarding.

where ϵ, a small positive number, is the smallest fraction by which G can be increased. From equation (4), given that all people have the same endowment, $(1+\epsilon)\theta$ is the minimum value of G that would result in an equilibrium in which R equals zero. Thus, equation (9) says that to maximize C producers collectively decide that each producer should allocate a fraction of his or her resources to guarding that is larger by a small amount than he or she would choose individually, just enough larger to deter all people from being predators. From equation (1), with R equal to zero p equals one.

Substituting $p = 1$ and $G = (1+\epsilon)\theta$ into equation (2), we obtain

$$C = \frac{\Omega}{1 + (1+\epsilon)\theta}. \tag{10}$$

Comparing equations (8) and (10), we see that, with a collective choice of the amount of guarding, although consumption is still less than potential consumption, consumption is larger than with individual choice of the amount of guarding. The social cost of predation is smaller because, by increasing G from θ to $(1+\epsilon)\theta$, the producers collectively are able to deter the fraction $\frac{\theta}{1+\theta}$ of the people from choosing to be predators, whose resources would be wasted.

Equation (10) also implies that with a collective choice of the amount of guarding consumption is still a decreasing function of θ. This result obtains because the more effective are predators in appropriating consumables the more resources must be allocated to guarding against predators in order to deter people from choosing to be predators.

4. WELL ENDOWED AND POORLY ENDOWED PEOPLE

This section extends the basic analytical framework by assuming that some people are well endowed with productive resources and other people are poorly endowed with productive resources. In this setup the interpersonal distribution of productive resources has two dimensions. One dimension is the ratio of poorly endowed people to well endowed people. The other dimension is the relative endowments of well endowed and poorly endowed people.

Assume that each poorly endowed person has an endowment of k units of productive resources, and that each well endowed person has an endowment of K units of productive resources, where $K > k \geq 0$. Also, assume that u, where $0 \leq u < 1$, is the fraction of people who are poorly endowed, and that $1 - u$ is the fraction of people who are well endowed. Let $U \equiv \frac{u}{1-u}$ denote the ratio of poorly endowed people to well endowed people. Given that Ω is still the average endowment, the interpersonal distribution of productive resources can reflect any combination of k, K, and u that satisfies

$$\Omega = (1-u)K + uk \equiv \frac{K + Uk}{1+U} \tag{11}$$

The analysis is the more interesting on the assumption that k is small relative to K and Ω.[10]

Let N denote the fraction of people who are well endowed and who choose to be producers, where $N \leq 1 - u$, let n denote the fraction of people who are poorly endowed and who choose to be producers, where $n \leq u$, and let r again denote the fraction of people, whether well endowed or poorly endowed, who choose to be predators. Thus, we have $N + n + r = 1$. Let $R \equiv \frac{r}{N+n}$ again denote the ratio of predators to producers.

Assume further that, although the consumption that a person can obtain from being a producer is an increasing function of his or her productive resources, the consumption that a person can obtain from being a predator does not depend on his or her productive resources. In other words, the analysis assumes that well endowed people and poorly endowed people are equally effective at predation. On this assumption the poorly endowed people have a comparative advantage as predators.[11] Also, given this assumption this model retains the

[10]The analysis in this paper takes the interpersonal distribution of productive resources as given. In Grossman and Kim (1997, 1998a) we explore the possibility that various redistributions of productive resources could result in increased consumption for either well endowed people, or poorly endowed people, or both.

[11]Although this assumption provides a useful simplification, the analysis could be generalized by allowing well endowed people to be more effective at predation than poorly endowed people, as long as a person's

specification in equation (1) according to which p depends on the ratio of predators to producers, but not on the identity of the predators.

Let C now denote the consumption of a well endowed producer, and let c denote the consumption of an poorly endowed producer. After allowing for the fraction of productive resources allocated to guarding against predators and for the fraction of consumables appropriated by predators, we have

$$C = \frac{pK}{1+G} \tag{12}$$

and

$$c = \frac{pk}{1+G}. \tag{13}$$

Let D again denote the consumption of a predator. Assuming again that each predator obtains an equal share of the total amount of consumables appropriated from the producers, we now have

$$D = \frac{1-p}{r} \frac{NK+nk}{1+G}. \tag{14}$$

If r and R equal zero, then the analysis again takes the value of D to be $\lim_{R \to 0} D$, which, using equation (1), again equals $\frac{\theta}{G}\frac{\Omega}{1+G}$.

To decide whether to be a producer or a predator, each well endowed person compares the values of C and D, and each poorly endowed person compares the values of c and D, again taking G and R as given. There are five possible relations among C, c, and D, and, substituting equation (1) into equations (12), (13), and (14), we find that that the choices of well endowed and poorly endowed people to be producers or predators, and the resulting value of R, depend on G in the following way:

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resource endowment has a larger effect on his or her ability to produce than on his or her effectiveness as a predator. With this generalization an appropriately weighted sum of the fraction of poorly endowed predators and the fraction of well endowed predators would replace r in equation (1).

1. $D > C > c$: If D were larger than both c and C, then every person would prefer to be a predator. Substituting equation (1) into equations (12), (13), and (14), we find that this case could occur if and only if G were smaller than θ. In this case, R would be infinite.

2. $D = C > c$: If D equals C but is larger than c, then poorly endowed people prefer to be predators, whereas well endowed people are indifferent between being producers or predators. This case would occur if and only if G equals θ. In this case, R can take any value larger than or equal to U.

3. $C > D > c$: If D is smaller than C but larger than c, then poorly endowed people prefer to be predators, whereas well endowed people prefer to be producers. This case would occur only if G is larger than θ, but smaller than $\theta K/k$. In this case, R is equal to U.

4. $C > D = c$: If D is smaller than C but equal to c, then poorly endowed people are indifferent between being producers or predators, whereas well endowed people prefer to be producers. This case would occur only if G is equal to or larger than $\theta\Omega/k$, but not larger than $\theta K/k$. In this case, the equality between D and c implies that R is equal to $\frac{G-\theta\Omega/k}{\theta(\frac{\Omega}{k}-1)}$. This implied value of R is equal to or smaller than U, but larger than or equal to zero.

5. $C > c > D$: If D were smaller than both c and C, then every person would prefer to be a producer. This case could occur only if G were larger than $\theta\Omega/k$. In this case, R would be zero.

Summarizing these results, the choices of well endowed and poorly endowed people to be producers or predators are such that

$$(15) \qquad R = \begin{cases} \infty & \text{if and only if} \quad G < \theta \\ x \in [U, \infty] & \text{if and only if} \quad G = \theta \\ U & \text{only if} \quad \theta < G < \theta K/k \\ \frac{G - \theta\Omega/k}{\theta(\frac{\Omega}{k} - 1)} & \text{only if} \quad \theta\Omega/k \le G \le \theta K/k \\ 0 & \text{only if} \quad G > \theta\Omega/k. \end{cases}$$

In Figures 2 and 3 the piecewise linear loci represent equation (15).

The analysis now returns to the assumption that producers (or small subsets of producers) individually choose the amount of resources to allocate to guarding. Each well endowed person who chooses to be a producer chooses G to maximize C, taking R as given, and each poorly endowed person who chooses to be a producer now chooses G to maximize c, taking R as given. For both well endowed people and poorly endowed people equation (5), $G = \sqrt{\theta R}$, gives the solution to this problem. In Figures 2 and 3 the smooth concave loci represent equation (5).

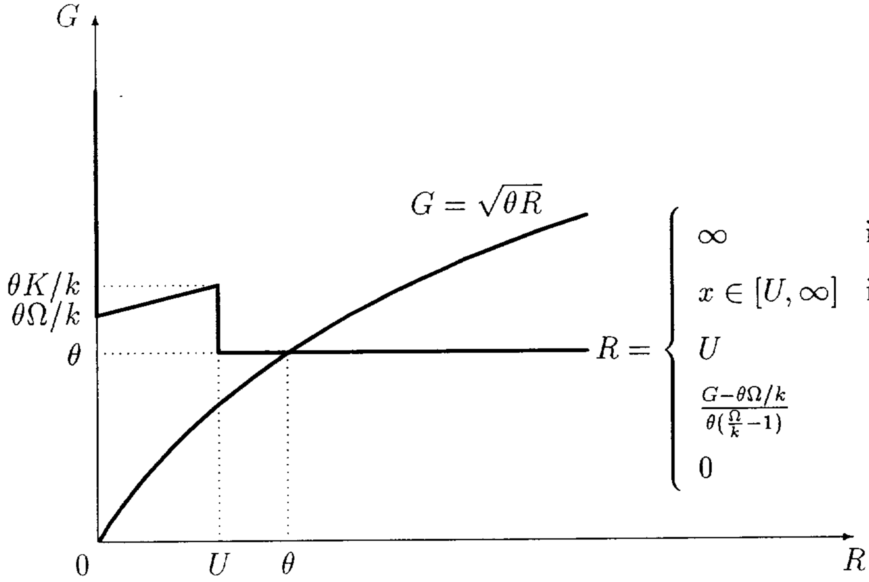
Solving equations (5) and (15) for R and G, and assuming that the ratio k/Ω is small relative to θ, we find that in equilibrium

$$(16) \qquad R = max\{\theta, U\}$$

and

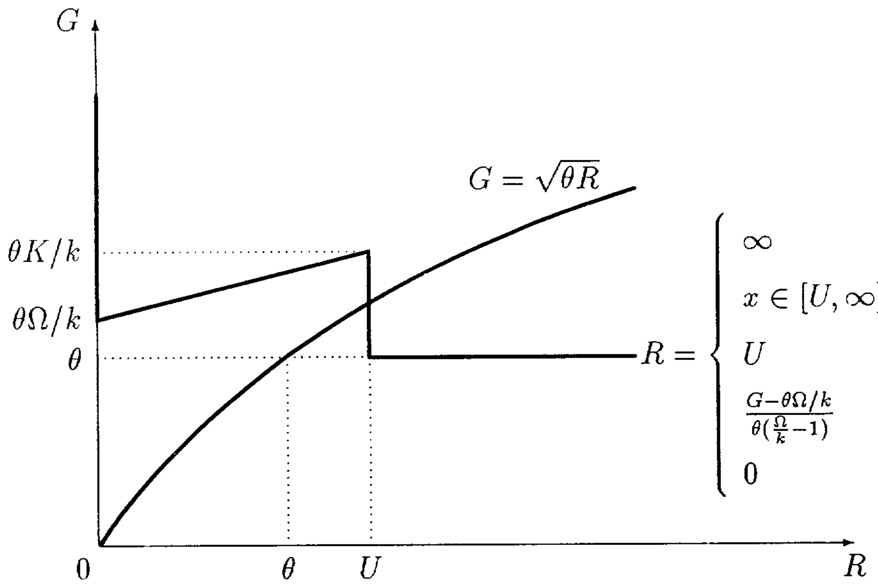
$$(17) \qquad G = max\{\theta, \sqrt{\theta U}\}$$

Equation (16) shows how the equilibrium ratio of predators to producers depends both on the technology of predation and on the interpersonal distribution of productive resources. If U is smaller than or equal to θ, then in equilibrium poorly endowed people prefer to be predators, well endowed people are indifferent between being producers and being predators, and R equals θ. In this case the existence of a small fraction of poorly endowed people



$$R = \begin{cases} \infty & \text{if and only if} \quad G < \theta \\ x \in [U, \infty] & \text{if and only if} \quad G = \theta \\ U & \text{only if} \quad \theta < G < \theta K/k \\ \frac{G - \theta\Omega/k}{\theta(\frac{\Omega}{k} - 1)} & \text{only if} \quad \theta\Omega/k \le G \le \theta K/k \\ 0 & \text{only if} \quad G > \theta\Omega/k. \end{cases}$$

Figure 2: $R = \theta \geq U$



$$R = \begin{cases} \infty & \text{if and only if} \quad G < \theta \\ x \in [U, \infty] & \text{if and only if} \quad G = \theta \\ U & \text{only if} \quad \theta < G < \theta K/k \\ \frac{G - \theta\Omega/k}{\theta(\frac{\Omega}{k} - 1)} & \text{only if} \quad \theta\Omega/k \le G \le \theta K/k \\ 0 & \text{only if} \quad G > \theta\Omega/k. \end{cases}$$

Figure 3: $R = U > \theta$

does not affect the equilibrium values of either R or G, which still depend only on the technology of predation. Alternatively, if U is larger than θ, then in equilibrium poorly endowed people prefer to be predators, well endowed people prefer to be producers, and R equals U. In this case the existence of a large enough fraction of poorly endowed people increases the equilibrium values of both R or G. Figure 2 illustrates the case of $R = \theta \geq U$, and Figure 3 illustrates the case of $R = U > \theta$.[12]

Equation (16) also reveals a weakly monotonic relation between U and the equilibrium value of R. If the fraction of poorly endowed people is so large that U is larger than the parameter θ, then in equilibrium R is larger than θ. But, if the fraction of poorly endowed people is so small that U is smaller than θ, then in equilibrium R would *not* be smaller than θ. Rather, if U were smaller than θ, then in equilibrium enough of the well endowed people would choose to be predators to make R equal θ.[13]

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[12]More generally, solving equations (5) and (15) for R would yield

$$R = \begin{cases} \theta & \text{for} \quad U \leq \theta \\ U & \text{for} \quad \theta < U \leq R_1 \\ R_1 & \text{for} \quad R_1 < U < R_2 \\ \{R_1, R_2, U\} & \text{for} \quad U \geq R_2, \end{cases}$$

where R_1 and R_2 are the values of R that satisfy both $R = \frac{G - \theta\Omega/k}{\theta(\frac{\Omega}{k} - 1)}$, from equation (15), and $G = \sqrt{\theta R}$, from equation (5). Such values of R would exist only if k/Ω were sufficiently large — specifically, only if k/Ω were at least as large as $\frac{2}{1+\sqrt{1+1/\theta}}$. Equation (16) assumes, in accord with the assumption that k is small relative to Ω, that R_1 and R_2 do not exist. Because both R_1 and R_2 would be larger than θ, the main qualitative implications of the model do not depend on whether or not R_1 and R_2 exist.

[13]To see the logic of these implications, recall that, if R were smaller than θ, then according to equation (5) the chosen value of G would be smaller than θ. But, if G were smaller than θ, then D would be larger than both c and C, and, as indicated by equation (15), every person would prefer to be a predator. Thus, regardless of the size of U, R smaller than θ would be a contradiction.

Also, recall that, if R were equal to θ, then according to equation (5) G would be equal to θ. But, if G were equal to θ, then D would be larger than c, and, as indicated by equation (15), R would be at least as large as U. Thus, if U is larger than θ, then R cannot equal θ. Conversely, given that R

Substituting equations (16) and (17) into equation (1), we find that in equilibrium the fraction of consumables that producers appropriate is

(18) $$p = min\{\frac{1}{1+\theta}, \frac{1}{1+\sqrt{\theta U}}\}$$

Comparing equation (18) with equation (7) we see that the existence of a small fraction of poorly endowed people does not affect the equilibrium value of p, whereas the existence of a large enough fraction of poorly endowed people reduces the equilibrium value of p.

Substituting for p from equation (18) and for G from equation (17) into equations (12), (13), and (14), we can calculate the consumption in equilibrium of well endowed people and poorly endowed people. Because well endowed people in equilibrium either prefer to be producers or are indifferent between being producers and being predators, the consumption of every well endowed person is given by

(19) $$C = \begin{cases} \dfrac{K}{(1+\theta)^2} & \text{for } U \leq \theta \\ \\ \dfrac{K}{(1+\sqrt{\theta U})^2} & \text{for } U > \theta. \end{cases}$$

Because poorly endowed endowed people in equilibrium either prefer to be predators or are indifferent between being predators or producers, the consumption of every poorly endowed endowed person is given by

(20) $$D = \begin{cases} \dfrac{K}{(1+\theta)^2} & \text{for } U \leq \theta \\ \\ \dfrac{K\sqrt{\theta/U}}{(1+\sqrt{\theta U})^2} & \text{for } U > \theta. \end{cases}$$

Equations (19) and (20) imply that, if U is larger than θ, then D is smaller than C, but that, if U is smaller than or equal to θ, then D is equal to C. Thus, the consumption of a poorly endowed person is less than or equal to the consumption of a well endowed person.

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cannot be smaller than θ, if U is larger than θ, then R is larger than θ.

More interestingly, from equations (19) and (20) we also can calculate average consumption to be

$$(21) \qquad (1-u)C + uD = \begin{cases} \dfrac{K}{(1+\theta)^2} & \text{for } U \leq \theta \\ \\ \dfrac{K}{(1+\sqrt{\theta U})(1+U)} & \text{for } U > \theta. \end{cases}$$

Comparing equation (21) with equation (8), and observing that, if U is positive, then K is larger than the average endowment, Ω, we see that the existence of poorly endowed people can result in larger average consumption. This result obtains either if U is positive but not larger than θ or if U is not too much larger than θ and k/Ω is sufficiently small.[14] Average consumption can be larger, and the social cost of predation can be smaller, because the existence of poorly endowed people concentrates the economy's productive resources in the hands of producers. With either all or, at least, some of the predators being poorly endowed people, predators waste a smaller fraction of the economy's productive resources than with everyone, both predators and producers, having the same endowment.

5. COLLECTIVE CHOICE OF THE AMOUNT OF GUARDING WITH WELL ENDOWED AND POORLY ENDOWED PEOPLE

This section returns to the assumption that producers make an irreversible collective choice to allocate resources to guarding against predators. Again, an irreversible collective choice of G differs from an individual choice of G in that an irreversible collective choice takes into account both the effect of G on p for a given ratio of predators to producers and the effect of G on the choices of the people to be producers or predators.

[14] More precisely, $(1-u)C+uD$ as given by equation (21) is larger than C and D as given by equation (8) either if $\theta > U > 0$ or if $U > \theta$ and $\frac{1+U}{U}[1 - \frac{1+\sqrt{\theta U}}{(1+\theta)^2}] > \frac{k}{\Omega}$.

Substituting equations (1) and (15) into equations (12) and (13), we find that, if k/K is small and U is not too large, then producers maximize both C and c by collectively choosing

$$G = max\{(1+\epsilon)\theta,\ \sqrt{\theta U}\}. \tag{22}$$

In equation (22) $G = \sqrt{\theta U}$ is the solution to the first-order conditions for an interior maximum, $dC/dg = dc/dg = 0$, given $R = U$. Thus, if with $G = \sqrt{\theta U}$ well endowed people would choose to be producers and poorly endowed people would choose to be predators, then $G = \sqrt{\theta U}$ is the amount of guarding that would maximize C. The alternative $G = (1+\epsilon)\theta$ is the minimum amount of guarding that would deter the well endowed people, but not the poorly endowed people, from choosing to be predators. Figure 4 illustrates the case in which the maximum is at $G = \sqrt{\theta U}$. Figure 5 illustrates the case in which the maximum is at $G = (1+\epsilon)\theta$.[15]

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[15] As Figures 4 and 5 show, both C and c have another local maximum at $G = (1+\epsilon)\theta K/k$. From equation (15), $(1+\epsilon)\theta K/k$ is the minimum value of G that would surely deter every person, whether well endowed or poorly endowed, from choosing to be a predator. The global maximum for both C and c would be at $G = (1+\epsilon)\theta K/k$ only if both k/K and U were large. The intuition for this result is that the smaller is k/K the larger is the amount of guarding that would be necessary to deter the poorly endowed people from choosing to be predators, whereas the smaller is U the smaller is the ratio of predators to producers and the resulting fraction of production appropriated by predators if the poorly endowed people are not deterred from choosing to be predators. More precisely, $G = (1+\epsilon)\theta K/k$ would be the unique local maximum if and only if k/K and U satisfied $k/K > (1+\epsilon)\sqrt{\theta/U}$. Further, whether or not $G = (1+\epsilon)\theta K/k$ is a unique local maximum, the global maximum would be at $G = (1+\epsilon)\theta K/k$ if and only if k/K and U satisfied

$$\frac{k}{K} > \begin{cases} \dfrac{1+\epsilon}{1+\epsilon+U[1+1/(1+\epsilon)\theta]} & \text{for } \sqrt{\theta U} \le (1+\epsilon)\theta \\ \\ \dfrac{1+\epsilon}{U+2\sqrt{U/\theta}} & \text{for } \sqrt{\theta U} > (1+\epsilon)\theta. \end{cases}$$

If the global maximum were at $G = (1+\epsilon)\theta K/k$, then the associated value of C would be $\frac{K}{1+(1+\epsilon)\theta K/k}$.

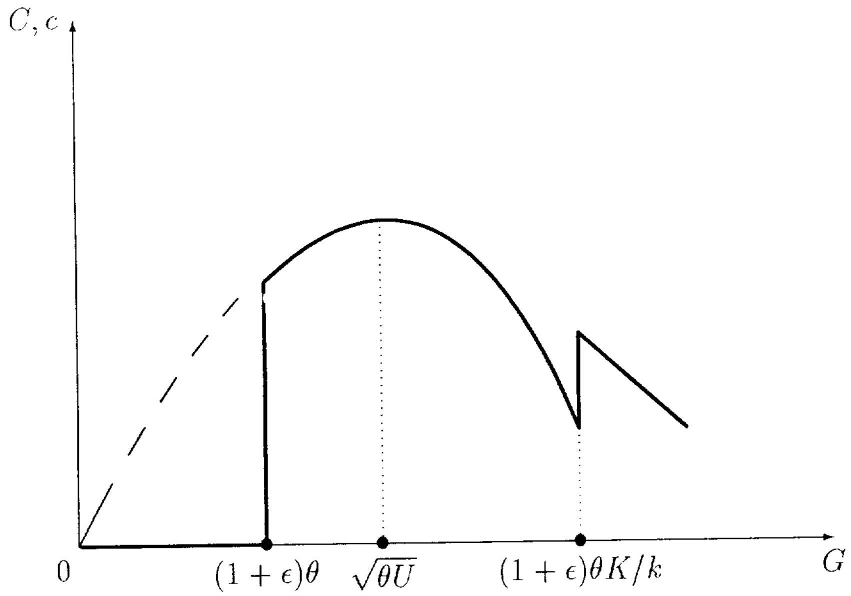

Figure 4: $\sqrt{\theta U} > (1+\epsilon)\theta$

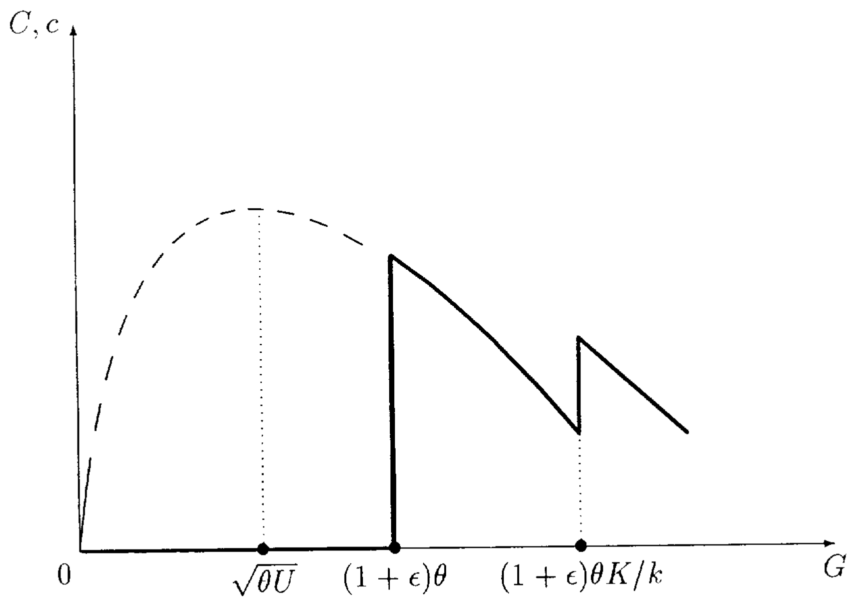

Figure 5: $\sqrt{\theta U} \leq (1+\epsilon)\theta$

Equation (22) implies that

$$R = U. \tag{23}$$

With collective choice of G, well endowed people are deterred from choosing to be predators, and, assuming that k/K is small and U is not too large, the ratio of predators to producers is equal to the ratio of poorly endowed to well endowed people.

Comparing equation (22) to equation (17) we see that the amount of guarding with collective choice of G is larger than the amount of guarding with individual choice of G for small values of U, but that the amount of guarding with collective choice of G is equal to the amount of guarding with individual choice of G for large (but not too large) values of U. Comparing equation (23) to equation (16) we see that, because with collective choice of G the well endowed people are deterred from choosing to be predators, the ratio of predators to producers with collective choice of G is smaller than the ratio of predators to producers with individual choice of G for small values of U, but that the ratio of predators to producers with collective choice of G is equal to the ratio of predators to producers with individual choice of G for large (but not too large) values of U.

Substituting equations (22) and (23) into equation (1), we find that the fraction of consumables that producers appropriate is

$$p = max\{\frac{1}{1+U/(1+\epsilon)}, \frac{1}{1+\sqrt{\theta U}}\}. \tag{24}$$

Equation (24) implies that, with collective choice of G, p is smaller than one only if U is positive.[16] Also, assuming that k/K is small and U is not too large, p is a decreasing function of U. Comparing equation (24) to equation (18) we see that the value of p with collective choice of G is larger than the value of p with individual choice of G for small

The associated value of c would be the same, except that k would replace K in the numerator.

[16]This result is consistent with the analysis of the model in Section 3, which we can interpret as the limiting case of the present model as U goes to zero.

values of U, but that the value of p with collective choice of G is equal to the value of p with individual choice of G for large (but not too large) values of U.

Substituting for p from equation (24) and for G from equation (22) into equations (12), (13), and (14), we can calculate the consumption of well endowed people and poorly endowed people with collective choice of G. Because well endowed people choose to be producers, the consumption of every well endowed person is given by

$$(25) \qquad C = \begin{cases} \dfrac{K}{[1+U/(1+\epsilon)][1+(1+\epsilon)\theta]} & \text{for } \sqrt{\theta U} \le (1+\epsilon)\theta \\ \\ \dfrac{K}{(1+\sqrt{\theta U})^2} & \text{for } \sqrt{\theta U} > (1+\epsilon)\theta. \end{cases}$$

Because poorly endowed people choose to be predators, the consumption of every poorly endowed person is given by

$$(26) \qquad D = \begin{cases} \dfrac{K/(1+\epsilon)}{[1+U/(1+\epsilon)][1+(1+\epsilon)\theta]} & \text{for } \sqrt{\theta U} \le (1+\epsilon)\theta \\ \\ \dfrac{K\sqrt{\theta/U}}{(1+\sqrt{\theta U})^2} & \text{for } \sqrt{\theta U} > (1+\epsilon)\theta. \end{cases}$$

Equations (25) and (26) imply that, with collective choice of G, D is smaller than C.

More interestingly, from equations (25) and (26) we calculate average consumption to be

$$(27) \qquad (1-u)C + uD = \begin{cases} \dfrac{K}{[1+(1+\epsilon)\theta](1+U)} & \text{for } \sqrt{\theta U} \le (1+\epsilon)\theta \\ \\ \dfrac{K}{(1+\sqrt{\theta U})(1+U)} & \text{for } \sqrt{\theta U} > (1+\epsilon)\theta. \end{cases}$$

To see the implications of equation (27), observe that equation (11) implies that

$$\frac{K}{1+U} = \Omega - \frac{U}{1+U}k.$$

Then, comparing equation (27) with equation (10), we see that with collective choice of G the existence of poorly endowed people results in smaller average consumption. If $\sqrt{\theta U} \le$

$(1+\epsilon)\theta$, then this result obtains because, for positive but small values of U, the existence of poorly endowed people results in the same amount of resources being allocated to guarding but also results in a positive ratio of predators to producers, and, assuming that k is positive, a positive amount of resources wasted by predators. Further, if $\sqrt{\theta U} > (1+\epsilon)\theta$, then, as long as U is not too large, the existence of poorly endowed people results in both a positive ratio of predators to producers and more resources being allocated to guarding. Given the existence of poorly endowed people, comparing equation (27) with equation (21) we see that, because with collective choice of G the well endowed people are deterred from choosing to predators, average consumption with collective choice of G is larger than average consumption with individual choice of G for small values of U, but that average consumption with collective choice of G is equal to average consumption with individual choice of G for large (but not too large) values of U.

6. SUMMARY

This paper has explored a series of four general-equilibrium models in which people can choose to be either producers or predators, and in which producers can allocate their resources either to production or to guarding their production against predators. All of these models assumed that each person chooses to be a producer or a predator according to whether predation or production would yield him or her more consumption.

In the first model all people had the same productive opportunities, and producers (or small subsets of producers) individually chose the amount of resources to allocate to guarding against predators. Analysis of this model showed how the technology of predation, as reflected in the effectiveness of predators, determines both the equilibrium ratio of predators to producers and the equilibrium amount of resources allocated to guarding against predators. We also saw how the social cost of predation is positively related to the effectiveness of predators.

In the second model all people again had the same productive opportunities, but producers made an irreversible collective choice of the amount of resources to allocate to guarding against predators. This collective choice of the amount of guarding took into account the deterrent effect of guarding on the fraction of people who chose to be predators. Analysis of this model showed how collective choice of the amount of guarding by deterring predation decreases the social cost of predation.

The third model extended the basic analytical framework by assuming that some people are well endowed with productive resources and other people are poorly endowed with productive resources. Because a well endowed person can produce more than a poorly endowed person, predation is less attractive for the well endowed than for the poorly endowed. Assuming individual choice of the amount of guarding, analysis of this model revealed that, with a small fraction of poorly endowed people, all of the poorly endowed people as well as some of the well endowed people would choose to be predators. In fact, the fraction of poorly endowed people, if it is small, would not affect either the equilibrium ratio of predators to producers or the equilibrium amount of resources allocated to guarding against predators, both of which still would depend only on the technology of predation. In contrast, with a large enough fraction of poorly endowed people, all of the poorly endowed people would choose to be predators and all of the well endowed people would choose to be producers. Accordingly, the fraction of poorly endowed people, if it is large enough, would increase both the equilibrium ratio of predators to producers and the equilibrium amount of resources allocated to guarding against predators.

Nevertheless, the analysis also revealed that, if the fraction of poorly endowed people is not too large, then the existence of poorly endowed people decreases the social cost of predation, because the existence of poorly endowed people concentrates the economy's productive resources in the hands of producers. With either all or, at least, some of the predators being poorly endowed people, predators waste a smaller fraction of the economy's productive resources than with everyone, both predators and producers, having the same endowment.

In the fourth model some people were well endowed and some people were poorly endowed, but producers made an irreversible collective choice of the amount of resources to allocate to guarding against predators. Analysis of this model showed that with collective choice of the amount of guarding producers allocate enough resources to guarding to deter the well endowed people from choosing to be predators. Consequently, with collective choice of the amount of guarding the ratio of predators to producers is (at most) equal to the ratio of poorly endowed to well endowed people.

The analysis also showed that with collective choice of the amount of guarding the existence of poorly endowed people increases either the ratio of predators to producers, or the amount of resources allocated to guarding, or both. Thus, with collective choice of the amount of guarding the existence of poorly endowed people increases the social cost of predation. Nevertheless, if the fraction of poorly endowed is small, then collective choice of the amount of guarding results in a smaller ratio of predators to producers and a smaller social cost of predation than with individual choice of the amount of guarding.

Taken together the analysis of these four models has shown how the ratio of predators to producers and the social cost of predation depend on the technology of predation, on the interpersonal distribution of productive resources, and in a fundamental way on whether the decision to allocate resources to guarding against predators is made individually or collectively. Perhaps the most interesting results were the following: If either there are no poorly endowed people or the fraction of poorly endowed people is small, then collective choice of the amount of guarding against predators decreases the social cost of predation. But, with collective choice of the amount of guarding the existence of poorly endowed people increases the social cost of predation, whereas with individual choice of the amount of guarding, if the fraction of poorly endowed people is not too large, then the existence of poorly endowed people decreases the social cost of predation.

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