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Abstract

Do monitoring technologies increase a principal's profits if he has to compete with others for an agent? While monitoring improves the risk-incentive tradeoff, it also reduces the costs for a rivaling principal to offer a more attractive contract. We show that when the agent's prudence is smaller than two times risk aversion, equilibrium profits are lower when monitoring is available if there is some competition. When prudence is larger than two times risk aversion, equilibrium profits are higher when motoring is available. Conversely, the agent benefits from monitoring when competition is intense but can be hurt when it is mild.

JEL Classification: D81, D82, D86

Keywords: competition, monitoring, moral hazard, prudence

1 Introduction

Recent technological breakthroughs enable principals to monitor the agents' private actions better. By the end of 2018, it is estimated that eighty percent of new cars for sale in the U.S. will come with on-board telematics devices and, by 2020, seventy percent of all auto insurers will use telematics.[1] The Chinese conglomerate Alibaba, which owns an insurance franchise, collects client data through

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[1] https://www.naic.org/documents/consumer_alert_understanding_usage_based_insurance.htm

mobile apps tied to other services it offers: finance, e-commerce, and map services. Wearable devices have also begun to make their ways to the health insurance industry (Raber et al. (2019)). UPS even finds monitoring its drivers an effective way to raise their productivity.[2]

Does monitoring technology bring more profits to principals when they compete with each other for an agent? While monitoring makes the risk-incentive tradeoff more efficient, larger surpluses also make it easier for rivaling principals to offer a more competitive contract. Hence it is unclear whether those technological breakthroughs increase competing principals' profits. We answer this question in a canonical agency model.

Consider a model in which risk-neutral principals contract exclusively with a risk-averse agent. The agent's actions determine the probabilities of good and bad outcomes. The principals attract the agent through the indirect utilities offered by the contracts. When there is no monitoring, the contracts have to be incentive compatible. When there is monitoring, incentive compatibility can be ignored. Competition intensity is captured by a parameter akin to the inverse of traveling costs in a Hotelling model so that the higher the intensity, the stronger the incentives for a principal to offer a more attractive contract.

We find that when the agent's prudence ($-u'''/u''$) is smaller than three times risk aversion ($-u''/u'$), the marginal cost of increasing the utility offered is smaller when there is monitoring. When prudence is smaller than two times risk aversion (e.g., CARA utilities), sufficiently-intense competition, coupled with the smaller marginal cost, makes the equilibrium profits with monitoring lower than that without monitoring. When the opposite condition holds, however, monitoring leads to higher equilibrium profits.[3] Conversely, the agent is not hurt by monitoring if competition is sufficiently intense but may receive lower utilities with monitoring when competition is mild.

We assume that monitoring, when available, is costless. This ensures that for each level of indirect utility promised to the agent, the principal's profit, conditional on a successful hire, is higher than the no-monitoring profit. Thus, even if monitoring (telematics devices, wearables) is an endogenous part of the contract, it is dominant for a principal to use it provided that the agent is not averse of being monitored.[4] Therefore, we take monitoring, or lack thereof, as exogenous.

[2] https://www.npr.org/sections/money/2014/04/17/303770907/

[3] Similar conditions have long appeared in the economics of uncertainty. For example, the case $k = 1$ of the inequality $-u'''u' + ku''^2 \leq 0$ dates back to Pratt (1964) and the case $k = 2$ is studied in Gollier (2004).

[4] For any no-monitoring contract with agent utility $\underline{u}$, the principal can instead choose a monitoring contract that promises the agent with a utility of $\underline{u} + \epsilon$ so that both the principal and the agent get better-off. This logic breaks down when there are two types of agents. For example, Jin & Vasserman (2019) find that in the U.S. auto insurance market,

The Literature This paper relates to the study of competition in markets with asymmetric information (Rothschild & Stiglitz (1976),Arnott & Stiglitz (1991),Biglaiser & Mezzetti (1993)). Those papers impose zero-profit conditions (i.e., perfect competition or Bertrand competition) and focus instead on who contract with which agent, the implemented effort level, etc. Imperfect competition models, which are indispensable to study profits, have appeared in the study of banking competitions (e.g., Villas-Boas & Schmidt-Mohr (1999)) and more recently in (Bénabou & Tirole (2016)) and (Mahoney & Weyl (2017)).

Villas-Boas & Schmidt-Mohr (1999) is also the first to show that more information may lead to lower profits. They show in a model of Hotelling competition between banks with adverse selection that the profits under asymmetric information can be higher or lower than that under symmetric information, depending on how low the low type is. Nevertheless, the literature has shown little interest in pursuing this question.

The effect of reducing information asymmetry on welfare in a competitive environment has also received some attention. Baltzer (2012) shows, in a model of Bertrand competition with product quality, that the welfare under asymmetric information is higher than that under full information. Lester et al. (2019) show in an adverse selection model that reducing information asymmetries can worsen the distortions from adverse selection.

The interplay of monitoring, or more generally, the precision of the agent's performance signal, with other endogenous variables in agency models, has also been investigated. Demougin & Fluet (2001) study the optimal monitoring-money incentive mix to induce efforts. Chaigneau et al. (2018) show that precision could lead to less agent effort.

We study, in a moral hazards model, how the absence or presence of the incentive compatibility constraint affect the principals' profits for different levels of competition intensity.

We state the model in Section 2, present the results in Section 3 and conclude in Section 4. Proofs are in the Appendix.

2 Model

Two principals, $i = 1, 2$, compete to hire an agent for a task through exclusive contracts.

The agent has a three-times differentiable utility function $u : [0, \infty) \to \mathbb{R}$ with $u' > 0, u'' < 0$ and $u^{-1} = v$. The total surplus is x_H in the high state and x_L in the low state, with $x_H > x_L > 0$.

only safe drivers self-select to be monitored.

The agent chooses an action $a \in \{L, H\}$ that results in probability p_a ending up in the high state, with $0 < p_L < p_H < 1$ and expected surplus $E_a = p_a x_H + (1 - p_a)x_L$. Action a has cost c_a where $c_H = c > 0$ and $c_L = 0$.

A contract is a tuple (w_H, w_L, a) where w_H, w_L are the wages the agent gets when the state is high or low and a is the implemented action.[5]

The expected utility of the agent under contract (w_H, w_L, a) is

$$p_a u(w_H) + (1 - p_a)u(w_L) - c_a.$$

The agent's autarky utility is $\underline{u}^* \in [0, p_H u(x_H) + (1 - p_H)u(x_L) - c]$. In an insurance model $\underline{u}^* = p_H u(x_H) + (1 - p_H)u(x_L) - c$ but in a delegation model $\underline{u}^* = 0$ is also reasonable.

The profit of a principal if an agent signs up a contract that implements action a is

$$\Pi_a = E_a - p_a w_H - (1 - p_a)w_L \tag{1}$$

A contract implementing a promises the agent an utility of $\underline{u}$ if

$$p_a u(w_H) + (1 - p_a)u(w_L) - c_a = \underline{u} \tag{PK}$$

The feasible set of $\underline{u}$ when implementing $a = L$ is $[\underline{u}^*, u(E_L)]$, where the lower bound ensures individual rationality and the upper bound ensures non-negative profit. The feasible set when implementing $a = H$ when there is monitoring is $[\underline{u}^*, u(E_H) - c]$.

Implementing $a = L$ with or without monitoring and implementing $a = H$ with monitoring are straightforward. The risk-neutral principal gives the risk-averse agent a constant wage w with $u(w) - c_a = \underline{u}$ and obtains optimal profits

$$\Pi_L(\underline{u}) = E_L - v(\underline{u}) \tag{2}$$

when implementing L and

$$\Pi_H^M(\underline{u}) = E_H - v(\underline{u} + c) \tag{3}$$

when implementing $a = H$ with monitoring.

To make the model non-trivial, we assume that when there is monitoring, implementing $a = H$ is more profitable for some $\underline{u} \geq \underline{u}^*$, which holds if c is sufficiently small.

Assumption 1. $\Pi_H^M(\underline{u}^*) > \Pi_L(\underline{u}^*)$.

[5] The model is isomorphic to an insurance model in which a contract specifies a deductible and a premium.

When there is no monitoring, a contract that implements the costly action $a = H$ has to be incentive-compatible:

$$p_H u(w_H) + (1 - p_H)u(w_L) - c \geq p_L u(w_H) + (1 - p_L)u(w_L). \tag{IC}$$

In particular, constant wage violates (IC).

Assume that the agent is incentivized if he owns the project.

Assumption 2. $p_H u(x_H) + (1 - p_H)u(x_L) - c > p_L u(x_H) + (1 - p_L)u(x_L)$.

This guarantees the existence of an IC contract that gives positive profit.

Proposition 2.1. *When there is no monitoring, there exists $\overline{u} > \underline{u}^*$ such that for $\underline{u} \in [\underline{u}^*, \overline{u}]$, a contract implementing $a = H$ that maximizes (1) subject to (PK) and (IC) exists. The optimal profit is*

$$\Pi_H^N(\underline{u}) = E_H - p_H v\left(\underline{u} + c + \frac{(1 - p_H)c}{p_H - p_L}\right) - (1 - p_H)v\left(\underline{u} + c - \frac{p_H c}{p_H - p_L}\right) \tag{4}$$

with $\Pi_H^N(\overline{u}) = 0$. Furthermore, $\Pi_H^M(\underline{u}) > \Pi_H^N(\underline{u})$ for all $\underline{u}$.

Competition is modeled by a matching function. Let u_1, u_2 be the utilities each principal offers. The probability that principal i is matched with the agent is given by a twice-differentiable matching function $p(u_i, u_{-i}; y)$ with matching efficiency parameter $y \geq 0$ such that

Assumption 3.

1. $p(u_1, u_2; y) + p(u_2, u_1; y) = 1$.

2. $p_1 = \partial p(u_1, u_2; y)/\partial u_1 \geq 0$, $p_3 = \partial p(u_1, u_2; y)/\partial y > 0$ *when* $u_1 > u_2$.

3. $p_1(u_1, u_2; y)/p(u_1, u_2; y)$ *is decreasing in* u_1*,* $p_2(u_1, u_2; y)/p(u_1, u_2; y)$ *is increasing in* u_1 *and* $p_1(u, u; y)/p(u, u; y) = y$.

Principal i's expected profit is $p(u_i, u_{-i}; y)\Pi(u_i)$ where $\Pi(u_i)$ is given by (2), (3) or (4) depending on a_i and monitoring.

We give two matching processes that generate such matching functions. The first is noisy offers: for a contract with indirect utility u_i, the agent observes signals $s_i = u_i + \epsilon_i$ where ϵ_1, ϵ_2 are i.i.d normal r.v. with variance $1/\pi y^2$. The agent is matched with the principal with the higher signal.

The second is Hotelling competition on the unit interval where an agent's location is uniformly distributed with marginal traveling cost $1/y$. In the latter case one has to be careful with the boundary values.[6]

An equilibrium of the competing-principals game is a pair of contracts $(w_H^1, w_L^1, a_1), (w_H^2, w_L^2, a_2)$ that are mutual best-responses. An equilibrium is symmetric if both principals implement the same action and give the agent the same indirect utility. We analyze the profits and utilities under symmetric equilibria and show in Proposition A.2 that asymmetric equilibria do not exist.

3 Results

We now derive the principals' equilibrium profits and the agent's equilibrium utilities.

For any y, consider the auxiliary two-player normal-form games

$$p(u_i, u_{-i}; y)\Pi(u_i)$$

with strategy spaces $[\underline{u}^*, \Pi^{-1}(0)]$, where $\Pi(u_i)$ is given by (2), (3) or (4), respectively. The best response of principal 1 to u_2 is to offer indirect utility u_1 that satisfies the first-order condition

$$p_1(u_1, u_2; y)\Pi(u_1) + p(u_1, u_2; y)\Pi'(u_1) \leq 0, \quad u_1 \geq \underline{u}^*, \text{ with complementary slackness.}$$

Since p_1/p is decreasing in u_1 and $-\Pi'(u_1)/\Pi(u_1)$ is increasing in u_1, the best-response is unique. Furthermore, Assumption 3 guarantees that for each y there exists a unique symmetric equilibrium $u^e(y)$ of the auxiliary game such that

$$\begin{aligned} y &= \frac{-\Pi'(u^e(y))}{\Pi(u^e(y))} \text{ if } y > \frac{-\Pi'(\underline{u}^*)}{\Pi(\underline{u}^*)} \\ u^e(y) &= \underline{u}^* \text{ if } y \leq \frac{-\Pi'(\underline{u}^*)}{\Pi(\underline{u}^*)} \end{aligned} \tag{5}$$

Furthermore, $u^e(y)$ is strictly increasing once $u^e(y) > \underline{u}^*$. Let $u_L(y), u_H^M(y), u_H^N(y)$ solve (5) with $\Pi = \Pi_L, \Pi_H^M, \Pi_H^N$, respectively.

[6]Under noisy offers, $p(u_1, u_2; y) = \Phi(\sqrt{\pi/2}y(u_1 - u_2))$, where Φ is the standard normal c.d.f. Under Hotelling competition, $p(u_1, u_2; y) = (1 + y(u_1 - u_2))/2$ but it satisfies Assumption 3 only when $p(u_1, u_2; y) \in (0, 1)$. One needs to select parameter values so that the maximization problem is a concave problem. The normal noise example does not have any complications.

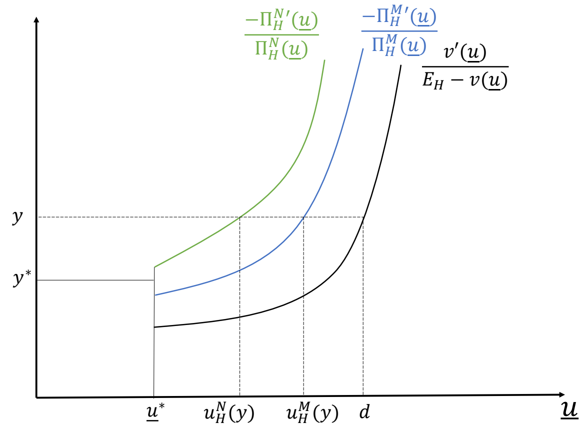

Figure 1: Equilibrium utilities of the auxiliary game

The following result is the backbone of this paper.

Lemma 3.1. *1. Suppose $-\frac{u'''}{u''} > -2\frac{u''}{u'}$ for all x, then*

$$\Pi_H^M(u_H^M(y)) > \Pi_H^N(u_H^N(y)) \quad \forall y \geq 0. \tag{6}$$

2. Suppose $-\frac{u'''}{u''} < -2\frac{u''}{u'}$ for all x, then there exists $y^* < -\Pi_H^{N'}(\underline{u}^*)/\Pi_H^N(\underline{u})$ such that

$$\Pi_H^M(u_H^M(y)) > \Pi_H^N(u_H^N(y)) \quad \forall 0 \leq y < y^* \tag{7}$$

$$\Pi_H^M(u_H^M(y)) < \Pi_H^N(u_H^N(y)) \quad \forall y > y^*. \tag{8}$$

3.

$$\Pi_L(u_L(y)) < \Pi_H^M(u_H^M(y)) \quad \forall y \geq 0. \tag{9}$$

Remark 3.1. *Applications of the Inverse Function Theorem give $v' = 1/u', v'' = -u''/u'^3, v''' = (-u'''u' + 3[u'']^2)/[u']^5$. Hence*

$$v' \text{ is convex} \Leftrightarrow -u'''(x)u'(x) + 3u''(x)^2 > 0 \Leftrightarrow \frac{-u'''(x)}{u''(x)} < -3\frac{u''(x)}{u'(x)} \quad \forall x. \tag{10}$$

$$\frac{v''}{v'} \text{ is increasing} \Leftrightarrow -u'''(x)u'(x) + 2u''(x)^2 > 0 \Leftrightarrow \frac{-u'''(x)}{u''(x)} < -2\frac{u''(x)}{u'(x)} \quad \forall x, \tag{11}$$

The ratio $-u'''/u''$ is called prudence and is key in the study of precautionary savings (see Kimball (1990)).

The intuition for (7) and (8) is as follows. When there is monitoring, the marginal cost for the principal to offer one more unit of indirect utility when implementing $a = H$ is

$$v'(c+u) \tag{12}$$

When there is no monitoring, the marginal cost is

$$p_H v'\left(u + c + (1-p_H)\frac{c}{p_H - p_L}\right) + (1-p_H)v'\left(u + c - p_H\frac{c}{p_H - p_L}\right) \tag{13}$$

When v' is convex, (12) is smaller than (13). Smaller marginal cost translates to higher incentives to compete. When y is low, proximity to monopoly implies $\Pi_H^M(u_H^M(y)) > \Pi_H^N(u_H^N(y))$. When y is high, however, it couples with different marginal costs of increasing u and makes $\Pi_H^M(u_H^M(y)) < \Pi_H^N(u_H^N(y))$ if v' is sufficiently convex.

The reason why we call $u_H^M(y), u_H^N(y)$ the equilibrium utilities of the auxiliary games rather than that of the competing-principals game is because that in the latter game the principals need to determine both the utility to offer and the action to implement. Implementing $a = H$ is dominant if

Configuration 1. $\Pi_H^N(\underline{u}) > \Pi_L(\underline{u})$ *for all* $\underline{u}$ *such that* $\Pi_L(\underline{u}) > 0$.

This is satisfied if c and E_L are low. Under Configuration 1, the equilibrium profits of the competing-principals games are

$$\begin{aligned} E\Pi^M(y) &= 0.5\Pi_H^M(u_H^M(y)) \\ E\Pi^N(y) &= 0.5\Pi_H^N(u_H^N(y)) \end{aligned} \tag{14}$$

Connecting (14) with (6), (7) and (8) obtains our main result:

Theorem 1. *Under Configuration 1,*

1. *When* $-\frac{u'''}{u''} > -2\frac{u''}{u'}$*, the equilibrium profit is always higher when there is monitoring.*
2. *When* $-\frac{u'''}{u''} < -2\frac{u''}{u'}$ *and there is at least some competition* ($y > y^*$)*, the equilibrium profit is lower when there is monitoring.*

Nevertheless, there are other possible configurations of Π_L, Π_H^M, Π_H^N.

Example 3.1. *Let* $u(x) = x^{0.4}$*. So* $v(u) = u^{\frac{1}{0.4}}$*. Set* $E_H = 1, p_H = 0.8, p_L = 0.4, c = 0.2$*. These set of parameters forces* $0.5 \le E_L < 1$*. We plot* Π_H^N, Π_H^M *and* Π_L *for* $E_L = 0.5, 0.55, 0.6$*, respectively, in Figure 2.*

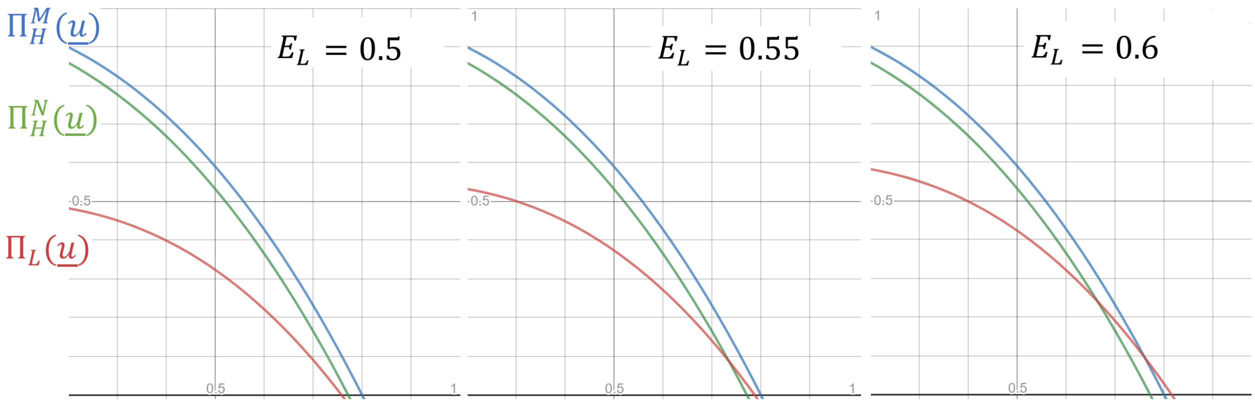

Figure 2: Possible Configurations of Profit Functions

If $\Pi_L(\underline{u}) > \Pi_H^N(\underline{u}) > 0$ or $\Pi_L(\underline{u}) > \Pi_H^M(\underline{u}) > 0$ for some $\underline{u}$, the auxiliary game fails to capture some of the profitable deviations. For example, if $\Pi_L(u_H^N(y)) > \Pi_H^N(u_H^N(y))$, it is profitable for a principal to deviate from implementing $a = H$. For such y's, there exists no competing-principals equilibrium that implements $a = H$.

We now analyze the equilibrium profits under the two other configurations in Figure 2.

Configuration 2. *There exists* $\tilde{u}^N \in (\underline{u}^*, \overline{u})$ *s.t.* $\Pi_L(\underline{u}) < \Pi_H^N(\underline{u})$ *for* $\underline{u}^* < \underline{u} < \tilde{u}^N$ *and* $\Pi_L(\underline{u}) > \Pi_H^N(\underline{u})$ *for* $\tilde{u}^N < \underline{u} < \overline{u}$. $\Pi_L(\underline{u}) < \Pi_H^M(\underline{u})$ *for all* $\underline{u} \leq u(E_L)$.

To see for which value of y there is an equilibrium implementing $a = H$, let

$$V_H^N(y) = 0.5\Pi_H^N(u_H^N(y)),$$
$$V_{HL}^N(y) = \max_{u_1 \in [\underline{u}^*, u(E_L)]} p(u_1, u_H^N(y); y)\Pi_L(u_1).$$

$V_H^N(y)$ is the on-path profit of implementing $a = H$ and $V_{HL}^N(y)$ is the optimal deviation profit. A symmetric equilibrium of implementing $a = H$ exists if and only if $V_H^N(y) \geq V_{HL}^N(y)$.

Like-wise, let

$$V_L(y) = 0.5\Pi_L(u^L(y))$$
$$V_{LH}^N(y) = \max_{u_1 \in [\underline{u}^*, \overline{u}]} p(u_1, u_L(y); y)\Pi_H^N(u_1)$$

A symmetric equilibrium of implementing $a = L$ exists if and only if $V_L(y) \geq V_{LH}^N(y)$. Since $\Pi_L(\underline{u}) < \Pi_H^M(\underline{u})$, it is always optimal to implement $a = H$ when there is monitoring.

Another possible configuration is

Configuration 3. *There exists* $\tilde{u}^N \in (\underline{u}^*, \overline{u})$ *s.t.* $\Pi_L(\underline{u}) < \Pi_H^N(\underline{u})$ *for* $\underline{u}^* < \underline{u} < \tilde{u}^N$ *and* $\Pi_L(\underline{u}) > \Pi_H^N(\underline{u})$ *for* $\tilde{u}^N < \underline{u} < \overline{u}$*. There exists* $\tilde{u}^M \in (\underline{u}^*, u(E_H) - c)$ *s.t.* $\Pi_L(\underline{u}) < \Pi_H^M(\underline{u})$ *for* $\underline{u}^* < \underline{u} < \tilde{u}^M$ *and* $\Pi_L(\underline{u}) > \Pi_H^M(\underline{u})$ *for* $\tilde{u}^M < \underline{u} < u(E_H) - c$*.*

In this case, we have to define and analyze $V_H^M(y)$, $V_{HL}^M(y)$, $V_{LH}^M(y)$ in the same fashion, where

$$
\begin{aligned}
V_H^M(y) &= 0.5\Pi_H^M(u_H^M(y)) \\
V_{HL}^M(y) &= \max_{u_1 \in [\underline{u}^*, u(E_L)]} p(u_1, u_H^M(y); y)\Pi_L(u_1) \\
V_{LH}^M(y) &= \max_{u_1 \in [\underline{u}^*, u(E_H) - c]} p(u_1, u_L(y); y)\Pi_H^M(u_1)
\end{aligned}
$$

An analysis of the value functions gives us

Lemma 3.2. *Under Configuration 2 and Configuration 3*

1. v_H^N *crosses* v_{HL}^N *exactly once, from above, at some* y_H^N*.*
2. v_L *crosses* v_{LH}^N *exactly once, from below, at some* y_L^N *s.t.* $y_L^N < y_H^N$

In addition, under Configuration 3,

3. v_H^M *crosses* v_{HL}^M *exactly once, from above, at some* y_H^M*.*
4. v_L *crosses* v_{LH}^M *exactly once, from below, at some* y_L^M *s.t.* $y_L^M < y_H^M$*.*

By Lemma 3.2, under Configuration 2, when $y \in [y_L^N, y_H^N]$, both equilibria that implement $a = H$ and $a = L$ exist when there is no-monitoring. Therefore,

$$
\begin{aligned}
E\Pi^N(y) &= \begin{cases} 0.5\Pi_H^N(u_H^N(y)), & y < y_L^N \\ 0.5\Pi_H^N(u_H^N(y)) \text{ or } 0.5\Pi_L(u_L(y)) \text{ depending on selection}, & y \in [y_L^N, y_H^N] \\ 0.5\Pi_L(u_L(y)), & y > y_H^N \end{cases} \\
E\Pi^M(y) &= 0.5\Pi_H^M(u^M(y))
\end{aligned} \tag{15}
$$

A modified Theorem 1 holds: when there is *some* competition ($y^* < y < y_H^N$), the no-monitoring profit can still be higher than the monitoring profit. Nevertheless, when $y > y_H^N$, (9) implies that the monitoring equilibrium profit is higher.

By Lemma 3.2, under Configuration 3, when $y \in [y_L^M, y_H^M]$, both equilibria that implement $a = H$ and $a = L$ exist when there is monitoring. Hence

$$
\begin{aligned}
E\Pi^N(y) &= \begin{cases} 0.5\Pi_H^N(u_H^N(y)), & y < y_L^N \\ 0.5\Pi_H^N(u_H^N(y)) \text{ or } 0.5\Pi_L(u_L(y)) \text{ depending on selection}, & y \in [y_L^N, y_H^N] \\ 0.5\Pi_L(u_L(y)), & y > y_H^N \end{cases} \\
E\Pi^M(y) &= \begin{cases} 0.5\Pi_H^M(u_H^M(y)), & y < y_L^M \\ 0.5\Pi_H^M(u_H^M(y)) \text{ or } 0.5\Pi_L(u_L(y)) \text{ depending on selection}, & y \in [y_L^M, y_H^M] \\ 0.5\Pi_L(u_L(y)), & y > y_H^M \end{cases}
\end{aligned}
\tag{16}
$$

This case is similar to Configuration 2. The major difference is that when the market is sufficiently competitive ($y > \max\{y_H^N, y_H^M\}$), the equilibrium profits with or without monitoring are the same because implementing $a = L$ is the only equilibrium.

Remark 3.2. *Since $\Pi_H^M(\underline{u}) > \Pi_H^N(\underline{u})$ for all $\underline{u} \geq 0$, $V_{LH}^N(y) < V_{LH}^M(y)$ for all $y \geq 0$. Hence $y_L^M > y_L^N$. Whether $y_H^M > y_H^N$ depends on u. When $-u'''u' + 2u''^2 < 0$, Lemma 3.1 says $V_H^M(y) > V_H^N(y)$ for all $y \geq 0$. Hence $y_H^M > y_H^N$. When $-u'''u' + 2u''^2 > 0$, $V_H^M(y) < V_H^N(y)$ for all y such that $u_H^N(y) > \underline{u}^*$. Hence $y_H^M < y_H^N$.*

(14), (15) and (16) also give us the agent's equilibrium utilities in the competing-principals game for different values of y.

Monitoring does not hurt the agent if the market is competitive: since $\overline{u} < u(E_H) - c$,

$$
\frac{-\Pi_H^{N'}(\underline{u})}{\Pi_H^N(\underline{u})} > \frac{-\Pi_H^{M'}(\underline{u})}{\Pi_H^M(\underline{u})}
\tag{17}
$$

when $\underline{u}$ is large. This implies that $u_H^M(y) > u_H^N(y)$ when y is large (see Figure 1). A similar reasoning shows that under Configuration 2, $u_H^M(y) > u_L(y)$ when y is large. Under Configuration 3, when $y > \max\{y_H^N, y_H^M\}$, the agent receives $u_L(y)$ with or without monitoring.

How monitoring affects the agent when the market is not competitive depends on the utility function. When prudence is smaller than three times risk aversion, v' is convex. This implies that (17) holds for all $\underline{u}$ and therefore $u_H^M(y) \geq u_H^N(y)$ for all y. When prudence is larger than three times risk aversion, v' is concave. In this case it is possible that

$$
\frac{-\Pi_H^{N'}(\underline{u})}{\Pi_H^N(\underline{u})} < \frac{-\Pi_H^{M'}(\underline{u})}{\Pi_H^M(\underline{u})}
\tag{18}
$$

when $\underline{u}$ is small. In such cases, $u_H^N(y) > u_H^M(y)$ when y is low. Below is an example.

Example 3.2. *Let $u(x) = x^{0.9}$. So that $u'''u'/u''^2 = (0.9-2)/(0.9-1) = 11$ and $v(u) = u^{\frac{1}{0.9}}$. Set $E_H = 4, p_H = 0.8, p_L = 0.4, c = 1$. We then have*

$$\Pi_H^M(\underline{u}) = 4 - (\underline{u}+1)^{\frac{1}{0.9}}$$
$$\Pi_H^N(\underline{u}) = 4 - 0.8(\underline{u}+1.5)^{\frac{1}{0.9}} - 0.2(\underline{u}-1)^{\frac{1}{0.9}}$$

The ratios $-\Pi_H^{M'}(\underline{u})/\Pi_H^M(\underline{u})$ and $-\Pi_H^{N'}(\underline{u})/\Pi_H^N(\underline{u})$ for small values of $\underline{u}$ are plotted in Figure 3.

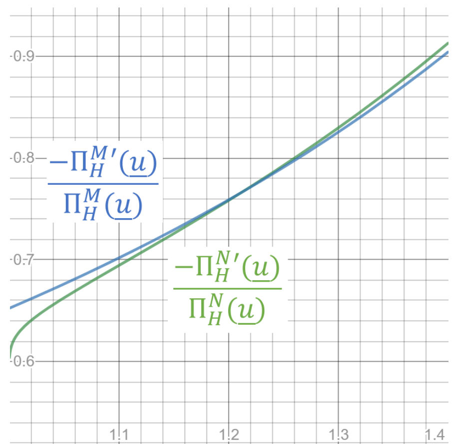

Figure 3

4 Conclusion

Technological innovations that help businesses extract more surpluses also make their rivals more competitive. Therefore, what is a monopolist's meat may be an oligopolist's poison. Further investigations to imperfect monitoring, monitoring as a screening device, will shed more light on how such technologies affect the profitability of industries with information asymmetry.

A Proofs

Proof of Proposition 2.1. Assumption 2 together with $\underline{u}^* \leq p_H u(x_H) + (1 - p_H)u(x_L) - c$ guarantees the existence of $\overline{u}$.[7]

We argue that in optimum (IC) binds. Suppose (IC) is slack. The slope of the promise-keeping constraint is $s_{PK} = -\frac{p_H}{1-p_H}\frac{u'(w_H)}{u'(w_L)}$ and the slope of the iso-profit line is $s_\Pi = -\frac{p_H}{1-p_H}$. Since u is concave and $w_H > w_L$, $s_{PK} < s_\Pi$. Hence we can decrease w_H and increase w_L along (PK) so that (IC) is still satisfied and profit is increased.

Solving $u(w_H)$ and $u(w_L)$ from the system below

$$p_H u(w_H) + (1 - p_H)u(w_L) = c + \underline{u} \tag{PK}$$

$$u(w_H) - u(w_L) = \frac{c}{p_H - p_L} \tag{IC}$$

and taking inverses yield

$$w_L = v\left(\underline{u} + c - p_H \frac{c}{p_H - p_L}\right)$$
$$w_H = v\left(\underline{u} + c + (1 - p_H)\frac{c}{p_H - p_L}\right)$$

Substituting them to (1) yields (4).

Lastly, $u' > 0$ and $u'' < 0$ imply that v is convex. Hence

$$\begin{aligned}
&p_H v\left(\underline{u} + c + \frac{(1-p_H)c}{p_H - p_L}\right) + (1 - p_H)v\left(\underline{u} + c - \frac{p_H c}{p_H - p_L}\right)\\
>&v\left(p_H\left(\underline{u} + c + \frac{(1-p_H)c}{p_H - p_L}\right) + (1 - p_H)\left(\underline{u} + c - \frac{p_H c}{p_H - p_L}\right)\right)\\
=&v(\underline{u} + c).
\end{aligned}$$

Therefore, $\Pi_H^N(\underline{u}) < \Pi_H^M(\underline{u})$. □

Proof of Lemma 3.1. We first prove (6), (7) and (8).

Fix $y \geq 0$. There are three possible cases. 1. $\underline{u}^* \leq u_H^M(y) \leq u_H^N(y)$, 2. $\underline{u}^* < u_H^N(y) < u_H^M(y)$ and 3. $\underline{u}^* = u_H^N(y) < u_H^M(y)$.

For case 1, it follows from Proposition 2.1 that $\Pi_H^M(u^M(y)) > \Pi_H^N(u_H^N(y))$.

[7] In fact, $\overline{u} = p_H u(w_H^*) + (1 - p_H)u(w_L^*) - c$, where (w_H^*, w_L^*) solves $E_H - p_H w_H + (1 - p_H)w_L = 0$ and $u(w_H) - u(w_L) = c/(p_H - p_L)$.

For case 2, we have

$$y = \frac{\Pi_H^{M\prime}(u_H^M(y))}{\Pi_H^M(u_H^M(y))} = \frac{\Pi_H^{N\prime}(u_H^N(y))}{\Pi_H^N(u_H^N(y))}. \tag{19}$$

Let d be the (unique) number such that

$$y = \frac{v'(d)}{E_H - v(d)}$$

Since $-\Pi_H^{M\prime}(\underline{u})/\Pi_H^M(\underline{u}) > v'(\underline{u})/(E_H - v(\underline{u}))$ for all $\underline{u}$, we have $u_H^M(y) + c = d$. Hence $\Pi_H^M(u_H^M(y)) = E_H[x] - v(d)$.

Consider the curve on the u_1-u_2 plane implicitly defined by

$$y = \frac{p_H v'(u_1) + (1 - p_H)v'(u_2)}{E_H - p_H v(u_1) - (1 - p_H)v(u_2)},$$

which passes $a = (d, d)$ and $b = (u_H^N(y) + c + p_H c/(p_H - p_L), u_H^N(y) + c - p_H c/(p_H - p_L))$ because of (19). Let $\{(u_1(t), u_2(t)), t \in [0, 1]\}$ be a differentiable monotone parametrization of the curve such that $(u_1(0), u_2(0)) = a$ and $(u_1(1), u_2(1)) = b$. The slope of the curve is

$$\frac{du_2}{du_1} = -\frac{p_H v'(u_1)y + p_H v''(u_1)}{(1 - p_H)v'(u_2)y + (1 - p_H)v''(u_2)} < 0, \tag{20}$$

hence $u_1(t) > u_2(t)$ for $t \in (0, 1]$.

Define $F : [0, 1] \to \mathbb{R}$ by

$$F(t) = E_H - p_H v(u_1(t)) - (1 - p_H)v(u_2(t)).$$

Then $F(0) = \Pi_H^M(u_H^M(y))$ and $F(1) = \Pi_H^N(u_H^N(y))$. Therefore,

$$F'(t) > 0 \text{ for all } t \in (0, 1] \Rightarrow \Pi_H^N(u_H^N(y)) > \Pi_H^M(u_H^M(y))$$
$$F'(t) < 0 \text{ for all } t \in (0, 1] \Rightarrow \Pi_H^N(u_H^N(y)) < \Pi_H^M(u_H^M(y)).$$

To this end, note that

$$F'(t) = -p_H v'(u_1(t))\frac{du_1(t)}{dt} - (1 - p_H)v'(u_2(t))\frac{du_2(t)}{dt}$$

Using (20), we have

$$\begin{aligned}
&F'(t) > 0 \\
\Leftrightarrow &\frac{du_2}{du_1} < -\frac{p_H}{1 - p_H}\frac{v'(u_1)}{v'(u_2)} \\
\Leftrightarrow &-\frac{p_H v'(u_1)y + p_H v''(u_1)}{(1 - p_H)v'(u_2)y + (1 - p_H)v''(u_2)} < -\frac{p_H}{1 - p_H}\frac{v'(u_1)}{v'(u_2)} \\
\Leftrightarrow &\frac{v''(u_1(t))}{v'(u_1(t))} > \frac{v''(u_2(t))}{v'(u_2(t))}
\end{aligned}$$

Since $u_1(t) > u_2(t)$ for $t \in (0, 1]$, it follows from (11) that in Case 2,

$$-\frac{u'''}{u''} > -2\frac{u''}{u'}\forall x \Rightarrow \Pi_H^M(u_H^M(y)) > \Pi_H^N(u_H^N(y)) \tag{21}$$

$$-\frac{u'''}{u''} < -2\frac{u''}{u'}\forall x \Rightarrow \Pi_H^M(u_H^M(y)) < \Pi_H^N(u_H^N(y)). \tag{22}$$

We now prove (6). If y is in case 1 then we are done. Case 2 follows from (21). If y is in case 3, raise y from zero to $-\Pi_H^{N'}(\underline{u}^*)/\Pi_H^N(\underline{u}^*)$. During the process $\Pi_H^N(u_H^N(y))$ stays constant at $\Pi_H^N(\underline{u}^*)$ and $\Pi_H^M(u_H^M(y))$ decreases to something still larger than $\Pi_H^N(\underline{u}^*)$ because of (19) and (21).

We then prove (7) and (8). y cannot be in Case 1 because $-u'''u' + 2u''^2 > 0$ implies that v' is convex, which then implies $-\Pi_H^{N'}/\Pi_H^N > -\Pi_H^{M'}/\Pi_H^M$. Case 2 follows from (22). If y is in case 3, the same continuity argument as above, together with (19) and (22), gives y^*.

Next, we prove (9).

Let $y \geq 0$. There are three possible cases. 1. $\underline{u}^* < \min\{u_L(y), u_H^M(y)\}$, 2. $\underline{u}^* = u_H^M(y) \leq u_L(y)$ and 3. $\underline{u}^* = u_L(y) < u_H^M(y)$.

In case 1, we have

$$y = \frac{v'(u_L(y))}{E_L - v(u_L(y))} = \frac{v'(u_H^M(y) + c)}{E_H - v(u_H^M(y) + c)} = \frac{v'(d)}{E_H - v(d)} \tag{23}$$

for some unique d. Since $v'(\underline{u})/(E_L - v(\underline{u})) > v'(\underline{u})/(E_H - v(\underline{u}))$, $u_L(y) < d$. Since $v'' > 0$, (23) implies

$$\Pi_L(u_L(y)) = \frac{v'(u_L(y))}{y} < \frac{v'(d)}{y} = \Pi_H^M(u_H^M(y)).$$

In case 2, we have

$$\Pi_L(u_L(y)) \leq \Pi_L(\underline{u}^*) < \Pi_H^M(\underline{u}^*) = \Pi_H^M(u_H^M(y)).$$

where the second inequality is from Assumption 1.

In case 3, we can increase y until we are in Case 1, where $\Pi_L < \Pi_H^M$. In this process, $\Pi_L(u_L(y)) = \Pi_L(\underline{u}^*)$ and $\Pi_H^M(u_H^M(y))$ is decreasing. Hence $\Pi_L(u_L(y)) < \Pi_H^M(u_H^M(y))$. □

Lemma 3.2 follows from the following result.

Proposition A.1. *Let $\Pi_a(\cdot), \Pi_b(\cdot)$ be two twice-differentiable concave decreasing functions such* *that $\Pi_a(u) > \Pi_b(u)$ for $u < \tilde{u}$ and $\Pi_a(u) < \Pi_b(u)$ for $u > \tilde{u}$, where $\Pi_a(\tilde{u}) > 0$ and $\tilde{u} > \underline{u}^*$. Let*

$$\begin{aligned}
V_a(y) &= 0.5\Pi_a(u_a(y)) \\
V_a^b(y) &= \max_{u\in[\underline{u}^*,\Pi_b^{-1}(0)]} p(u, u_a(y); y)\Pi_b(u) \\
V_b(y) &= 0.5\Pi_b(u_b(y)) \\
V_b^a(y) &= \max_{u\in[\underline{u}^*,\Pi_a^{-1}(0)]} p(u, u_b(y); y)\Pi_a(u)
\end{aligned}$$

where $u_a(y), u_b(y)$ solve (5) when $\Pi = \Pi_a, \Pi_b$ respectively. Then $V_a(y)$ crosses $V_a^b(y)$ exactly once, from above, at some y_a, $V_b(y)$ crosses $V_b^a(y)$ exactly once, from below, at some y_b. Finally, $y_b < y_a$.

Proof. For y such that $u_a(y) = \underline{u}^*$, $V_a(y) > V_a^b(y)$. For y such that $u_a(y) > \tilde{u}$, $V_a(y) < 0.5\Pi_b(u_a(y)) < V_a^b(y)$. Hence V_a crosses V_a^b from above at some y_a where $y_a > -\Pi_a'(\underline{u})/\Pi_a(\underline{u})$.

To show that they cross exactly once, it suffices to show that $V_a'(y) < V_a^{b'}(y)$ whenever $V_a(y) = V_a^b(y)$. Let y_a be a crossing point. Let $u_a = u_a(y_a)$ and u_a^b be such that $V_a^b(y_a) = p(u_a^b, u_a; y_a)\Pi_b(u_a^b)$. Then it must be

$$u_a \le \tilde{u} \le u_a^b. \tag{24}$$

and at least one is a strict inequality.[8] By the envelope theorem,

$$\begin{aligned}
V_a'(y_a) &= (p_2(u_a, u_a; y_a)u_a'(y_a) + p_3(u_a, u_a; y_a))\Pi_a(u_a) \\
V_a^{b'}(y_a) &= (p_2(u_a^b, u_a; y_a)u_a'(y_a) + p_3(u_a^b, u_a; y_a))\Pi_b(u_a^b)
\end{aligned}$$

Using $p(u_a, u_a; y_a)\Pi_a(u_a) = p(u_a^b, u_a; y_a)\Pi_b(u_a^b)$, we have

$$\begin{aligned}
&V_a'(y_a) < V_a^{b'}(y_a) \\
\Leftrightarrow &\frac{p_2(u_a, u_a; y_a)}{p(u_a, u_a; y_a)}u_a'(y_a) + \frac{p_3(u_a, u_a; y_a)}{p(u_a, u_a; y_a)} < \frac{p_2(u_a^b, u_a; y_a)}{p(u_a^b, u_a; y_a)}u_a'(y_a) + \frac{p_3(u_a^b, u_a; y_a)}{p(u_a^b, u_a; y_a)}
\end{aligned}$$

which follows from Assumption 3.[9] An identical argument shows that V_b crosses V_b^a, exactly once, from below, at some y_b. Moreover, at y_b, $u_b^a(y_b) \le \tilde{u} \le u_b(y_b)$ with at least one strict inequality.

Next, we show $y_b < y_a$. Since V_b crosses V_b^a at y_b from below, it suffices to show $V_b^a(y_a) < V_b(y_a)$. To see this, let

$$\begin{aligned}
W_a(u_2) &= \max_u p(u, u_2, y_a)\Pi_a(u) \\
W_b(u_2) &= \max_u p(u, u_2, y_a)\Pi_b(u).
\end{aligned} \tag{25}$$

[8] If both are equalities, FOC implies $y_a = \frac{-\Pi_a'(\tilde{u})}{\Pi_a(\tilde{u})} = \frac{-\Pi_b'(\tilde{u})}{\Pi_b(\tilde{u})}$. Since $\Pi_a(\tilde{u}) = \Pi_b(\tilde{u})$, this contradicts $\Pi_a'(\tilde{u}) < \Pi_b'(\tilde{u})$.

[9] Assumption 3 implies $p_2 < 0$, p_2/p is increasing in u_1, $p_3(u_a, u_a; y_a) = 0$ and $p_3 > 0$ when $u_1 > u_2$.

Then $W_a(\cdot), W_b(\cdot)$ are decreasing and

$$W_a(u_a(y_a)) = V_a(y_a) = V_a^b(y_a) = W_b(u_a(y_a)) \tag{26}$$

$$W_a(u_b(y_a)) = V_b^a(y_a), \quad W_b(u_b(y_a)) = V_b(y_a). \tag{27}$$

We now prove two claims:

Claim 1 $u_a(y_a) < u_b(y_a)$

Claim 2 $W_a(u) = W_b(u) \Rightarrow W_a'(u) < W_b'(u)$.

$V_b^a(y_a) < V_b(y_a)$ will follows from the two claims because of (26) and (27).

Proof of Claim 1: Claim 1 follows from that $-\Pi_b'(u)/\Pi_b(u)$ is increasing and that

$$\frac{-\Pi_b'(u_b(y_a))}{\Pi_b'(u_b(y_a))} = y_a > \frac{-\Pi_b'(u_a(y_a))}{\Pi_b(u_a(y_a))},$$

where the equality is (5) and the inequality follows from decreasing u_a^b to $u_a(y_a)$ (recall (24)) from both sides of the FOC of u_a^b:

$$\frac{p_1(u_a^b, u_a(y_a); y_a)}{p(u_a^b, u_a(y_a); y_a)} = \frac{-\Pi_b'(u_a^b)}{\Pi_b(u_a^b)}.$$ [10]

Proof of Claim 2: Let u_a solve $W_a(u)$ and u_b solve $W_b(u)$. Assume $W_a(u) = W_b(u)$. Then

$$W_a(u) = p(u_a, u; y_a)\Pi_a(u_a) = p(u_b, u; y_a)\Pi_b(u_b) = W_b(u) \tag{28}$$

Moreover, (24) holds: $u_a < u_b$. The envelope theorem implies $W_a'(u) = p_2(u_a, u; y_a)\Pi_a(u_a)$ and $W_b'(u) = p_2(u_b, u; y_a)\Pi_b(u_b)$. Substituting in (28) and rearranging, we have

$$\begin{aligned} & W_a'(u) < W_b'(u) \\ \Leftrightarrow & \frac{p_2(u_a, u; y_a)}{p(u_a, u; y_a)} < \frac{p_2(u_b, u; y_a)}{p(u_b, u; y_a)} \end{aligned}$$

which follows from Assumption 3 and $u_a < u_b$. □

Proposition A.2. *The competing-principals game does not have an asymmetric equilibrium.*

Proof. We prove two claims, from which non-existence follows.

Claim 1: There is no asymmetric equilibria $(w_H^1, w_L^1, a_1), (w_H^2, w_L^2, a_2)$ in which $a_1 = a_2$.

Claim 2: There is no asymmetric equilibria $(w_H^1, w_L^1, a_1), (w_H^2, w_L^2, a_2)$ in which $a_1 = H$ and $a_2 = L$.

[10] Assumption 3 implies p_1/p is decreasing in u_1. So when one decreases u_a^b to $u_a(y_a)$, the LHS (left hand side) increases to y_a while the RHS decreases to $-\Pi_b'(u_a(y_a))/\Pi_b(u_a(y_a))$.

Proof of Claim 1: Suppose there is such an equilibrium for some y. Let $a_1 = a_2 = a$ and u_1, u_2 be the indirect utilities with $u_1 < u_2$. Let $\Pi_a(\underline{u})$ be the relevant profit function $(\Pi_L, \Pi_H^M, \Pi_H^N)$. Then (5) implies

$$\begin{aligned} \frac{p_1(u_1,u_2;y)}{p(u_1,u_2;y)} &\leq -\frac{\Pi_a'(u_1)}{\Pi_a(u_1)}, u_1 \geq \underline{u}^*, \text{ c.s.} \\ \frac{p_1(u_2,u_1;y)}{p(u_2,u_1;y)} &= -\frac{\Pi_a'(u_2)}{\Pi_a(u_2)} \end{aligned} \tag{29}$$

Assumption 3 implies that

$$\frac{p_1(u_1,u_2;y)}{p(u_1,u_2;y)} > \frac{p_1(u_2,u_1;y)}{p(u_2,u_1;y)},$$

together with (29) we have

$$-\frac{\Pi_a'(u_2)}{\Pi_a(u_2)} < -\frac{\Pi_a'(u_1)}{\Pi_a(u_1)},$$

contradicting that $-\Pi_a'(\underline{u})/\Pi_a(\underline{u})$ is increasing.

Proof of Claim 2: Suppose there is such an equilibrium for some y. Then Π_L has to cross Π_H^N or Π_H^M depending on whether there is monitoring. We prove the former case; the latter is identical.

Let u_1, u_2 be the equilibrium indirect utilities. Then

$$u_1 \leq \tilde{u}^N \leq u_2$$

and one of the inequalities are strict.[11] This implies that $u_1 < u_2$. Under an equilibrium, principal 1 does not want to deviate to implement $a = L$ given that principal 2 offers u_2, and principal 2 does not want to deviate to implement $a = H$ either. Hence

$$\begin{aligned} W_H(u_2) &\geq W_L(u_2) \\ W_L(u_1) &\geq W_H(u_1) \end{aligned} \tag{30}$$

where W_H, W_L are defined as in (25) with $\Pi_a = \Pi_H^N$ and $\Pi_b = \Pi_L$. However, since $u_1 < u_2$, (30) implies that W_H crosses W_L from below at some $u \in [u_1, u_2]$. This contradicts Claim 2 of Proposition A.1. □

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[11] See Footnote 8.

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