Copyright and market structure under vertical relations

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Abstract

The purpose of this study is to investigate the copyright protection of intellectual property under vertical relations. Vertical relations among author, manufacturer and retailer are considered. We develop several models, each with a different structure of vertical integration. R&D levels, total quantities, profits and social welfare levels are compared. We also investigate the effect of copyright protection by modeling the cases of perfect protection, partial protection and no protection. We analyze whether copyright benefits social welfare. We explain the policy implications of our results for the protection of copyright.

JEL classification number: O31,O32,O34,C34

Key words: R&D, Patent, Copyright, Vertical Relations, Market Structure

1 Introduction

Recently, Apple Computer launched its new tablet computer iPad, which is selling well. An important facility of the iPad is that, like Amazon's Kindle, it can be used to read a digital book. Sales of digital books are expanding because of competition between Apple's iPad and Amazon's Kindle. However, the recent emergence of the digital book has created problems. The most important problem relates to the copyright of books. It is generally difficult to copy books because the copying of hundreds of pages is tiring and time consuming. Hence, there is little danger of the infringement of copyright arising because of the copying of printed books. However, it is easy to copy digital books. Therefore, many cases of copyright infringement may arise.

Boldrin and Levine (2005) claim that digital books are free. They also assert that all digital products, such as computer programs, music, art and literary works, must be free, because they are public goods and can only prosper if many people participate in voluntarily creating them. Because digital products are free, many people are motivated to create them.

Shy (2001) and Kinokuni (2003) investigated copyright. Stronger copyright protection raises the profits of both publishers and authors. Profit increases raise publishers' monopoly rents. Weaker copyright protection lowers monopoly rents and prices and thereby increases social welfare.

Another important problem is the potential destruction of the structure of the publishing industry, which comprises authors, publishers, printing houses, agencies and bookstores. Digital books are easy to copy, rather than buy from bookstores. Furthermore, digital books do not need printing, which makes printing houses redundant. Authors selling digital books directly on the Internet diminish the role of publishers. Hence, the emergence of digital books is bound to transform the structure of the book world under vertical relations.

Generally, vertical structures comprising separate upstream and downstream firms are inefficient because they generate double margins (Tirole, 1988). Being monopolists, upstream and downstream firms earn monopoly rents. Therefore, the vertical integration of upstream and downstream firms improves efficiency. The purpose of this study is to investigate the protection of the copyright of intellectual property considering the structure of vertical integration. Therefore, we develop several models, each with a different structure of vertical integration. Research and development (R&D) levels, total quantities, profits and social welfare levels are compared. The effect of copyright protection is also considered. We explain the policy implications of our results.

Our paper is organized as follows. The model is presented in Section 2. A model with copyright protection is investigated in Section 2.1. A model without copyright protection is studied in Section 2.2. The conclusion is presented in Section 3.

2 Model

We model the invention of intellectual property by an individual author, artist or programmer. There are contracts between individuals and publishing companies dealing with the copyright of invented intellectual property. The intellectual property invented by authors, artists and programmers is transformed into final products for consumers by publishing companies. Products are sold to consumers by publishing companies or retailers, such as bookstores, record shops and computer shops. Therefore, a three-stage process governs the dissemination of products from authors, artists and programmers to consumers through publishing companies and retailers.

[Fig. 1]

In the first stage, the upstream stage, the author, artist or programmer (henceforth termed the author) invents some intellectual property through R&D investment. In the second, middle, stage, the publishing company (henceforth, the manufacturer) produces products based on the intellectual property of the author and supplies these products to downstream firms. In the third stage, the downstream stage, the downstream firm (henceforth, the retailer) supplies the manufactured products directly to consumers.

Participants in different stages are independent of each other. That is, different companies and individuals are engaged in each stage. Stages are not vertically integrated. In practice, these stages may be vertically integrated or not, so we model both situations. The three stages are authorship, manufacture and retailing. Depending on the structure of the vertical integration of each stage, these three stages reduce to two or one stage.

Currently, intellectual property is actively protected. Many argue that copyright protection is not conducive to social welfare (Boldrin and Levine, 2008). Moreover, copyright protection differs among countries. Therefore, the strength of copyright protection should be considered. We consider the following three cases. The first is the case in which copyright protection is perfect. The second is the case in which there is no copyright protection. In the third case, copyright protection is partial. We draw out the policy implications of copyright protection.

2.1 Perfect protection

2.1.1 Nonvertical integration

In this section, we consider a three-stage market: that is, one with no vertical integration. In this section, copyright protection is perfect. We solve our model backwards to obtain a subgame perfect Nash equilibrium. Thus, we first solve the final stage of the game, corresponding to the downstream. We assume that there are

two retailers in the market. The duopolists sell their products under Cournot competition. Therefore, product quantities are determined. In the second stage, which corresponds to the middle stream, there is only one firm in the market, and that firm owns the copyright of the work invented by the author. Hence, the firm is a monopoly. The monopolist manufacturer determines the prices at which products are shipped to retailers. In the first stage of the game, which corresponds to the upstream, the level of R&D is determined by the author. The level of R&D determines the quality of the invention.

First, we model the behavior of retailers in the third stage. We let q_i denote the output of retailer i and let e denote the R&D investment of the author. Two retailers engage in Cournot competition in this stage. The inverse demand function is:

$$p = a - Q + e. \tag{1}$$

We let $Q = q_1 + q_2$, where Q denotes total output and a is a parameter. The individual's R&D investment in the invention is included in the above inverse demand function. R&D determines product quality. An increase in R&D investment raises output by increasing quality. The profit of firm 1 is:

$$\pi_{R,1}^{PNV} = pq_1 - wq_1 - cq_1. \tag{2}$$

The selling cost is denoted by c. The subscript R denotes the retailer and the superscript PNV denotes no vertical integration under perfect protection, which means that each retailer, manufacturer and author are not integrated. The first-order condition for firm 1 leads to:

$$q_1 = \frac{a - c + e - w}{2} - \frac{q_2}{2}. \tag{3}$$

This is the reaction function of firm 1. The equilibrium output is:

$$q_1 = \frac{a - c + e - w}{3}. \tag{4}$$

The total output of the industry is:

$$Q = \frac{2(a - c)}{3} + \frac{2}{3}e - \frac{2}{3}w. \tag{5}$$

In the second stage, there is only one firm, which we call the manufacturer. This firm buys the copyright from the author, produces the products and sells them to the retailer. Therefore, the manufacturer has a contract with the author. The manufacturer must pay a fee to the author. The contract specifies that a fixed fee be paid by the manufacturer to the author. The profit of the manufacturer is:

$$\pi_M^{PNV} = wQ - dQ - F \tag{6}$$

The manufacturer is denoted by M, and d is the cost of production and F is the fixed fee paid by the manufacturer to the author. The manufacture$r$ chooses the shipment price, w, to maximize profit. Hence, the shipment price is:

$$w = \frac{(a-c)+d}{2} + \frac{e}{2}. \tag{7}$$

In the first stage, the author produces intellectual property. The effort expended in producing the intellectual property is interpreted as the author's R&D. Therefore, the author maximizes profit subject to the constraint that the manufacturer's profit is nonnegative. This ensures that the manufacturer participates in the industry.

$$Max_e \ \pi_A^{PNV} = F - \frac{e^2}{2} \tag{8}$$

$$s.t. \ wQ - dQ - F = 0 \tag{9}$$

R&D is given by:

$$e_A^{PNV} = \frac{a-c-d}{2}. \tag{10}$$

The author is denoted by A. The author's R&D depends on production and selling costs. Substituting (10) into (7) yields:

$$w^{PNV} = \frac{3(a-c)+d}{4}. \tag{11}$$

An increase in the manufacturer's production cost increases the shipment price. An increase in the retailer's selling cost decreases the shipment price. Substituting (10) and (11) into (5) yields:

$$Q^{PNV} = \frac{(a-c-d)}{2} \tag{12}$$

An increase in either the manufacturer's production cost or the retailer's selling cost decreases the total quantity of products. Substituting (10) and (12) into (1) yields:

$$p^{PNV} = \frac{3a+2d}{3} \tag{13}$$

An increase in the manufacturer's production cost increases the industry price. Substituting (10), (11), (12) and (13) into (2) yields:

$$\pi_R^{PNV} = \frac{(a-c-d)^2}{4} \tag{14}$$

This is the profit of the retailer. Substituting (9), (10), (11), (12) and (13) into (8) yields:

$$\pi_A^{PNV} = \frac{(a-c-d)^2}{4} \tag{15}$$

This is the profit of the author. Social welfare is:

$$SW^{PNV} = \frac{5(a-c-d)^2}{16} \tag{16}$$

2.1.2 Vertical Integration between retaler and manufacture

The model of the previous section has a separate retailer, manufacturer and author. In this section, we construct a model in which the retailer and manufacturer are integrated. Therefore, the market is assumed to be monopolistic. The price is given by:

$$p = a - Q + e. \tag{17}$$

First, the retailer and manufacturer are integrated. (We call this company RM.) The author receives a fixed fee from RM. The profit of RM is:

$$\pi_{RM}^{PV} = pQ - dQ - cQ - F. \tag{18}$$

Vertical integration under perfect protection is denoted by the superscript PV. The RM maximizes its profit. The first-order condition is:

$$Q = \frac{a+e-c-d}{2}. \tag{19}$$

The problem of the author can be written as:

$$Max_e \ \pi_A^{PV} = F - \frac{e^2}{2} \tag{20}$$

$$s.t.\ pQ - dQ - cQ - F = 0. \tag{21}$$

R&D is determined by:

$$e_A^{PV} = a - c - d. \tag{22}$$

$$Q^{PV} = a - c - d \tag{23}$$

$$p^{PV} = a \tag{24}$$

The level of R&D under vertical integration is higher than that under no vertical integration. Quantity is higher under vertical integration than under no vertical integration. These results indicate the effects of vertical integration. Generally, separate upstream and downstream firms are less efficient than vertically integrated firms because of the generation of double margins (Tirole, 1988). The profit of the author and social welfare are given by:

$$\pi_A^{PV} = \frac{(a - c - d)^2}{2} \tag{25}$$

$$SW^{PV} = (a - c - d)^2 \tag{26}$$

Proposition 1 *The profit of the author and social welfare are higher under vertical integration than under no vertical integration.*

Proof of Prposition 1 *See Table 1 in 2.3.*

This result arises because vertical integration eliminates double margins.

2.1.3 Vertical integration among, retaler, manufacuture and author

The model in Section 2.1.1 has a separate retailer, manufacturer and author. The model in Section 2.2.2 has a vertically integrated retailer and manufacturer. In this section, the retailer, manufacturer and author are all integrated. Therefore, there is complete vertical integration. To be specific, the author, who has the right to his or her intellectual property, produces products and sells them to consumers. (We call this organization RMA.) The price is given by:

$$p = a - Q + e \tag{27}$$

The problem that the individual company faces is:

$$Max \;\; \pi_{RMA}^{PV} = F - \frac{e^2}{2} \tag{28}$$

$$s.t.\; pQ - dQ - cQ - F = 0. \tag{29}$$

The individual company chooses quantity and R&D levels to maximize profit:

$$\frac{\partial \pi_{RMA}^{PV}}{\partial Q} = a - 2Q + e - d - c = 0 \tag{30}$$

$$\frac{\partial \pi_{RMA}^{PV}}{\partial e} = Q - e = 0. \tag{31}$$

When only the manufacturer and retailer are integrated, R&D and quantity levels are obtained from (19) and (22). When the author, manufacturer and retailer are integrated, R&D and quantity levels are obtained from (30) and (31). Despite slight differences in obtaining solutions, the problems are the same in both cases. Hence, complete and partial vertical integration generate identical levels of profit and social welfare.

2.2 Non protextion

So far, we have assumed that protection of the intellectual property rights of authors is perfect. Authors are paid fixed amounts by publishing companies for their intellectual property rights. In this section, we eliminate the assumption that authors' intellectual property rights are protected perfectly. This lack of protection affects market behavior. We compare the outcomes under protection with those under none.

2.2.1 Non vertical integration

The manufacturer produces products without paying a fee to an author. The retailer buys the products from the manufacturer and sells them to consumers.

[Fig. 2]

This is a two-stage model. In the first stage, the manufacturer produces products without paying an author. The manufacturer sells the products to the retailer. In the second stage, the retailer sells the products to consumers. The structure of this model is the same as that in which there is no vertical integration between retailer, manufacturer and author (2.1.1), and there is no author. (The game described in this section is independent of the author.) Therefore, the second stage of the game in this model is the same as that in the model of Section 2.1.1, with the author excluded. The behavior of retailers is described by equation (2). The optimal quantity is given by equation (5). The manufacturer chooses the optimal shipment price based on the price and quantity obtained from the second stage of the game.[1] The behavior of the manufacturer is the same as in the model in Section 2.2.1. The optimal shipment price solves equation (6). The shipment price is given by equation (7). Therefore, the shipment price charged by the publishing company is:

[1] The quantity is given by equations (4) and (5).

$$w_M^{NPNV} = \frac{a - c + e + d}{2}. \tag{32}$$

No protection and no vertical integration is denoted by NPNV. The shipment price depends on R&D. If copyright is protected, R&D is determined by the author. In a model incorporating the protection of property rights, R&D is endogenously determined by the author. By contrast, in this model, which excludes the protection of property rights, R&D is an exogenous variable. We do not assume that property rights are protected in this model; however, one can assume that property rights are partly protected. In such a case, the author's property rights are protected by a contract with one manufacturer, but other manufacturers can produce products without having a contract with the author. We model this in a later subsection.

The market price and quantity are:

$$Q^{NPNV} = \frac{(a - c) + e - d}{3} \tag{33}$$

$$p^{NPNV} = \frac{2a + c + 2e - d}{3}. \tag{34}$$

Proposition 2 *Total quantity depends on R&D. Total quantity under partial copyright protection is higher (lower) than under perfect copyright protection if the level of R&D is particularly high (low).*

Proof of Prposition 2 *See Table 1.*

If the R&D level is particularly high, total quantity is high when there is no protection. Therefore, quantity depends on the level of R&D. If the level of R&D is low, so is quantity.

Based on the quantity and price expressions given by (33) and (34), we obtain the following expressions for profit and social welfare:

$$\pi_M^{NPNV} = \frac{(a - c + e - d)^2}{36} \tag{35}$$

$$SW^{NPNV} = \frac{3(a - c + e - d)^2}{12} \tag{36}$$

Proposition 3 *The profit of the manufacturer and social welfare are both higher (lower) when there is no protection of property rights than when property rights are protected if the level of R&D is particularly high (low).*

Proof of Prposition 3 *See Table 1 in 2.3.*

The policy implication of these results is that the protection of property rights should be abolished. This is because of the case in which welfare is lowest when there is perfect protection. However, in this section, the R&D level is exogenous. Because property rights are not protected, authors cannot benefit from such protection. Hence, it is not surprising that the level of R&D is low. Social welfare is also low.

2.2.2 Vertical integration

In the model of the previous section, the retailer and manufacturer are not integrated. In this section, we assume that the retailer and manufacturer are integrated. The price is given by (27).

The profit is:

$$\pi^{NPV} = pQ - cQ - dQ. \tag{37}$$

No protection under vertical integration is denoted by NPV. The integrated firm chooses quantity to maximize profit. We obtain the following first-order condition:

$$Q^{NPV} = \frac{a - c + e - d}{2}. \tag{38}$$

The price is given by:

$$p^{NPV} = \frac{a + c + e + d}{2}. \tag{39}$$

Proposition 4 *In the absence of copyright protection, total quantity under vertical integration is higher than under no vertical integration. Total quantity under vertical integration without protection is higher than under no vertical integration with protection even if the R&D level is low.* [2]

Proof of Prposition 4 *See Table 1 in 2.3.*

The above result is noteworthy because the policy implication is that eliminating double margins under no vertical integration is better than copyright protection. Therefore, copyright protection is not necessarily the best policy. The structure of the industry constituted by retailers, manufacturers and authors is important.

By using (37) and (38), profit and social welfare can be written as:

$$\pi_{RM}^{NPV} = \frac{(a - c + e - d)^2}{4} \tag{40}$$

$$SW_{RM}^{NPV} = \frac{3(a - c + e - d)^2}{8}. \tag{41}$$

[2]Under vertical integration, total quantity with protection is higher than without protection if R&D is low.

Proposition 5 *In the absence of copyright protection, profit and social welfare are higher under vertical integration than under no vertical integration. Profit and social welfare under vertical integration without protection are higher than under no vertical integration with protection even if the level of R&D is low.*[3]

Proof of Prposition 5 *See Table 1 in 2.3.*

Efficiency under vertical integration without the protection of property rights is always higher than that under no vertical integration with protection. In this section, because the R&D level is treated as exogenous, we cannot control the level of R&D. Even if there is little R&D, efficiency under vertical integration without the protection of property rights is always higher than that under no vertical integration with protection. These results arise because of vertical integration. By integrating retailer and author, vertical integration eliminates their double margins. Vertical integration is more effective than the protection of property rights.

2.2.3 Duopoly

In this section, there are two firms in the industry: one is a contract firm (C firm) and the other is a noncontract firm (NC firm). The structure of the C and NC firms is that retailer and manufacturer are integrated. The C firm has a contract with the author. We assume that this contract satisfactorily protects property rights. The NC firm produces products without having a contract with the author. This firm violates the author's property rights. The model of this section describes a two-stage game. In the first stage, the author determines the R&D level. In the second stage, each firm determines its quantity.

The price is determined by (1). Under the protection of property rights, the profit of the C firm is:

$$\pi_{D,C}^{PPV} = pq_{D,C} - dq_{D,C} - cq_{D,C} - F \tag{42}$$

Duopoly is denoted by D, and partial protection under vertical integration is denoted by PPV. The problem is:

$$Max_{q_{D,C}} \ \pi_{D,C}^{PPV} = pq_{D,C} - dq_{D,C} - cq_{D,C} - F, \tag{43}$$

The first-order condition is:

$$q_{D,C}^{PPV} = \frac{a-c-d+e}{2} - \frac{q_{D,NC}^{PPV}}{2} \tag{44}$$

The profit of the NC firm is:

[3]Under vertical integration, retailer profit and social welfare are higher with protection than without protection if the R&D level is low.

$$\pi_{D,NC}^{PPV} = pq_{D,NC} - dq_{D,NC} - cq_{D,NC} \tag{45}$$

The problem is:

$$Max_{q_{D,NC}} \ \pi_{D,NC}^{PPV} = pq_{D,NC} - dq_{D,NC} - cq_{D,NC}. \tag{46}$$

The first-order condition is:

$$q_{D,NC}^{PPV} = \frac{a - c - d + e}{2} - \frac{q_{D,C}^{PPV}}{2} \tag{47}$$

The total market quantity is:

$$Q_{D}^{PPV} = \frac{2(a - c - d)}{3} + \frac{2e}{3}. \tag{48}$$

The problem of the author is:

$$Max \ \pi_{A}^{PPV} = F - \frac{e^2}{2} \tag{49}$$

$$s.t. \ pq_{D,C} - dq_{D,C} - cq_{D,C} - F = 0. \tag{50}$$

The R&D level is:

$$e^{PPV} = \frac{2(a - c - d)}{7} \tag{51}$$

Proposition 6 *In the duopolistic market, the R&D level with partial protection under vertical integration is lower than that with perfect protection whether or not there is vertical integration.*

Proof of Prposition 6 *See Table 1 in 2.3.*

Because partial protection reduces the incentive to undertake R&D, its level declines. The C firm has a contract with the author whereas the NC firm does not. Only the C firm pays a fee to the author. In using the intellectual property of the author, the NC firm behaves as a free rider. Therefore, the R&D of the author is determined based on the quantity of the C firm. When there is perfect protection, the C firm's quantity is lower than the combined quantities of the C and NC firms whether or not there is vertical integration. Hence, under duopoly, R&D is lower when there is partial protection than when there is perfect protection whether or not there is vertical integration.

The market quantity and price are given by:

$$Q_D^{PPV} = \frac{6(a-c-d)}{7} \tag{52}$$

$$p_D^{PPV} = \frac{3a+2c+2d}{7} \tag{53}$$

Proposition 7 *In the duopolistic market, quantity is higher with partial protection under vertical integration than with perfect protection under no vertical integration, and lower than with perfect protection under vertical integration.*

In the duopolistic market, quantity with partial protection is second only to quantity under vertical integration with perfect protection. The duopoly quantity with partial protection is higher than when there is no vertical integration with perfect competition. Hence, the effects of vertical integration are strong.

By using the above results, we obtain the following profit and social welfare levels:

$$\pi_A^{PPV} = \frac{(a-c-d)^2}{7} \tag{54}$$

$$\pi_{NC}^{PPV} = \frac{9(a-c-d)^2}{49} \tag{55}$$

$$SW^{PPV} = \frac{9(a-d)^2}{49} + \pi_A^{PPV} + \pi_{NC}^{PPV} \tag{56}$$

Proposition 8 *In the duopolistic market, the profits of the author and retailer and social welfare are higher with the partial protection of property rights than with perfect protection under no vertical integration. Duopoly author and retailer profits and social welfare with partial protection are lower than with perfect protection under vertical integration.*

Proof of Prposition 7 *See Table 1 in 2.3.*

The results relating to profit and social welfare match those relating to quantity. The ranking of R&D levels differs from those of quantity and social welfare. This difference arises because of the different number of participating firms. Under duopoly, only one firm participates in determining R&D. Otherwise, two firms participate in the determination of R&D. The increase in the number of firms increases efficiency in the industry.

2.3 Comparison of the results and policy implication

In this subsection, we compare equilibria and discuss policy implications. In particular, we examine the levels of R&D, total quantity and social welfare. All results are shown in Table 1.

[Table 1]

First, we discuss the R&D level. The highest R&D levels occur when retailer and manufacturer are integrated and there is perfect copyright protection, or when retailer, manufacturer and author are integrated and there is perfect copyright protection. The second-highest R&D level occurs when retailer and manufacturer are not integrated and there is perfect copyright protection. The lowest R&D level occurs under duopoly with partial copyright protection.

However, the R&D level is not uniquely determined under any level of copyright protection. Property rights confer no benefit unless there is copyright protection. Therefore, it is unsurprising that the R&D level is low when there is no protection. If authors are highly motivated to develop new technology, the R&D level may be high. For example, many scientists are willing to participate in developing Linux. Despite receiving little money for doing so, they are quite motivated to participate in development. Therefore, R&D levels could be high with or without copyright protection.

Second, we discuss the equilibrium total quantities. Total quantity is highest when retailer and manufacturer are integrated and there is perfect copyright protection, or when retailer, manufacturer and author are integrated and there is perfect copyright protection. Total quantity is second highest under duopoly when there is partial protection of property rights. Total quantity is lowest when retailer and manufacturer are not integrated and there is copyright protection. However, total quantity is not uniquely determined under any level of copyright protection. When there is no protection, total quantity depends on the level of R&D. If the R&D level is high, equilibrium total quantity may well be high. Total quantity is higher when there is no protection and little R&D than when protection is perfect and retailer and manufacturer are not integrated. Hence, policies that affect vertical relations in the market are more important than copyright policy.

Next, we compare equilibrium levels of social welfare. Results for social welfare are similar to those for quantity. Therefore, the ideal policy is to protect copyright and promote vertical integration. However, social welfare might be highest when there is no copyright protection. Hence, promoting voluntary R&D through education might be best for social welfare.

3 Concluding Remarks

In this paper, we investigated market structure and the copyright protection of inventions. We developed several models, each differing in terms of the structure of vertical integration and the level of copyright protection. Comparing equilibrium solutions enabled us to draw policy implications.

First, we developed and analyzed models in which the protection of property rights is perfect. In all the models, vertical integration maximizes efficiency. Second, we modeled the lack of copyright protection. In

this case, the level of R&D is exogenous. When there is no copyright protection, there is no contract between publisher and author. Because there is no compulsion to invent, there is no incentive to expend R&D effort. Therefore, in this model, no R&D is undertaken. However, if R&D were high for some reason, efficiency might also be high. We found that, under no vertical integration, efficiency is higher when there is no copyright protection than when there is copyright protection. Third, we modeled partial copyright protection under vertical integration. The players in this model are an author and two retailers or publishers. Because only one firm has a contract with the author for copyright, copyright protection is partial. In this model, relative to one in which there is perfect protection under vertical integration, efficiency is high.

Our model is useful for evaluating the effects of protecting property rights in a general context. However, if there are particular incentives to, for example, develop open software such as Linux, there is no need to protect property rights. Hence, copyright protection might harm social welfare. Resolving this issue requires further research.

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Table 1: Comparion of model

	PNV	*PV(RM)*	*PV(RMA)*	*NPNV*	*NPV*	*PPV*
e	$\frac{21(a-c-d)}{42}$	$\frac{42(a-c-d)}{42}$	$\frac{42(a-c-d)}{42}$			$\frac{12(a-c-d)}{42}$
Q	$\frac{21(a-c-d)}{42}$	$\frac{42(a-c-d)}{42}$	$\frac{42(a-c-d)}{42}$	$\frac{14(a-c+e+d)}{42}$	$\frac{21(a-c+e-d)}{42}$	$\frac{36(a-c-d)}{42}$
π_R	$\frac{1764(a-c-d)^2}{7056}$			$\frac{196(a-c-d+e)^2}{7056}$	$\frac{1764(a-c-d+e)^2}{7056}$	$\frac{1296\ (a-c-d)^2}{7056}$
π_A	$\frac{1764(a-c-d)^2}{7056}$	$\frac{3528(a-c-d)^2}{7056}$	$\frac{3528(a-c-d)^2}{7056}$			$\frac{1008(a-c-d)^2}{7056}$
SW	$\frac{2205\ (a-c-d)^2}{7056}$	$\frac{7056\ (a-c-d)^2}{7056}$	$\frac{7056\ (a-c-d)^2}{7056}$	$\frac{720(a-c-d+e)^2}{7056}$	$\frac{2430(a-c-d+e)^2}{7056}$	$\frac{2736\ (a-c-d)^2}{7056}$

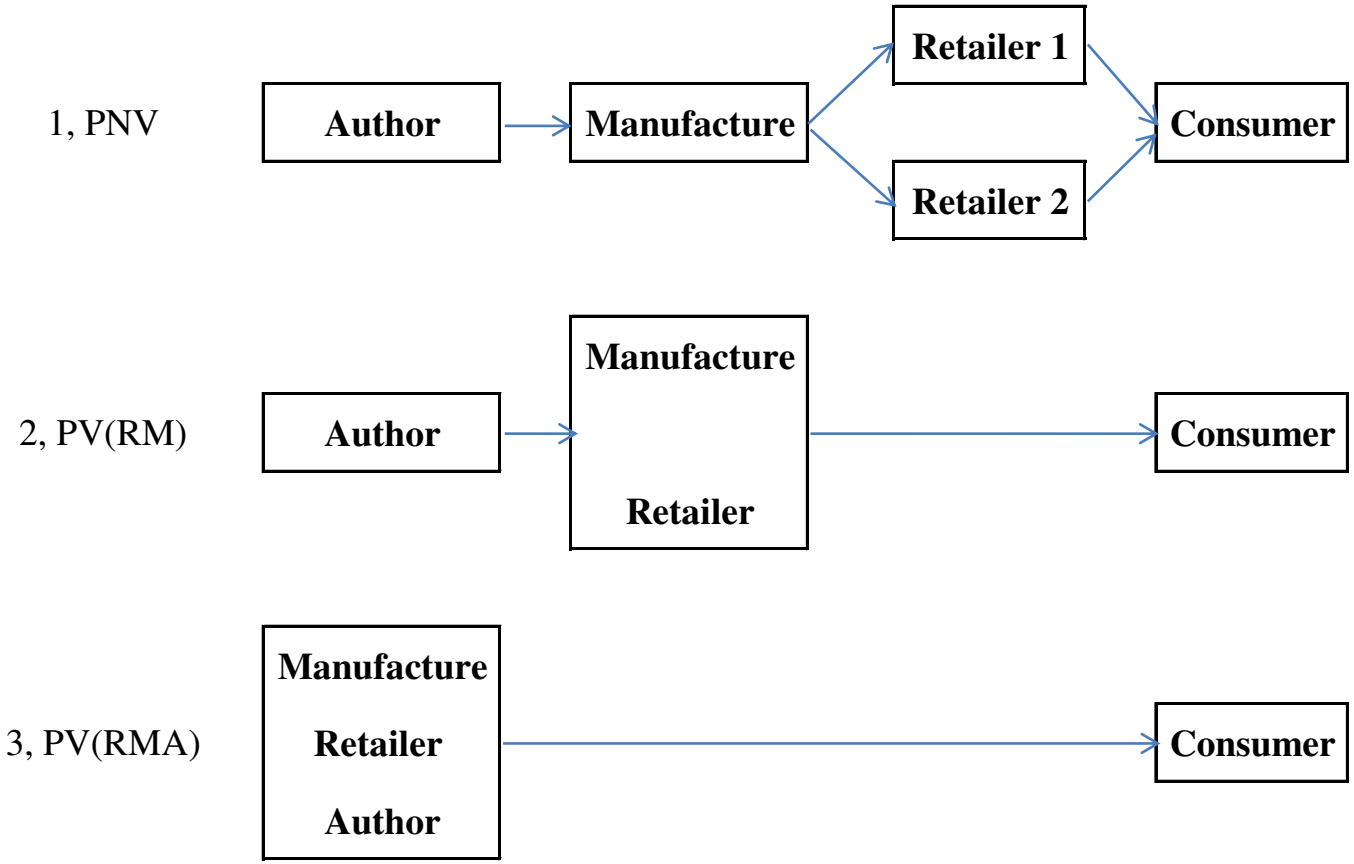

Fig. 1 Structure of Vertical relations (Perfect Protection)

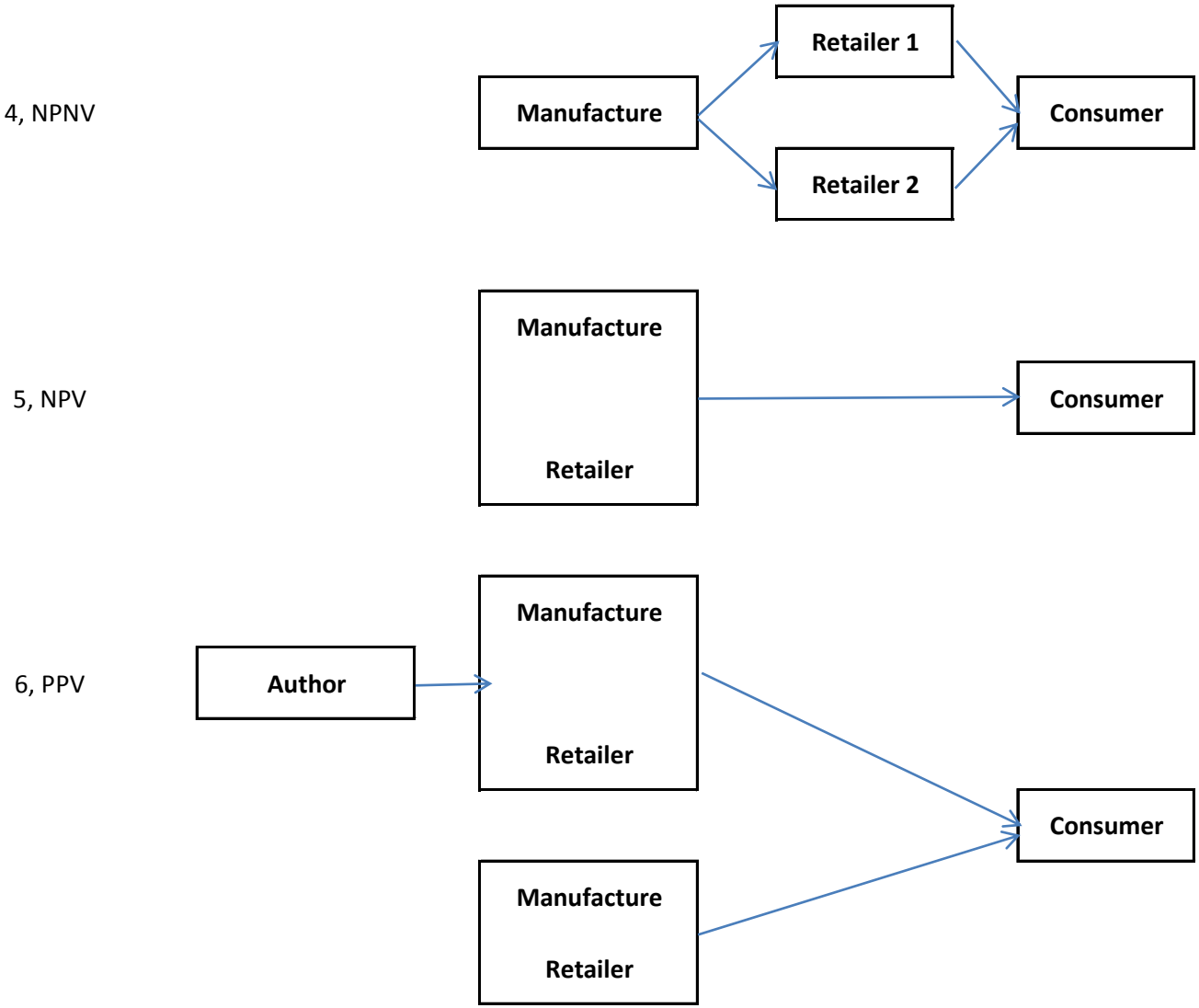

Fig. 2 Structure of Vertical relations (Non-Perfect Protection)