INCREASING BLOCK TARIFFS FOR PRICING POLLUTION: AN ANALYTICAL FRAMEWORK AND ASSESSMENT

Peter Kennedy
Department of Economics
University of Victoria

26 January 2001

ABSTRACT

Increasing block tariffs (IBTs) are a pricing scheme whereby successively higher unit prices are applied to discrete consumption blocks. The purpose of this paper is to construct an analytical framework to assess the merits and shortcomings of applying IBTs to taxing pollution. The paper draws three main conclusions. First, an IBT scheme will tend to induce too much pollution from smaller polluters. Second, abatement costs at the equilibrium level of aggregate pollution level will tend to be too high. Third, technology adoption decisions will tend to be biased towards marginally cleaner technologies and against significantly cleaner technologies.

An earlier version of this paper was prepared for the *World Bank*.

1. INTRODUCTION

Increasing block tariffs (IBTs) are a pricing scheme whereby successively higher unit prices are applied to discrete consumption blocks. This scheme is commonly used to price water in developing countries, and there appears to be an increasing trend in developing countries towards a similar practice with respect to taxing pollution.[1] The purpose of this paper is to construct an analytical framework to assess the merits and shortcomings of applying IBTs to taxing pollution.

The paper begins with a brief review of the standard Pigouvian taxation rule. This is the economic foundation on which pollution taxation is built. The discussion distinguishes between situations where the marginal environmental damage from pollution is constant and situations where marginal damage is increasing in the level of pollution. This is a crucial distinction for the efficiency properties of taxation schemes, including IBTs. Sections 3 and 4 address some important extensions to the basic framework that deal with information asymmetry, and dynamic incentives. Section 5 summarizes the standard theory of pollution taxation in relation to IBTs. Section 6 then examines the efficiency properties of IBTs in the context of the general framework. Section 7 concludes with directions for further research.

2. ANALYTICAL FOUNDATION: THE PIGOUVIAN PRICING RULE

The theoretical foundation for pricing taxation is the standard Pigouvian rule: the tax on pollution should be based on the marginal damage it causes. The goal of this pricing rule is to internalize the cost of pollution and thereby ensure that the polluter faces the correct incentives when balancing the costs and benefits of the pollution-causing activity. Thus, the goal of the Pigouvian pricing rule is to achieve economic efficiency with respect to the allocation of resources.

The mechanics of applying the Pigouvian pricing rule in practice depend importantly on whether or not the marginal damage from pollution increases with the amount of pollution. We examine each case in turn.

---

[1] See Boland and Whittington (1999) for an analysis of water tariff design in developing countries.

2.1 Constant Marginal Damage

In the case of constant marginal damage, the pricing rule is very simple: the unit price on pollution is constant and set equal to marginal damage. This case is illustrated in Figure 1, which depicts the decision problem for a single polluter. The level of pollution (emissions or effluent) is denoted *e*. The *MD* schedule represents the marginal damage from pollution. The *MAC* schedule represents the marginal abatement cost for the polluter (the cost to the polluter of reducing pollution). In the absence of any price on pollution, the polluter would discharge $\bar{e}$ units of pollution. This level of pollution is excessive from an efficiency perspective since it does not account for the damage caused by the pollution. This problem can be remedied by charging the polluter a tax p^* for each unit of pollution. This tax effectively internalizes the damage from the pollution and creates the correct incentives for the polluter. The polluter discharges e^* units of pollution, where $MAC(e^*) = p^*$, and this implements the efficient solution, given by $MAC(e^*) = MD$.

The same logic extends to the case of many polluters. Figure 2 illustrates a case with two polluters, with different marginal abatement costs. The unit tax on pollution is set equal to marginal damage and that tax is applied to both polluters. In response, polluter 1 discharges e_1^*, where $MAC_1(e_1^*) = p^*$, and polluter 2 discharges e_2^*, where $MAC_2(e_2^*) = p^*$. This achieves the efficient outcome at two levels: marginal abatement cost is equated across the polluters (which means that the cost of reducing pollution is minimized); and marginal damage is equated to marginal abatement cost.

Note that both polluters face the same unit tax on pollution despite their differences in terms of marginal abatement costs, and despite their different levels of discharge at the optimal solution. Note also that no information about marginal abatement costs is needed to set the pollution tax; it is based on marginal damage alone.

2.2 Increasing Marginal Damage

The Pigouvian pricing problem becomes more complicated when marginal damage is increasing. Figure 3 illustrates this case for a single polluter. The pollution tax must be set equal to marginal damage *evaluated at the optimal solution*; that is, $p^* = MD(e^*)$.

Note that this Pigouvian tax is charged on every unit of pollution despite the fact that marginal damage is increasing. Note also that the regulator must have information about both the marginal damage schedule and the marginal abatement cost schedule in order to determine e^* and p^*.

Figure 4 illustrates the case of two polluters. In this case the tax on pollution is set equal to marginal damage evaluated at the optimal level of *aggregate* pollution: that is, $p^* = MD(E^*)$, where $E^* = e_1^* + e_2^*$. This Pigouvian tax is applied uniformly across the polluters, and is applied to every unit of pollution discharged. This pricing scheme implements the efficient solution but the regulator must know the marginal damage schedule and the marginal abatement cost schedule for every polluter in order to set the correct tax.

3. ASYMMETRIC INFORMATION AND INCENTIVE-COMPATIBLE MECHANISMS

The informational requirements of the Pigouvian pricing rule (when marginal damage is increasing) present a major obstacle to implementation in practice. The regulator can in principle calculate an estimate of the marginal damage schedule based on scientific research, but information on abatement costs is usually private information held by the polluting entities. Thus, the regulator faces an information asymmetry with respect to abatement costs. Under some limited circumstances it may be possible for the regulator to learn about abatement costs by experimenting with different tax rates and observing the polluter’s response. [See Livernois and Karp (1994)]. However, there are two main problems with that approach. First, the polluter has an incentive to respond strategically with a view to securing a lower tax. Second, pollution taxes can induce sunk investments in abatement that cannot be reversed if the regulator later reduces the tax, and this can cause significant welfare losses. Thus, experimentation is a very limited solution to the asymmetric information problem.[2]

---

[2] It is conceivable that an IBT scheme could have some value as an information revelation mechanism (as an alternative to experimentation). That possibility is not pursued in this paper but it is an idea worthy of further consideration.

An alternative approach with more theoretical appeal is an incentive-compatible price mechanism. This approach was first proposed by Dasgupta, Hammond and Maskin (1980), henceforth DHM. The DHM mechanism levies a total damage fee rather than a unit tax on pollution. In the case of a single polluter, the damage fee is $F(e) = D(e)$, where $D(e)$ is the environmental damage function. That is, the polluter is required to pay an amount just equal to the monetary value of the environmental damage. The optimal response for the polluter is to choose pollution level e^*, where $MD(e^*) = MAC(e^*)$. Thus, the DHM mechanism implements the efficient solution without the regulator having to know anything about marginal abatement cost.

Note that the DHM mechanism effectively involves an increasing unit price schedule. That is, the price on the first unit of pollution is $MD(1)$; the price on the second unit is $MD(2)$; the price on the third unit is $MD(3)$; and so on. Thus, the DHM mechanism can be interpreted as a perfectly discriminating IBT, where the blocks are single pollution units.

Kim and Chang (1993) show that a generalization of the DHM mechanism also implements efficiency when there are many polluters (if abatement technologies are fixed).[3] The Kim-Chang generalization assigns a total payment to each polluter based on its pollution relative to total pollution. In particular, let e_i denote pollution from firm *i*, and let E_{-i} denote the total pollution from all other firms in the regulated area. Then the total payment for firm *i* is $F(e_i) = D(e_i + E_{-i}) - D(E_{-i})$, where $D(E)$ is the environmental damage function defined over total pollution. The rational expectations Nash equilibrium under this mechanism implements the efficient solution.

The Kim-Chang mechanism can also be interpreted in terms of an IBT, though not in the traditional sense. Figure 5 illustrates the total damage fees paid by two polluters under the Kim-Chang scheme. Firm 1 pollutes e_1^* and pays a total damage fee equal to area H; firm 2 pollutes e_2^* and pays a total damage fee equal to the sum of areas G and H. Thus, we can interpret the Kim-Chang scheme as an IBT scheme where the blocks are single units of pollution, and those blocks are priced at marginal damage

---

[3] We discuss the issue of technology choice in section 4.1 below.

measured backwards from the last unit of pollution. That is, the tax (for all polluters) on their *last* unit of pollution is $MD(E)$; the tax (for all polluters) on their second last unit is $MD(E-1)$; the tax on their third last unit is $MD(E-2)$; and so on. This means that the smaller polluter in Figure 5 (firm 1) faces a *higher* tax rate on its *first* unit of pollution than the larger polluter (firm 2); the tax on the first unit is p_1^0 for firm 1 and p_2^0 for firm 2. Each firm then pays a successively higher tax rate for additional units, with each firm paying p^* on their last unit (where p^* is the standard Pigouvian tax). Thus, each polluter faces its own IBT, with an initial price that is different for each polluter. These individual IBT schedules for firms 1 and 2 are illustrated in Figure 6 as IBT_1 and IBT_2 respectively.

4. DYNAMIC INCENTIVES

If marginal damage is constant then the total tax payments for a polluter under the standard Pigouvian tax are exactly equal to the total environmental damage done by that polluter. The same is not true in the case of increasing marginal damage. In that case the total tax payment at any level of pollution exceeds the total value of the environmental damage associated with that level of pollution. This is illustrated in Figure 7 for the case of a single polluter. The environmental damage associated with pollution level e^* is the area labeled H but the total tax payment by the polluter at the Pigouvian tax p^* is the sum of areas G and H.

This over-payment property of the Pigouvian pricing rule has a number of important implications for its dynamic incentive effects. Two issues in particular have received attention in the literature on pollution pricing: incentives for technological change; and incentives for entry and exit. We briefly discuss each of these in turn.

4.1 Incentives for Technological Change

A key role for pollution pricing is the creation of incentives for technological change. However, it is important for policy-makers to recognize that the optimal technology is not necessarily the cleanest technology available. This is especially true when an existing production technology is already employed and the associated investment has been sunk.

Retooling with a less polluting production method or retrofitting abatement equipment can be very costly, and that cost must be carefully weighed against the benefits of reduced pollution from technological change. Thus, it is important that a pollution pricing scheme creates the *right* incentives for technological change, in the sense that it induces technology adoption decisions which correctly balance the benefits and costs of alternative technologies.

The Pigouvian pricing rule described in section 2 does create the right incentives for technological change when marginal damage is constant. [See Kennedy and Laplante (2000)]. In that simple case the social benefit from adopting a cleaner technology, in terms of reduced pollution, is correctly reflected in the Pigouvian tax; the private and social net benefits from alternative technology options are thereby aligned.

The same is not true in the case of increasing marginal damage. The general nature of the problem is illustrated in Figure 8 for the case of a single polluter. Two technology options are represented by the marginal abatement cost schedules labeled MAC_A (the dirtier technology) and MAC_B (the cleaner technology). The efficient pollution level for technology *A* is e_A^* and the appropriate Pigouvian tax is p_A^*; the efficient pollution level and tax under technology *B* are e_B^* and p_B^*, respectively. The difference between the two technologies in terms of total environmental damage (evaluated at the efficient pollution levels) is the shaded area labeled H. However, the difference in total tax payments for the polluter under the two technologies is the sum of the areas labeled G and H. That is, there is an additional private benefit to the polluter from choosing the cleaner technology (area H). This excessive private benefit arises because the difference in total tax payments between the two technologies exceeds the difference in environmental damage.

The excessive incentive to adopt the cleaner technology under the Pigouvian pricing rule also extends to the case of many polluters. Only in the limiting case of a continuum of polluters does the distortion vanish; in that case, each polluter is insignificant relative to the whole, and marginal damage is effectively constant with respect to the emissions of any individual polluter. [See Kennedy and Laplante (2000)].

4.2 Incentives for Entry and Exit

There is an extensive literature on incentives for entry and exit under Pigouvian pricing, focussing primarily on the issue of whether or not the over-payment property of the Pigouvian price rule creates a distorting disincentive for entry into the taxed industry.[4] The basic point is illustrated in Figure 9 for the case of a single potential polluter facing an investment decision (such as whether or not to establish a factory by a river). The investment will generate marginal social benefits (exclusive of environmental costs) given by the *MB* schedule. The efficient level of production is that corresponding to a pollution level e^*, and the associated social surplus created is equal to the sum of areas J and G. However, if a tax p^* is levied on each unit of pollution, the regulator captures area G as revenue (in addition to area H), and so the private return to the investment (area J) understates its true social value. Hence, the investment decision is distorted.

This distortion vanishes in a "competitive" setting with a continuum of polluters; that is, the long run competitive equilibrium under the Pigouvian tax is efficient [See Spulber (1985)]. This reflects the fact that marginal damage is effectively constant with respect to the pollution from an individual firm when that firm is insignificant relative to the whole. However, many policy settings are characterized by a relatively small number of polluters and potential polluters, each of which is significant relative to the whole. In such settings, the distorting effect of the Pigouvian pricing rule is a potentially serious problem.

4.3 The DHM Mechanism Revisited

Recall the DHM mechanism from section 3. That mechanism assigns a perfectly discriminating tax to each unit of pollution according to its actual marginal damage. In the case of a single polluter, the total tax payment at any level of pollution under that scheme is exactly equal to the environmental damage, and so the dynamic incentives (with respect to technological change and entry) under the DHM mechanism are correct. Thus, a perfectly discriminating IBT is an optimal mechanism in the case of a single polluter (or potential polluter).

---

[4] See Spulber (1985) for a comprehensive treatment of the issue.

This result does not extend to the case of many polluters. The Kim-Chang generalization of the DHM mechanism does not create correct dynamic incentives because it does not account for the impact that technological change or entry have on the abatement costs of other polluters when their pollution levels change in response to changes in the damage fee. Efficiency requires the Kim-Chang damage fee to be coupled with a subsidy for technological change, and a tax for entry. [See Kennedy and Laplante (1998)].

5. STANDARD THEORY IN RELATION TO IBT SCEMES

This section summarizes the main points from the preceding discussion in terms of how standard theory on pollution taxes relates to IBT schemes. First, the standard Pigouvian pricing scheme does not have an IBT structure; it sets a uniform tax on each unit of pollution and on every polluter. It creates the right marginal incentives but in the case of increasing marginal damage it suffers from substantial information requirements and a distorting effect on dynamic incentives (except in the limiting case of a continuum of firms).

Second, the DHM mechanism avoids the shortcomings of the standard Pigouvian pricing scheme (in terms of information requirements and dynamic incentives), in the case of a single polluter. The DHM mechanism is a perfectly discriminating IBT: each unit of pollution is priced at its marginal damage. It creates the right marginal incentives because the price on the last unit of pollution is exactly equal to its marginal damage, and it creates the right dynamic incentives because the total tax payment is equal to the total environmental damage.

Third, the Kim-Chang generalization of the DHM mechanism for the case of many firms also creates the right marginal incentives (with minimal information requirements) but is distortionary with respect to dynamic incentives. It too can be interpreted as a perfectly discriminating IBT scheme, but one in which each firm is faced with an individualized IBT whose initial price is *inversely related* to that firm's pollution level.

In summary, non-linear pricing schemes have a conceptual foundation in standard theory (with some associated advantages over the Pigouvian pricing rule), but they generally do not correspond to traditional IBT schemes. The next section examines the efficiency properties of traditional IBT.

6. EFFICIENCY PROPERTIES OF TRADITIONAL IBT SCHEMES

We consider an IBT scheme with two price blocks. The analysis extends easily to a scheme with more than two blocks but the key characteristics of the traditional IBT can be illustrated most clearly in the simplest possible setting. We begin with the case of constant marginal damage.

6.1 Constant Marginal Damage

The preceding discussion shows that the standard Pigouvian pricing rule performs well when marginal damage is constant, with respect to both marginal and dynamic incentives. Thus, it should come as no surprise that that an IBT scheme has the potential to be highly distorting in this case. Figure 10a illustrates a situation with two firms who differ according to their marginal abatement costs. The efficient solution is $\{e_1^*, e_2^*\}$. The IBT scheme sets a unit tax for both firms at p^1 on the first pollution block (up to $\tilde{e}$ units), and a unit tax for both firms at p^2 on the second block (everything above $\tilde{e}$ units). This pricing scheme implements the efficient solution for the particular case illustrated (for given technologies). The first block is sufficiently small that both polluters face the higher price at the margin, and this price has been chosen to correspond to the standard Pigouvian tax (that is, $p^2 = MD)$. Thus, the traditional IBT is not *necessarily* distorting with respect to marginal incentives.

In contrast, Figure 10b illustrates a case in which the IBT is distorting. The first price block is larger in this case, and the privately optimal response by the smaller polluter is to pollute at $\tilde{e}$, in excess of the efficient level. The problem is that the smaller polluter faces a price lower than the true marginal damage of its pollution and consequently it pollutes too much. The associated welfare loss is the shaded area in Figure 10b. In general, the IBT will distort marginal incentives if the first block is smaller than the efficient pollution level for the smallest polluter, and the price on that first block is different from true marginal damage.

Dynamic Incentives

The IBT has the potential to distort dynamic incentives even when it does not distort marginal incentives. Figure 11 reproduces the situation depicted in Figure 10b but focussing on the larger polluter, for whom there is no marginal distortion at the initial technology. Suppose the firm has a choice between two technologies: technology A (the dirtier technology) and technology B (the cleaner technology). The difference in total tax payments for the firm between the two technologies is the shaded area H, but the difference in environmental damage at the efficient operation of the cleaner technology (at pollution level e^*_{2B}) is the sum of areas G and H. Thus, the cleaner technology is under-valued by the firm relative to its true social value.[5] This can distort the technology adoption decision in favour of the dirtier technology.

6.2 Increasing Marginal Damage

The analysis of an IBT with many polluters when marginal damage is increasing is highly case-specific, and therefore quite complicated. It is therefore useful to begin with the case of single polluter in order to make some key points in the simplest possible setting.

A Single Polluter

In section 3 we showed that the DHM price mechanism outperforms the standard Pigouvian pricing rule when marginal damage is increasing, at least in the case of a single polluter. This might suggest that an IBT scheme has some merit in this case. However, a traditional IBT only approximates the DHM mechanism when there are a very large number of small price blocks. In the case of just a few blocks the IBT can be seriously distorting.

Figure 12 illustrates an IBT with two price blocks, in which the second block price is chosen to reflect true marginal damage at the efficient solution, given the technology in place (technology A). Thus, the marginal incentives are correct for the current technology.[6] The first block price has been chosen to ensure that total tax

---

[5] This assumes that private and social abatement costs coincide.

[6] Clearly, if the first block extends beyond e^*_A then marginal incentives are distorted.

payments are just equal to environmental damage at the efficient solution. Thus, this IBT mimics the DHM mechanism in terms of the equality of tax payments and damage. However, the IBT is nonetheless distorting. Consider the incentive to adopt a cleaner technology. The tax savings to the firm from adopting technology B exceed the reduction in environmental damage, by an amount equal to the shaded area in figure 12.[7] Thus, technology B is over-valued by the firm. Similarly, any technology between A and B (in terms of the position of the MAC schedule) is also over-valued.

In contrast, technologies cleaner than technology B tend to be under-valued. In particular, all technology choices between B and C in Figure 12 yield exactly the same tax benefit to the firm, despite the fact that technologies closer to technology C yield greater environmental benefits. For technologies cleaner than technology C, the tax savings increase with the cleanliness of the technology, but those tax savings are unambiguously smaller than the associated reduction in environmental damage (relative to technology A).[8] Thus, overall the firm tends to over-value technologies that are slightly cleaner but under-value technologies that are significantly cleaner.

Many Polluters

Figure 13 illustrates a case with two polluters, in which marginal incentives are distorted for the smaller polluter (firm 1). Firm 1 pollutes too much relative to the efficient solution because it faces a price lower than marginal damage; thus, aggregate pollution is too high ($\hat{E}$ versus E^*). It should also be noted that marginal abatement costs are not equated across the two firms, so the equilibrium pollution level is not only too high, it is not achieved at least cost. The overall welfare loss relative to the efficient solution is equal to the sum of the shaded areas in Figure 13.

The dynamic incentives are distorted in the same way as for the single polluter case, although the quantitative results are more case-specific since the relationship between

---

[7] Technology B has been chosen deliberately to correspond to an efficient outcome at $\tilde{e}$.

[8] This difference is reinforced if the IBT is such that the total tax payments at technology A are less than environmental damage, and weakened if the converse is true. (Recall that Figure 12 reflects a case in which total payments and damage are equal at the initial technology).

total tax payments and environmental damage under a particular IBT structure will differ across firms.

6.3 Summary of Results

The key results from this section can be summarized as follows:

- an IBT scheme will tend to induce too much pollution from smaller polluters;
- abatement costs at the equilibrium level of aggregate pollution level will tend to be too high; and
- technology adoption decisions will tend to be biased towards marginally cleaner technologies and against significantly cleaner technologies.

7. DIRECTIONS FOR FURTHER RESEARCH

There are two primary directions in which this research should be taken. First, a more comprehensive theoretical analysis of the IBT scheme is likely to yield further insights into its efficiency properties. Issues of particular interest include: the potential role for an IBT scheme as an information revelation mechanism; the characterization of an IBT as a generalized pricing structure (incorporating the DHM mechanism at one extreme and pollution standards coupled with variable penalties at the other); and the implications of an IBT for truthful reporting under a self-reporting enforcement policy.

Second, it is important to gain an understanding of why regulators in developing countries appear to favour IBT schemes despite the shortcomings we have highlighted here. It is possible that particular realities of the regulatory process are absent from our analytical framework but are important in practice. Equity considerations and political economy issues are the most obvious candidates.[9] However, it is also possible that regulators do not fully understand the incentive properties of IBTs. In particular, at a superficial level it might appear that an IBT penalizes large polluters more severely than smaller ones and might therefore create enhanced incentives for the adoption of cleaner technologies. However, we have shown that precisely the opposite outcome could arise.

---

[9] In this respect there may be much to learn from experience with IBTs in other applications, such as in water pricing. See Boland and Whittington (1999).

At this point we can only speculate on the motives for using IBTs in practice; more analysis is needed to provide definitive answers.

REFERENCES

Boland, John J. and Dale Whittington (1999), “The political economy of water tariff design in developing countries: increasing block tariffs versus uniform price with rebate”, [incomplete reference]

Dasgupta, Partha, Peter Hammond and Eric Maskin (1980), “On imperfect information and optimal pollution control”, Review of Economic Studies, 47, 857-860.

Livernois, John and Larry Karp (1994), “Using automatic tax changes to control pollution emissions”, Journal of Environmental Economics and Management 27, 38-48.

Kennedy, Peter W. and Benoit Laplante (1998), “Dynamic incentives and the Pigouvian tax”, University of Victoria Discussion Paper 98-05.

Kennedy, Peter W. and Benoit Laplante (2000), “Environmental policy and time consistency: emission taxes and emissions trading”, in E. Petrakis, E. Sartzetakis and A. Xepapadeas (ed.), Environmental Regulation and Market Power, 2000. Edward Elgar: Hants, England, 116-144.

Kim, Jae-Cheol and Ki-Bok Chang (1993) “An optimal tax/subsidy for output and pollution control under asymmetric information in oligopoly markets”, Journal of Regulatory Economics, 5, 193-197.

Spulber, Daniel F. (1985), “Effluent regulation and long-run optimality”, Journal of Environmental Economics and Management, 12, 103-116.

FIGURES

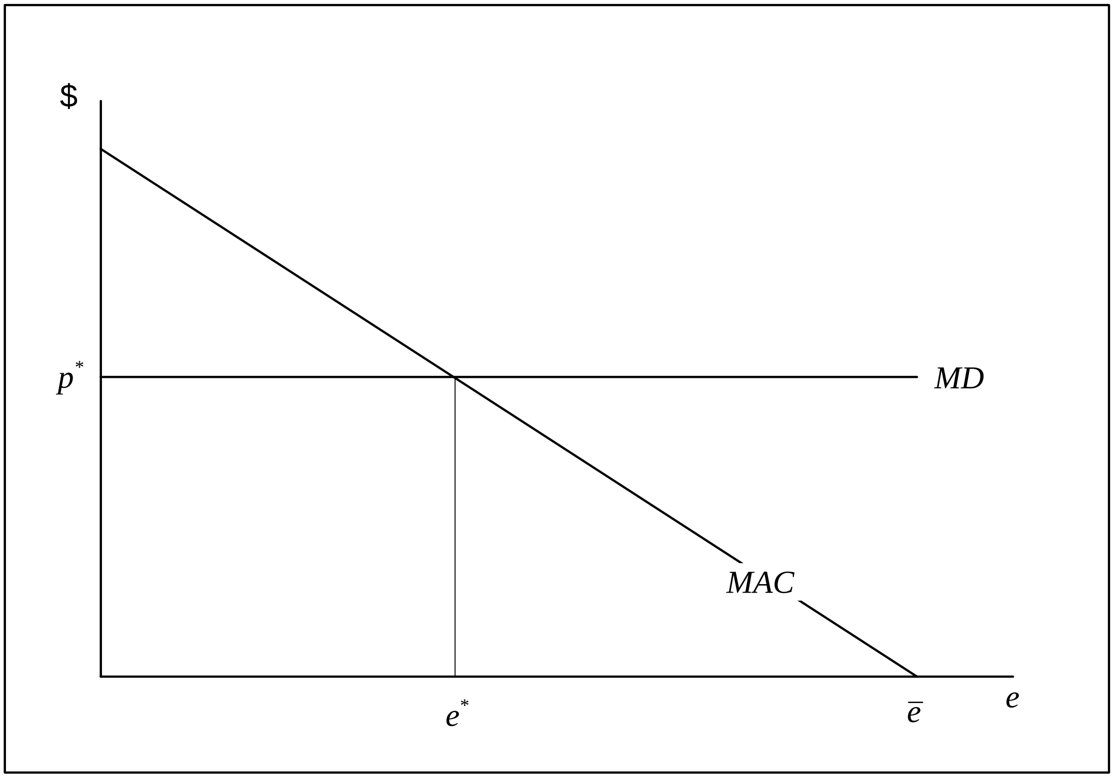

Figure 1

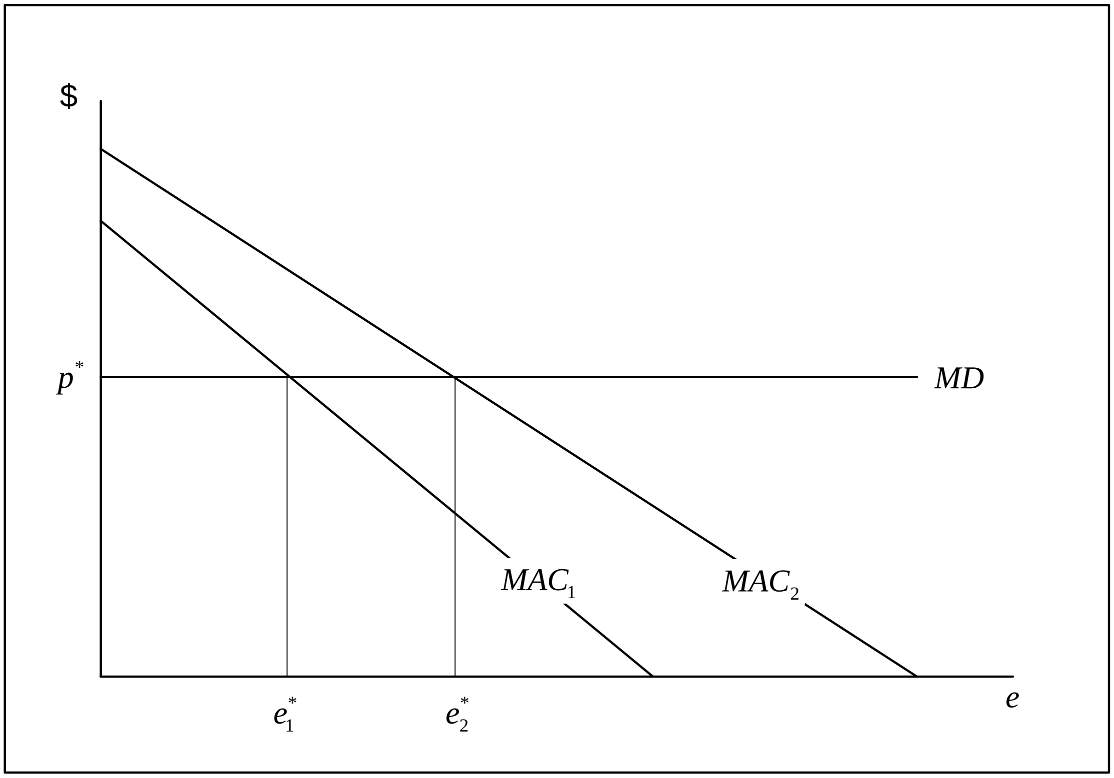

Figure 2

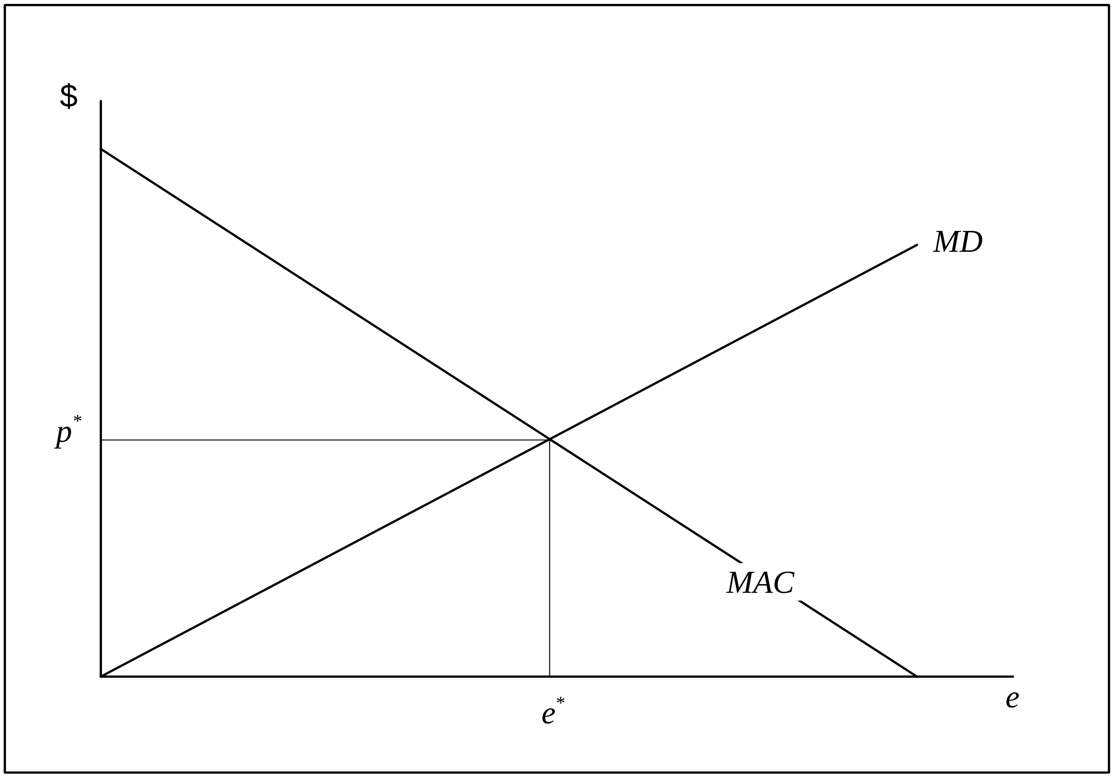

Figure 3

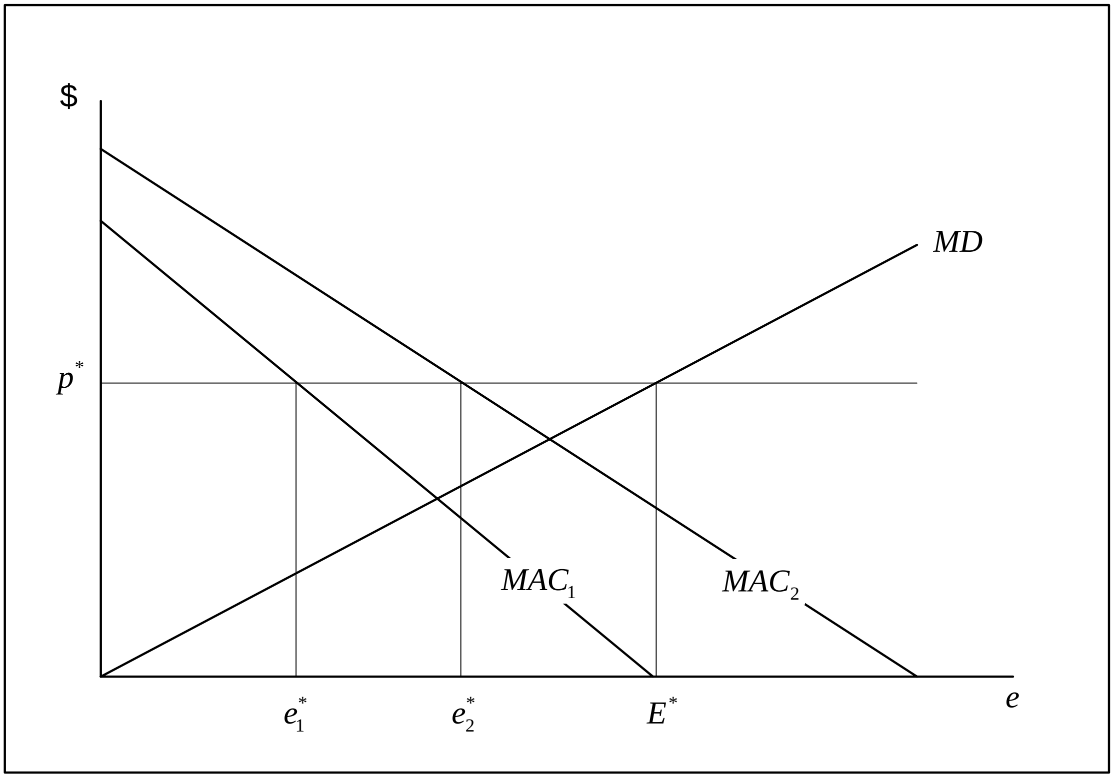

Figure 4

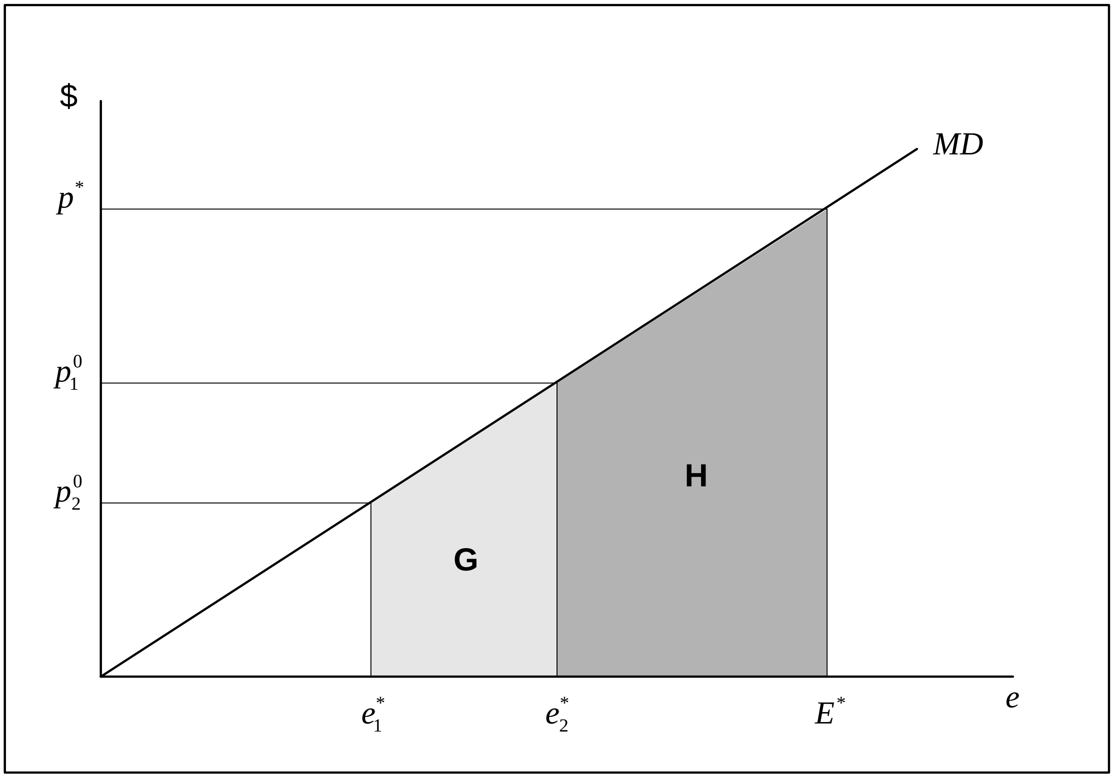

Figure 5

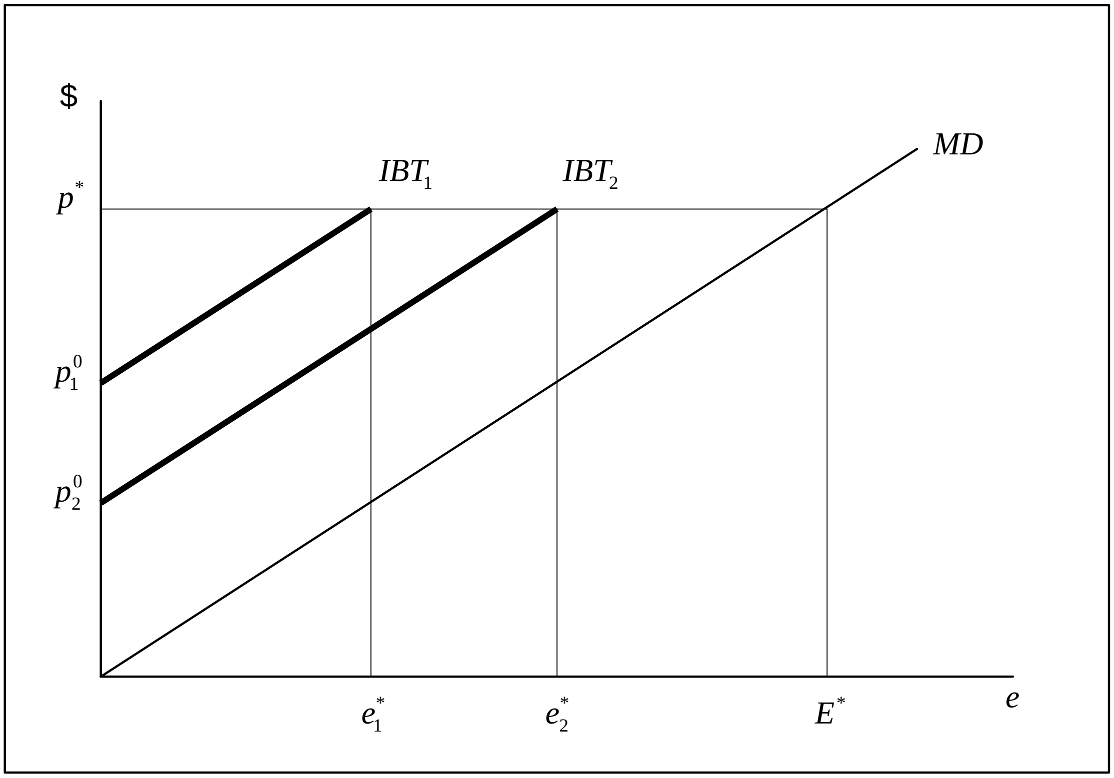

Figure 6

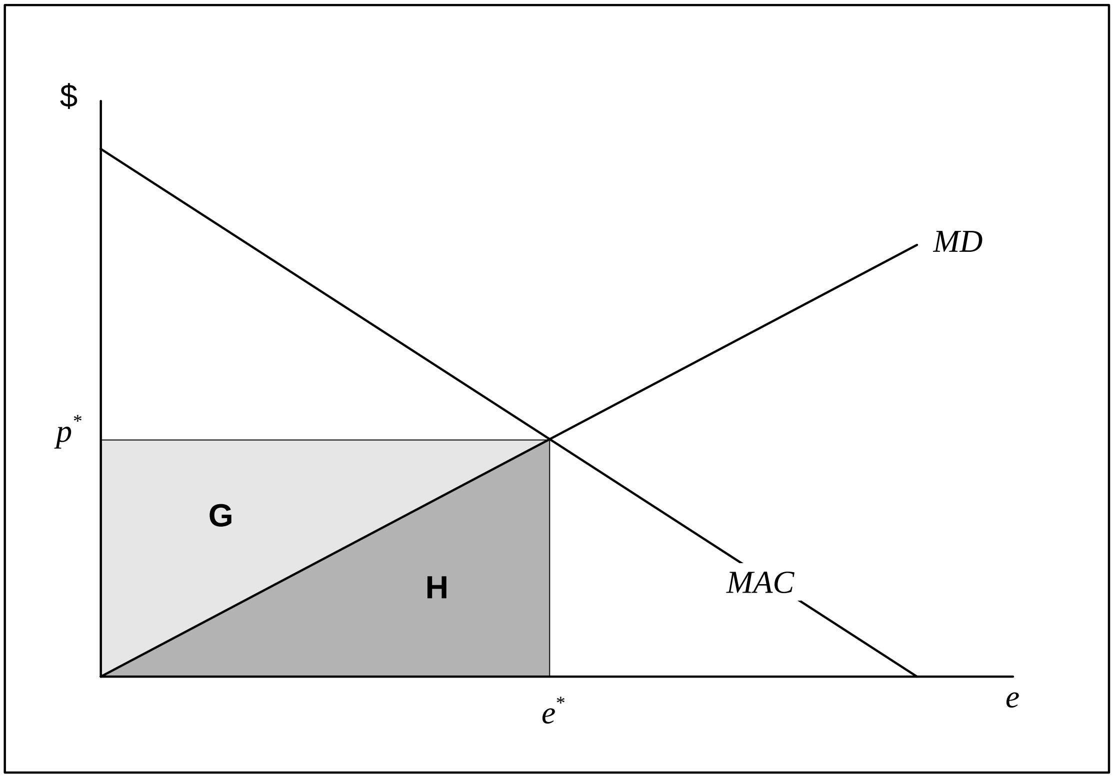

Figure 7

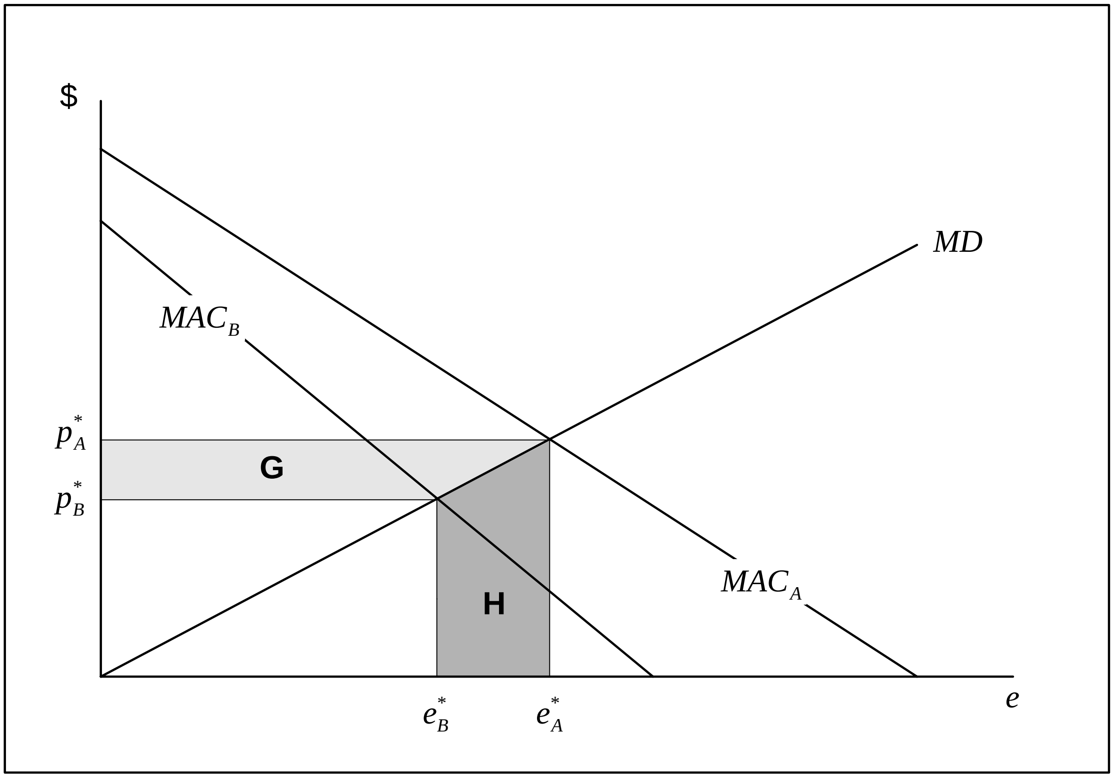

Figure 8

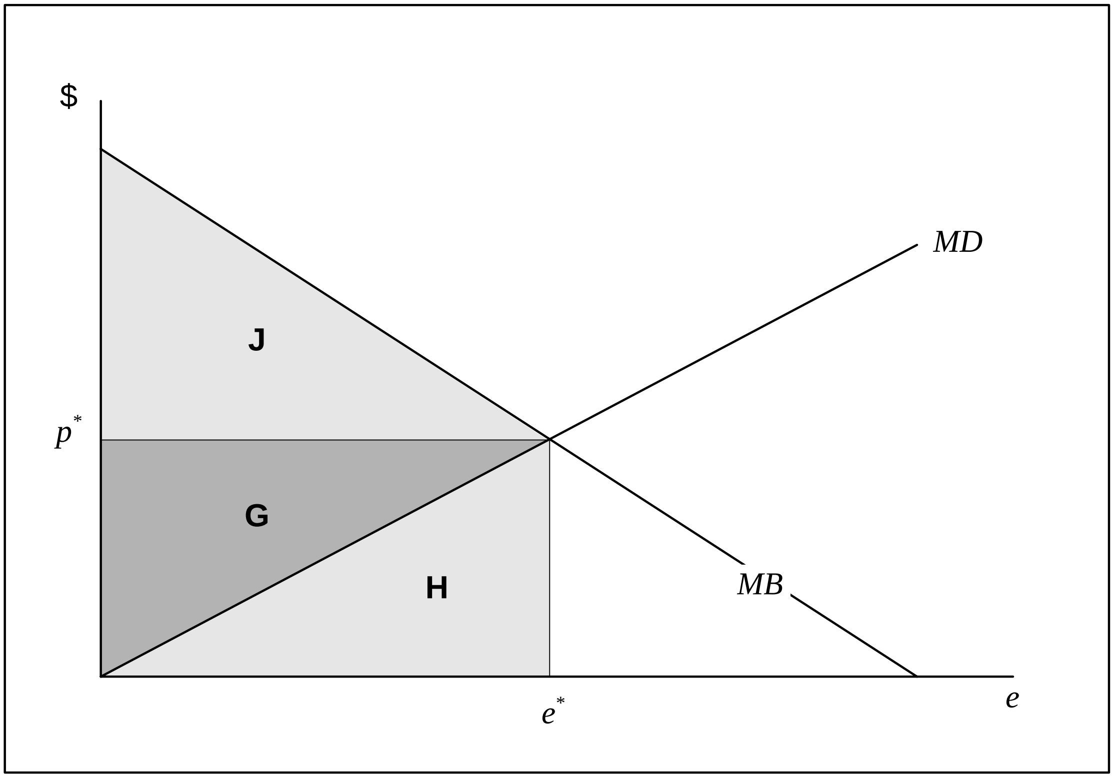

Figure 9

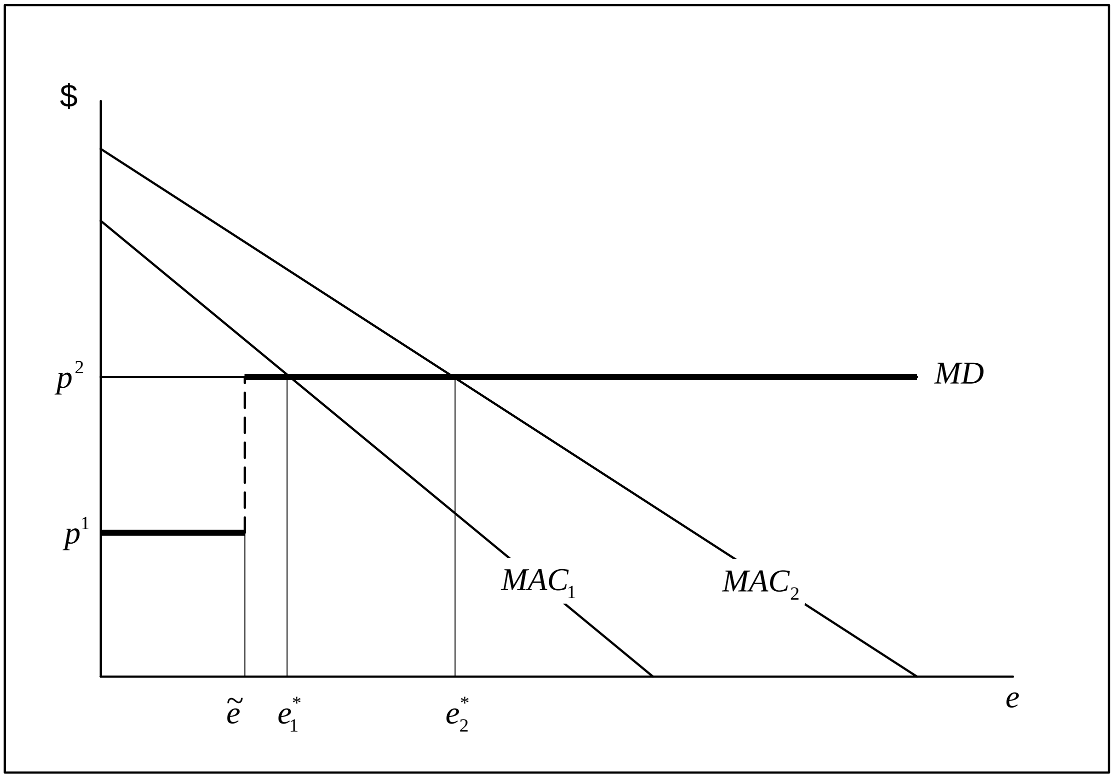

Figure 10a

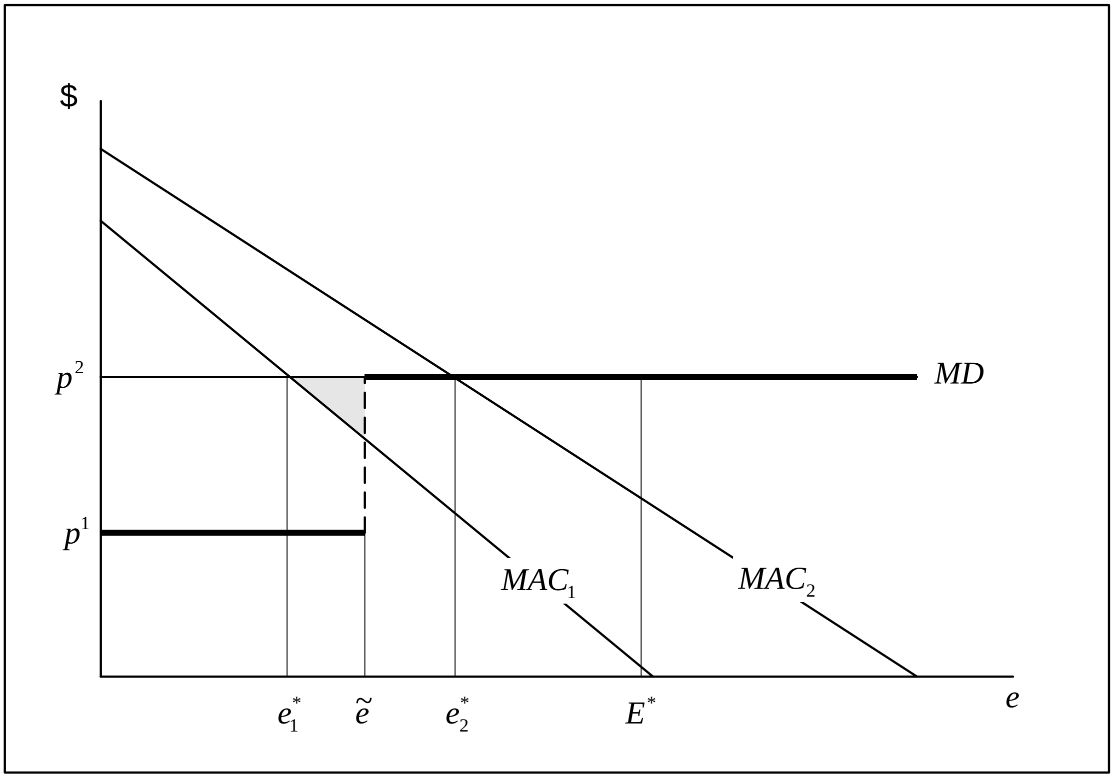

Figure 10b

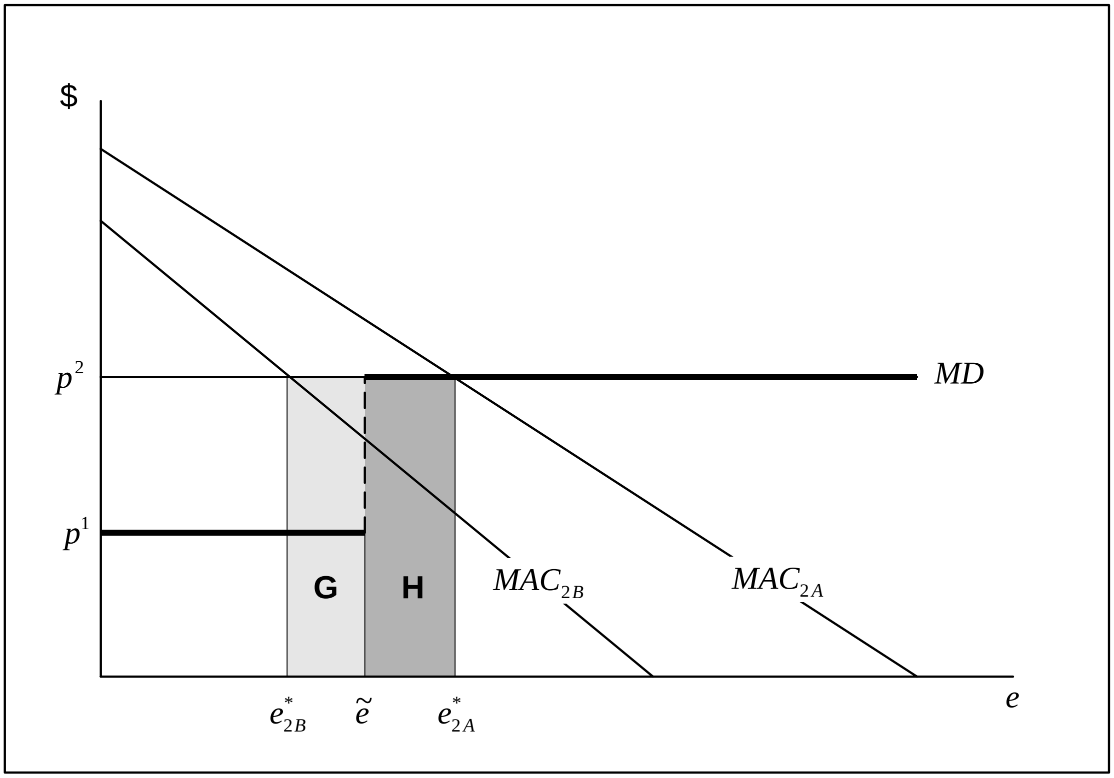

Figure 11

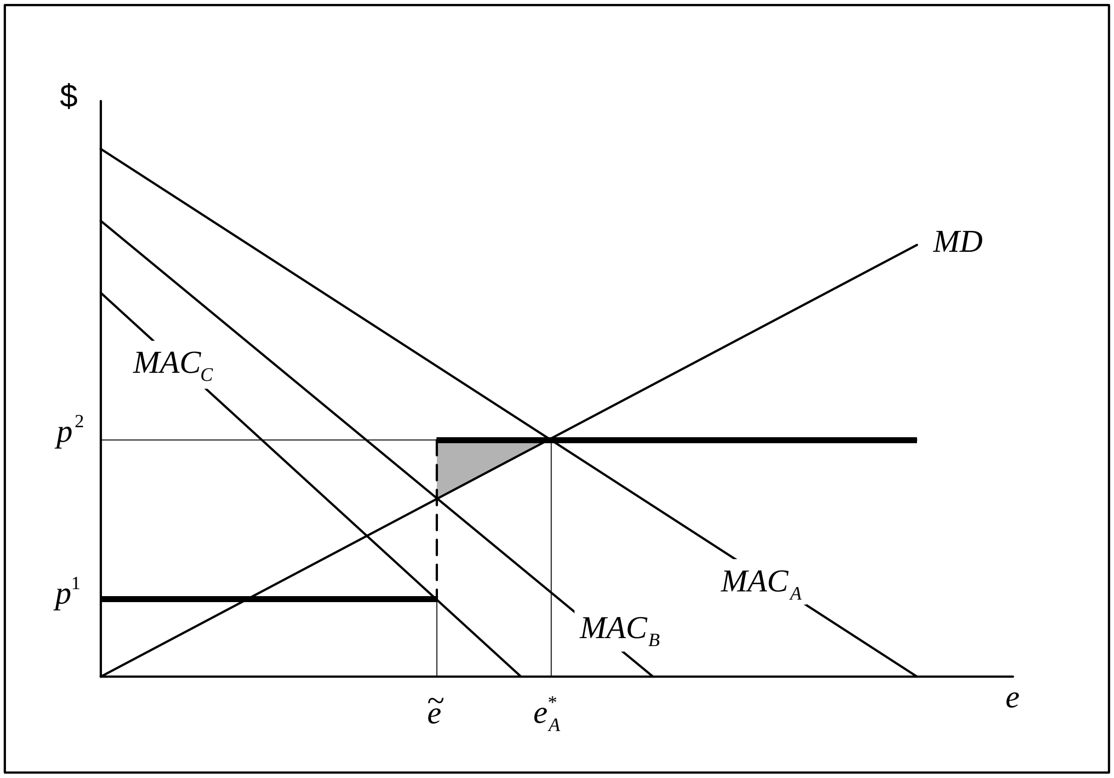

Figure 12

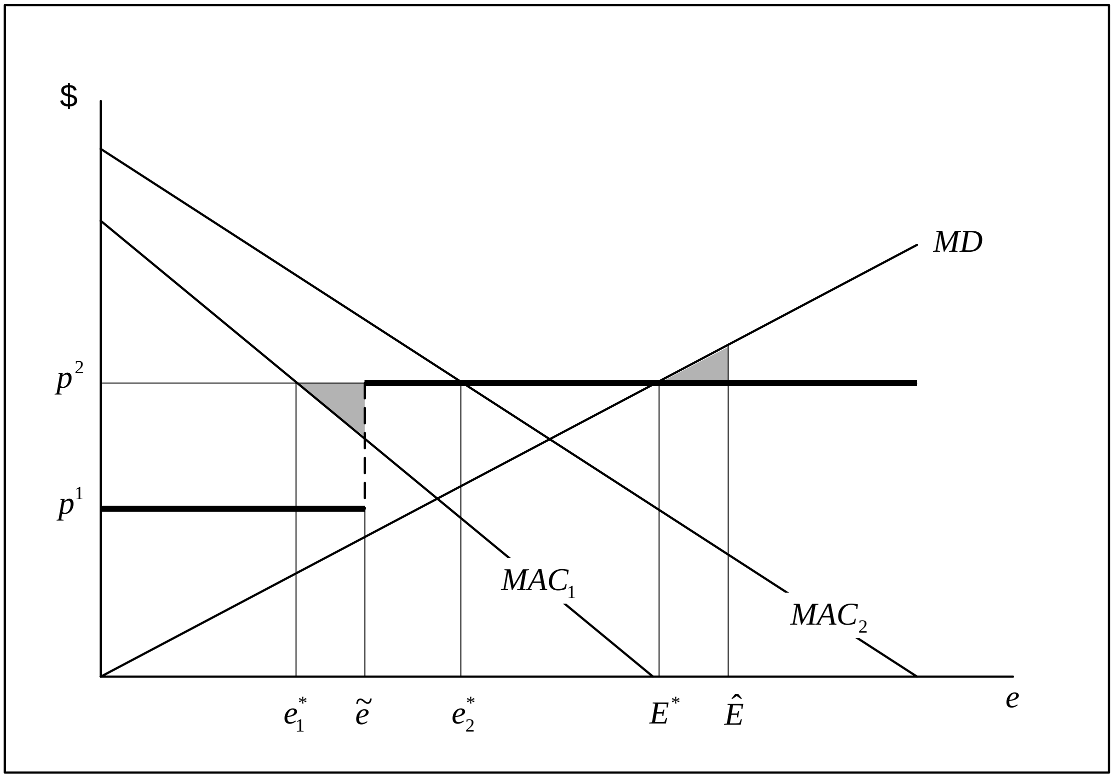

Figure 13