HORIZONTAL COORDINATION AND TRANSPARENCY OF INFORMATION

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2016

HORIZONTAL COORDINATION AND TRANSPARENCY OF INFORMATION

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Economics

by

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2016

DECLARATION OF ORIGINALITY

I, Yunus Topbaş, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institutions;
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ABSTRACT

Horizontal Coordination and Transparency of Information

Rational agents might choose to invest in a certain kind of capital in a period in the hope of making higher returns from their investments made in consecutive periods. We examine the impact of such an interaction on the incidence of coordination failure and accordingly social welfare. In our set-up, investment complementarities are present both within periods (call vertical complementarity) and between periods (call horizontal complementarity). In particular, other than the underlying economic fundamental, the return on investment depends on its aggregate level in that period as well as the aggregate investment made in the previous period. The results suggest that full transparency is optimal at the social level as long as agents have an access to relatively more precise private information and complementarities are sufficiently low. More transparency otherwise reduces social welfare as the gain from better vertical coordination is outweighed by the loss resulted from lesser horizontal coordination.

ÖZET

Yatay Koordinasyon ve Bilginin Şeffaflğı

Rasyonel iktisadi aktörler ardışık dönemlerde yaptıkları yatırımlardan daha yüksek getiriler elde etme amacıyla bir dönem içinde sermaye yatırımı yapmayı tercih edebilirler. Bu çalışmada böyle bir etkileşimin koordinasyon yetersizliği ve sosyal refah üzerine etkisini inceliyoruz. Modelimizde, yatırım tamamlayıcılıklar hem dönemler içinde (dikey tamamlayıcılık) hem de dönemler arasında (yatay tamamlayıcılık) mevcuttur. Daha belirgin olarak, modelde altta yatan ekonomik temel ve esaslar dışında, yatırımdan elde edilen getiri o dönem içinde yapılan toplam yatırıma ve önceki dönemlerde yapılan toplam yatırımlara bağlıdır. Elde ettiğimiz sonuçlara göre toplumsal düzeyde tam şeffaflık şu durumlarda en iyidir: aktörler nispeten daha kesin özel bilgilere erişim imkanına sahip ise ve tamamlayıcılıklar yeterince düşük seviyelerde ise. Aksi takdirde daha fazla şeffaflık sosyal refahı düşürmektedir, çünkü daha az yatay koordinasyon sonucunda ortaya çıkan kayıp daha iyi dikey koordinasyondan elde edilen kazançtan daha fazla olmaktadır.

ACKNOWLEDGMENTS

I would like to thank first and foremost my thesis advisor Prof. Ünal Zenginobuz without whom this thesis would never have come into existence. I am grateful to him first for introducing me to the literature on global games and then for providing me with much-needed assistance in the theoretical background.

I would like to thank Assist. Prof. Tolga Umut Kuzubaş for his invaluable comments and helpful feedback. I would also like to thank Assist. Prof. Burak Ünveren for his feedback on the theoretical background of the thesis. I would also like to thank Dr. Mehmet Oğuz Karahan for conversations on financial markets.

I would like to acknowledge my gratitude to Önsel Gürel Bayralı and Ramazan Daşbaşı for their support during the entire process. Finally, I am totally indebted to my beloved family, who have always been very supportive during my studies.

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CHAPTER 1

INTRODUCTION

The content and source of information is always a matter of subject for a decision maker in finding an optimal course of action under uncertainty. The decision maker needs to balance her own private information against the one that is publicly known and observed by other market participants. However, because both are noisy, it's not obvious how to combine the two sources of information when making decisions. The issue becomes more and more complicated in the presence of strategic complementarities (or substitutes). Strategic complementarities make it necessary for agents to coordinate their actions in order to acquire a desirable outcome. In such cases, greater access to information might be enticing for a decision maker to better predict others' actions and take appropriate actions accordingly.

However, coordination failure might arise in these settings when agents fail to take those set of actions that are in their collective interest. In order to prevent such failures, central authorities such as central banks or governments choose to disseminate information about economic fundamentals through direct policy announcements or via media. This in turn shapes people's expectations about the future of the economy and affects their decisions. Besides, certain kinds of public devices, such as asset prices, help people learn about others' expectations and beliefs about economic fundamentals[1]. However, that is a case of a curate's egg. On the one hand, agents become more informed about economic fundamentals as well as others' beliefs and therefore are presumed to make more accurate decisions. On the other hand, they might over-react to the disseminated information and choose to ignore their private signals. In such a case, the effectiveness of public information as a

[1]See, for instance, Angeletos and Werning (2006).

coordination device becomes an issue and is of importance from a social point of view.

Morris and Shin (2002) constructed a model to explore the impact of public and private information on social welfare in which individuals are rational utility maximizers and have two different objectives, given exogenous public and private information about the economic fundamental. First, they try to take actions as close as possible to the underlying fundamental. Second, they try not to take extreme actions compared to the others. The latter provides agents with coordination motive and is incorporated into the model by introducing the Keynesian beauty contest. Their results suggest that the impact of public information is ambiguous when there is imperfect information and depends on whether agents have access to socially valuable private information.

In particular, increased provision of public information tends to be more detrimental to social welfare as private information becomes more and more precise. This is a consequence of the fact that the coordination motive entails placing too much weight on the public signal relative to the weights that would be used by the social planner (Morris and Shin, 2002). In this sense, being transparent or not depends on the information structure of a particular economy and full transparency might not be advisable to an economy in which agents do have independent information sources. It is also found that social welfare is positively correlated with the precision of private information irrespective of other parameter values.

In a different setting, Angeletos and Pavan (2004) found contrasting results with the ones in Morris and Shin (2002). When the complementarities are weak it is always optimal to be full transparent because it helps investors internalize the positive externality and entails more effective coordination. Besides, more precise private information creates more heterogeneous expectations and deteriorates social coordination and accordingly social welfare under certain circumstances.

The difference in the results stems from the environments in which agents coordinate their actions. In the former model, the complementarity has a considerable impact on individual returns whereas it is socially wasteful to exert extra effort in the hope of providing more effective coordination. In contrast, the complementarity is present at the social level in the latter model so that more transparent public information, by permitting more effective coordination in the market, necessarily increases welfare (Angeletos and Pavan, 2004).

In both settings, there exists only one investment tool on which agents try to align their actions or agents are able to invest only for one-period. However, there are many cases in which agents need to choose among different investment options (or tools) whose returns are possibly dependent upon each other; or, agents choose to invest in a certain kind of capital in a period in the hope of making higher returns from their investments made in consecutive periods. The optimal bundle of investment in this case depends on individual preferences, information structure, beliefs about the returns on investment in different periods as well as whether individual investments are strategic complements or substitutes of each other.

The main goal in this study is to examine the impact of such an interaction on the incidence of coordination failure and accordingly social welfare in the presence of investment complementarities both within periods (call vertical complementarity) and between periods (call horizontal complementarity). In particular, taking Angelets and Pavan (2004) as a starting point, we construct a two-period model as follows. The return on investment in period one depends both on the economic fundamental and aggregate level of investment in that period. However, other than those two, the return of investment in period two also depends on the aggregate investment made in period one.

In this context, we first focus on the impact of horizontal complementarity on the incidence of coordination failure and accordingly social welfare. Coordination failures waste socially valuable investments and hence might hamper the growth of the economy as a whole. Second, we examine how the precision of public and private information affects social welfare and analyse to what extent more transparent (public) information would be desirable from a social perspective.

The results suggest that the introduction of horizontal complementarity makes coordination failures more likely and hence might deteriorate social welfare in the sense that it provides the economy with extra source of uncertainty. An investor can choose extreme bundles, such as high investment in period one and a lower one in period two or vice verse, or prefer more balanced bundles. In this sense, investors need to decide how much weight they give on public and private information as well as need to predict inter-temporal composition of others' investment bundles to form her own bundle.

We also find that more transparency is not always optimal from a social point of view. Whether or not it is socially desirable depends on both complementary levels and the precision of public information relative to the private one. When the public information is relatively less precise, increase in transparency is beneficial to the society as a whole. However, it reduces social welfare in the opposite case. The adverse impact of public information results from the fact that agents begin to ignore their private signals and give more and more weight on the public signal, as it becomes more precise, relative to the weights that would be used by the social planner (Morris and Shin, 2002). These results are valid in both simultaneous and sequential versions of the game.

The impact of the precision of private information is also ambiguous in the sense that whether or not it improves social welfare depends on the degree of complementarities, relative precision of private information, and absolute precision of public information. When the precision of public information is too low, the increase in private precision has a positive impact on social welfare. However, as the precision of public information becomes greater in absolute terms the impact turns out to be negative since the benefit of lower uncertainty, due to higher private precision, is outweighed by the cost of lower coordination (Angeletos and Pavan, 2004).

The rest of the paper is organized as follows. The literature review is given in Section 2, the model is presented in Section 3, equilibrium analysis of the simultaneous version of the game is conducted and the results are presented in Section 4, the sequential version of the game is presented in Section 5, some extensions of our model will be discussed in Section 6, and Section 7 concludes.

CHAPTER 2

LITERATURE REVIEW

In addition to Morris and Shin (2002) and Angeletos and Pavan (2004), the effect of public information has also been examined in the literature within the framework of global games. Morris et al. (2006) have shown that public information is still harmful to social welfare even if we allow for correlated signals. In a different setting, Cornand and Heinemann (2008) have demonstrated that public information is socially beneficial and hence should always be provided with maximum precision but, under certain conditions, not to all agents.

Chan and Chiu (1999) and Metz (2002) have analyzed the consequences of information dissemination on currency crisis. In contrast with the results of the former, Metz (2002) has found that more transparency reduces the likelihood of a currency crisis when the economic conditions are strong and the opposite occurs in case of weaker fundamentals. In a similar fashion, Heinemann and Illing (2002) has found that higher transparency might reduce strategic uncertainty and accordingly helps to reduce incentives for speculative attacks.

Coordination problems, its ramifications and possible amelioration have also been widely investigated in the literature. Cooper and Andrew (1988) is an early instance of how coordination problems arises in the existence of strategic complementarities. Hellwig (2005) has established a model based on Woodford (2002) to examine monetary economies in which complementarities arise in pricing decisions and their results are in line with the findings of Angeletos and Pavan (2004).

Angeletos, Hellwig and Pavan (2003) have shown, in a global coordination game, that the possibility that policy choices convey information might lead to policy traps where both the optimal policy and the coordination outcome are dictated by self-fulfilling market expectations. In this regard, it has been argued that the impact of higher transparency does depend on policy choices as well as the interpretations of them by market participants. Morris and Shin (2004) constructed a model in which creditors of a distressed borrower face a coordination problem and found that more transparency does not generally mitigate the coordination problem.

There are also other studies examining the role of public information from a social perspective: See, for instance, Hellwig (2002), Woodford (2005), Svensson (2006), Angeletos and Pavan (2007), Anctil et al. (2010), and Bouvard et al. (2015).

CHAPTER 3

THE MODEL

We design a two-period investment game using the framework proposed by Angeletos and Pavan (2004). There is a continuum of risk neutral agents indexed by i over the unit interval $[0,1]$. Agents (or investors) choose how much capital they invest in period one and two in order to maximize their life-time utility:

$$v_i(k_{i,1}, k_{i,2}) = u_i(k_{i,1}) + \frac{1}{1+r_f} u_i(k_{i,2})\,, \tag{1}$$

with

$$u_i(k_{i,t}) = A_t k_{i,t} - \frac{1}{2} k_{i,t}^2 \ \text{ for } \ t = 1, 2\,, \tag{2}$$

where $k_{i,t} \in \mathbb{R}$, $\frac{1}{2}k_{i,t}^2$ is the cost of the investment in period t and r_f is the risk-free rate. A_t represents the gross return on the investment in period t and it is given by

$$A_t = (1-\lambda)\theta + \lambda K_t + \mathbb{1}_{(t=2)}[\Lambda(K_{t-1} - \theta)]\,, \tag{3}$$

with

$$K_t = \int_0^1 k_{j,t} dj\,, \tag{4}$$

where $\mathbb{1}$ is an indicator function. The return of investment in both periods depends on an exogenous state variable θ that summarizes economic fundamentals. It can be thought as an aggregate variable containing all the relevant information about the general economic environment. Individuals have a common prior about the fundamental which is uninformative in the sense that it follows a uniform distribution over entire the real line. The return on investment in period t also depends on the aggregate level of investment K_t which makes the actions strategic complements of each other within a particular period where the degree of complementarity is parametrized by λ. That is, λ parametrizes the degree of vertical complementarity which is assumed to be the same across periods [2].

The true value of the fundamental θ is unknown at the time when investors need to decide their investment levels since its true value will be realized at the end of the second period. However, each investor receives an exogenous private signal x_i with a certain precision rate β, given by

$$x_i = \theta + \frac{1}{\sqrt{\beta}}\varepsilon_i \, , \tag{5}$$

where ε_i is standard normal, independent of θ, and independent and identically distributed across agents. All investors also observe a public signal with precision α:

$$z = \theta + \frac{1}{\sqrt{\alpha}}\varepsilon \, , \tag{6}$$

where ε is standard normal and independent of θ and ε_i.

Other than the economic fundamental and intra-period complementarity, return on investment in period two (i.e. A_2) also depends on the aggregate level of investment made in period one (i.e. K_1). The latter introduces complementarity between periods which is captured by the parameter Λ. That is, Λ parametrizes the degree of horizontal complementarity.

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[2]Nothing substantial hinges on this assumption, which is made for the purpose of simplifying the statement of our results.

The social welfare function we adopt is a utilitarian aggregator:

$$W(\theta) = \int_0^1 v_i di. \tag{7}$$

As in Angeletos and Pavan (2004), we are also interested in the region where the social welfare function is concave in K_t in order for lotteries not to be desirable from a social point of view. To this end, we assume $\lambda \in [0, 1/2)$. We note that there is no need to put an extra restriction on Λ, which means it could take any value between zero and one.

CHAPTER 4

EQUILIBRIUM ANALYSIS

4.1 Equilibrium Analysis

Each agent chooses $k_{i,1}$ and $k_{i,2}$ in order to maximize his expected life-time utility (1) conditioned on the available information, $E_i\left[v_i(k_{i,1}, k_{i,2}) \mid x_i, z\right]$, and assuming the risk-free rate is zero [3], this results in

$$k_{i,1} = (1-\lambda)E_i\left[\theta \mid x_i, z\right] + \lambda E_i\left[K_1 \mid x_i, z\right]. \tag{8}$$

Using Lemma 1 given in Appendix 1, an agent i has the following posterior belief about θ. Conditional on x_i and z, it is normally distributed with mean $\frac{\alpha z+\beta x_i}{\alpha+\beta}$ and variance $\frac{1}{\alpha+\beta}$. In a similar setting, Morris and Shin (2002) proved that equilibrium investment strategies are linear in private and public signal, and, moreover, this (rational-expectations) equilibrium is unique. The optimal amount of period-one investment at the equilibrium could then be found as (see Appendix 2 for further details)

$$k_{i,1} = \eta_1 x_i + (1-\eta_1)z\,, \tag{9}$$

where

$$\eta_1 = \frac{\beta(1-\lambda)}{\alpha+\beta(1-\lambda)}\,.$$

[3]The results continue to hold for plausible values of risk-free rate.

An agent also chooses how much investment he should make in period two, leading to the optimality condition given as follows:

$$k_{i,2} = (1-\lambda-\Lambda)E_i\left[\theta \mid x_i, z\right] + \Lambda E_i\left[K_1 \mid x_i, z\right] \ + \lambda E_i[K_2 \mid x_i, z] \,. \tag{10}$$

In a similar fashion, assume that agents follow a linear strategy when choosing their period-two investments. This leads to the following (rational-expectations) equilibrium strategy (see Appendix 2 for further details):

$$k_{i,2} = \eta_2 x_i + (1-\eta_2) z \,, \tag{11}$$

where

$$\eta_2 = \frac{\beta(1-\lambda)}{[\alpha+\beta(1-\lambda)]} - \Lambda\frac{\alpha\beta}{[\alpha+\beta(1-\lambda)]^2} \,.$$

Given the optimum investment strategies, expected social welfare, conditional on the realization of the fundamental, is equal to

$$E\left[W(\theta)\right] = \theta^2 + \gamma - \frac{1}{2}\sum_{t=1}^{2}\varkappa_t \,, \tag{12}$$

where

$$\gamma = \Lambda(1-\eta_1)(1-\eta_2)\frac{1}{\alpha} \,,$$

and

$$\varkappa_t = \eta_t^2\frac{1}{\beta} + (1-2\lambda)(1-\eta_t)^2\frac{1}{\alpha} \,.$$

Equation (12) suggests that expected social welfare depends on three things. The first term parametrizes the effect of the underlying fundamental. The second term γ is due to the existence of horizontal complementarity and is a function of the covariance between aggregate investment levels in period one and two (see Appendix 3 for further details). Finally, the last term $\varkappa$ measures welfare consequences of the heterogeneity in individual investment levels and captures the effect of volatility in aggregate investment.

Angeletos and Pavan (2004) have shown that the third term in an increasing monotonic function of public precision. That is, higher transparency always provides a better vertical coordination irrespective of other parameters. However, whether the second term in increasing in public precision or not depends on both the precision of private information and complementarity levels. In particular, we have

$$\begin{aligned} \gamma &= \Lambda(1-\eta_1)(1-\eta_2)\frac{1}{\alpha} \\ &= \Lambda\frac{\alpha}{\alpha+\beta(1-\lambda)}\left(\frac{1}{\alpha+\beta(1-\lambda)}+\Lambda\frac{\beta}{[\alpha+\beta(1-\lambda)]^2}\right) \\ &= \frac{\alpha^2+\alpha\beta(1+\Lambda-\lambda)}{[\alpha+\beta(1-\lambda)]^3}\,, \end{aligned}$$

which leads to

$$\frac{\partial\gamma}{\partial\alpha} = \Lambda\frac{\beta^2(1-\lambda)(1+\Lambda-\lambda)-2\Lambda\beta\alpha-\alpha^2}{[\alpha+\beta(1-\lambda)]^4}\,. \tag{13}$$

Define $r=\frac{\alpha}{\beta}$ as before, and $\Gamma=(1-\lambda)(1+\Lambda-\lambda)+\Lambda^2$. We then have

$$\frac{\partial\gamma}{\partial\alpha}<0 \Leftrightarrow \alpha > \beta\left[\sqrt{\Gamma}-\Lambda\right]\,, \tag{14}$$

which opens a room for public precision to have a negative impact on social welfare.

4.2 Results and Findings

In our setting, an agent could make a certain return from his investment irrespective of the complementarity levels because his total return depends on the underlying economic fundamental as well. This in turn affects his investment decisions depending upon his expectation about the fundamental. In this context, he needs to choose how much weight he puts on his private information and public information. When making this decision, he also needs to choose an optimal bundle of investment within and between periods due to the presence of two kinds of complementarity. Vertical complementarity was examined by Angeletos and Pavan (2004) and they showed that it makes coordination failures more likely. Here we focus on horizontal complementarity as well as vertical vertical complementarity.

Horizontal complementarity also increases strategic uncertainty and makes coordination failures more likely in the following sense. Period-two investment level of an agent depends on his expectation about the aggregate level of investment in that period as well as the aggregate level of the previous period. If he expects other agents to put more weight on period-one or -two investment, he also tends to do so. However, this might be socially wasteful in such a case if the complementarity of investments between periods is high. The opposite will be the case when the complementarity between periods is sufficiently low in the sense that choosing a more balanced bundle would not provide enough gain at the social level.

In light of these observations, we can now examine the impact of private and public information on social welfare. Since it is analytically hard in our setting to analyze the expected social welfare, we simulate the results under different specifications[4]. We focus first on the social consequences of transparency, which is measured by absolute or relative precision of public information as in Angeletos and Pavan (2004). When horizontal complementarity is sufficiently low, the results are basically the same as Angeletos and Pavan (2004). In particular, increase in the precision of public information α improves social welfare irrespective of the precision of private information β because it helps agents better coordinate their actions. In this regard, full transparency is always optimal.

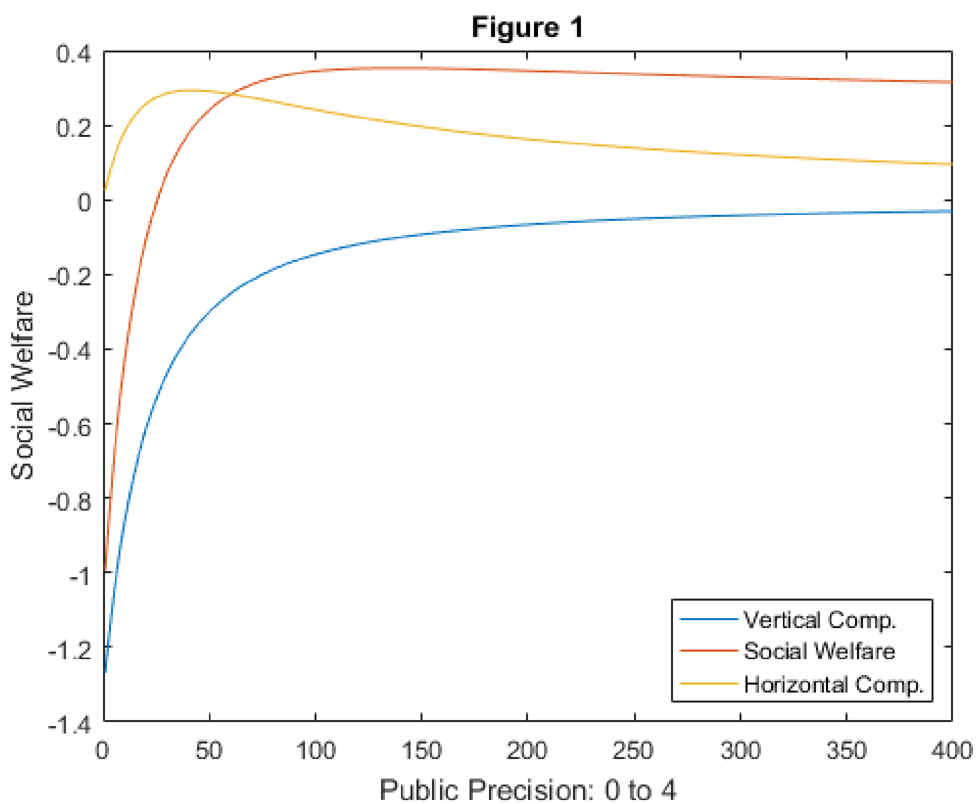

Figure 1: Social welfare function: $\theta = 0.5$, $\beta = 1$, $\lambda = \Lambda = 0.45$

[4]The results are robust in different simulation settings; here we present only the results for uniformly distributed parameters.

The impact of α on social welfare however becomes ambiguous when horizontal complementarity is sufficiently high (see Figure 1 and Figure 2). Relative precision of public information and the degree of vertical complementarity do matter in this case. In the interval where the relative precision α/β is less than $\sqrt{\Gamma} - \Lambda$, the γ function is an increasing function of α. In this interval, welfare increases in transparency regardless of the degree of vertical complementarity. That is, more precise public information is socially beneficial in this case since it provides better horizontal coordination as well as better vertical coordination. The full transparency is then still optimal under these circumstances.

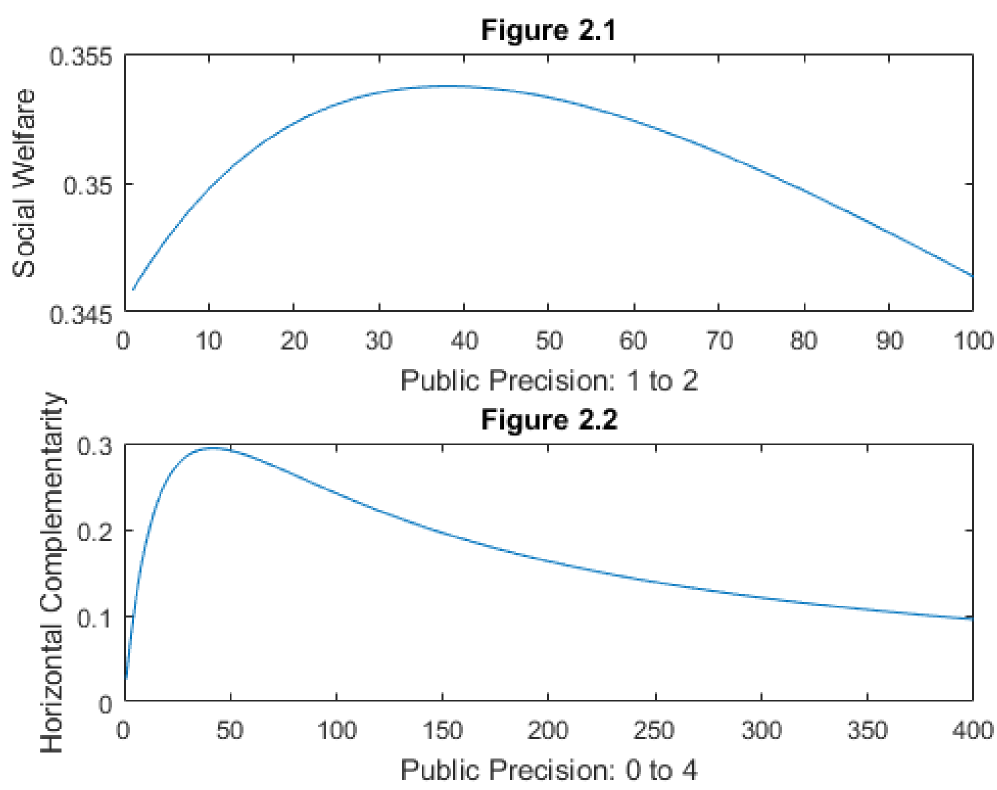

Figure 2: Social welfare function: $\theta = 0.5$, $\beta = 1$, $\lambda = \Lambda = 0.45$

If α/β is greater than $\sqrt{\Gamma} - \Lambda$, an increase in α has two opposing effects on social welfare. As in the former case, it provides better coordination in a vertical manner. However, it magnifies the effectiveness of public information when making investment allocation between periods. This might result in an overreaction of agents to public information and partial ignorance of their privately valuable information. Although public information is extremely effective in influencing actions in this case, the danger arises from the fact that it is too effective at doing so (Morris and Shin, 2002).

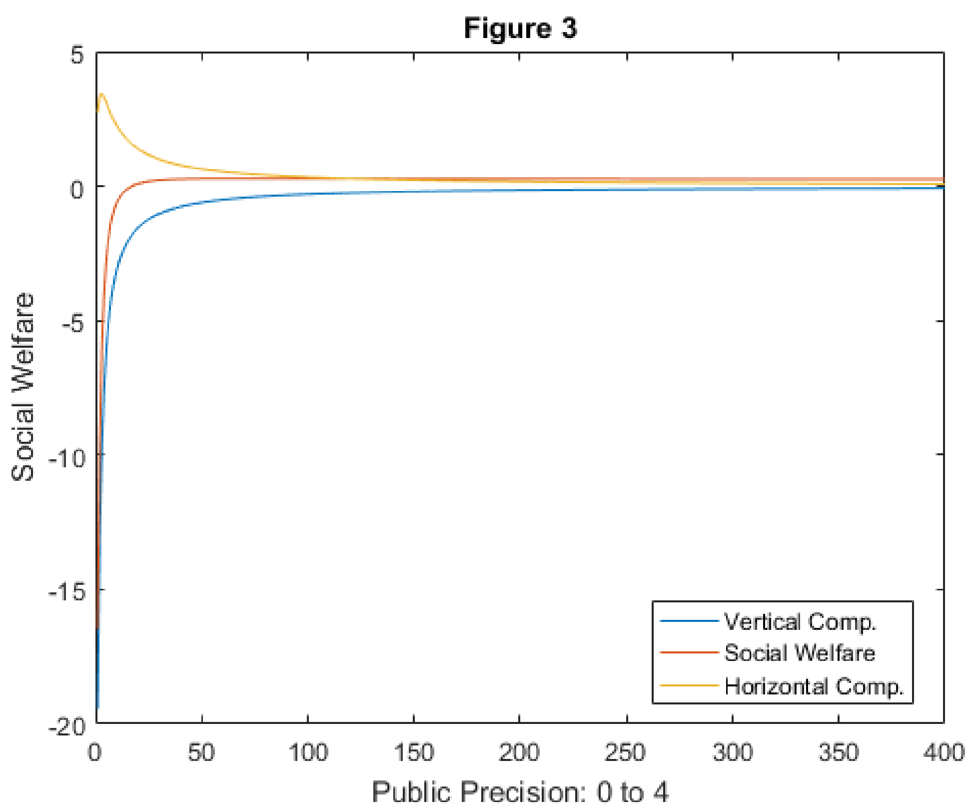

Figure 3: Social welfare function: $\theta = 0.5$, $\beta = 0.05$, $\lambda = \Lambda = 0.35$

The degree of vertical complementarity matters in this case from a social point of view. That is, whether the total effect of an increase in α on social welfare is positive or negative depends on λ. If it is sufficiently low, social welfare increases in transparency because the gain obtained from better vertical coordination outweighs the loss resulted from the deteriorated horizontal coordination. However, as the degree of vertical complementarity gets larger and larger, the impact of worsened horizontal coordination on social welfare magnifies and increase in α deteriorates social welfare.

The results above continue to hold when the private precision is too small (see Figure 3). In this case, an increase in public precision results in a large increase in relative precision α/β and accordingly might cause an over-reaction even if the public precision is also too small in absolute terms.

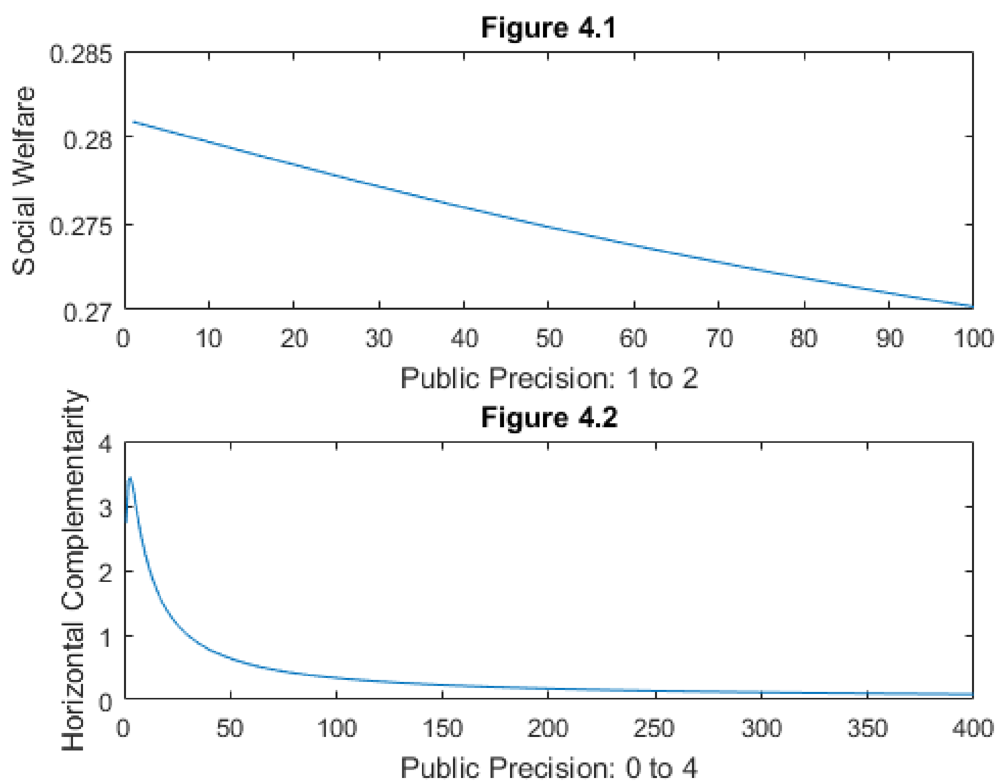

Figure 4: Social welfare function: $\theta = 0.5$, $\beta = 0.05$, $\lambda = \Lambda = 0.35$

Figure 4 further reveals the impact of horizantal complimentarity on the optimal level of transperancy (Figure 4.1) and on social welfare (Figure 4.2). Figure 4.2 shows that horizontal coordination starts to deteriorate much before than the optimal level in Figure 2.1. This in turn causes optimal level of transparency to decrease from about 1.35 in Figure 2.1 to slightly over 0 in Figure 4.2. It is also noteworthy stating that both the vertical and horizontal complementarity parameters are taken as 0.35 in Figure 3 and Figure 4 on purpose, since the situation becomes much worse when both are equal to 0.45 as in Figure 1 and Figure 2.

As in Angeletos and Pavan (2004), the impact of the precision of private information on welfare is unambiguous. Aside from the degrees of complementarities and relative precision, the impact also depends on absolute precision. There are four possible scenarios in terms of complementarity levels. In the first case, both vertical and horizontal complementarities are low in which case social welfare increases in β regardless of α. In the opposite case, when both are high, higher private precision is detrimental to horizontal coordination and in most cases to vertical coordination. Therefore, it results in lower social welfare in most cases unless public information has unrealistically low precision.

To illustrate more, observe that given α the term γ in equation (12) is negatively related with β, since γ is positively related with relative precision. In this setting if the precision of public information is (unrealistically) too low in absolute terms, the loss that results from worsening horizontal coordination is outweighed by the gain from better vertical coordination. However, if α exceeds a certain threshold , the last term in equation (12) also decreases in private precision. In this case, an increase in private precision deteriorates both vertical and horizontal coordination and results in a significant drop in social welfare. This effect gets much worse when absolute public precision gets higher.

In either of the remaining two cases, agents can better coordinate as long as the relative precision α/β is not too high. They tend to invest more in period one if horizontal complementarity is too low and vice versa, which in turn makes coordination failures less likely. In the first case, when vertical complementarity is low and horizontal complementarity is high, increases in private precision improves social welfare even though it might cause a slight decrease at the first place. This argument is in fact more valid for lower levels of horizontal complementarity. In the other case, the impact of private information becomes more ambiguous and depends on the very parameter values of other variables. However, in general, social welfare tends to decrease up to a certain point, and then improves slightly as the loss from worsened horizontal coordination begins to be compensated by the gain from better vertical coordination.

CHAPTER 5

THE SEQUENTIAL VERSION

We continue to use the same model in Part 3, but agents now make period-two investment decisions after observing the aggregate level of period-one investment. In this set-up, our equilibrium definition is a hybrid of rational expectations and perfect Bayesian equilibrium concepts. The first period remains the same as before since the decisions in period 2 do not have an impact on the decisions in period 1. Hence, the optimum level of investment for an agent in the first period is

$$k_{i,1} = \eta x_i + (1-\eta) z \,, \tag{15}$$

where

$$\eta = \frac{\beta(1-\lambda)}{\alpha + \beta(1-\lambda)} \,. \tag{16}$$

As for the second period, the equilibrium investment strategies continue to be linear in public and private information as in the simultaneous version of the game. Then the equilibrium strategy is found as

$$k_{i,2} = \eta_0 + \eta_1 x_i + \eta_2 z \tag{17}$$

(see appendix 4 for further details), where

$$\eta_0 = \frac{\Lambda}{1-\lambda} K_1, \;\; \eta_1 = \frac{(1-\lambda-\Lambda)\beta}{\alpha+\beta(1-\lambda)} \,, \;\; \text{and} \;\; \eta_2 = \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha+\beta(1-\lambda)\right]} \,. \tag{18}$$

Given the optimum investment strategies, expected social welfare conditional on the realization of the fundamental is given by (see Appendix 5 for further details)

$$E\left[W(\theta)\right] = \theta^2 - \frac{1}{2}\varkappa + \Lambda \cdot \gamma\,, \tag{19}$$

where

$$\varkappa = \frac{1}{\beta}\left(\eta^2 + \eta_1^2\right) + 2(1-2\lambda)(1-\eta)^2\frac{1}{\alpha}\text{ , and} \tag{20}$$

$$\gamma = \frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]^2} \tag{21}$$

We know from previous calculations that $\partial\varkappa/\partial\alpha < 0$ which means social welfare increases in public precision in the absence of horizontal complementarity. However:

$$\frac{\partial\gamma}{\partial\alpha} = \frac{-\alpha + \beta(1-\lambda)}{\left[a + \beta(1-\lambda)\right]^3}\,, \tag{22a}$$

so that

$$\frac{\partial\gamma}{\partial\alpha} < 0 \Leftrightarrow \alpha/\beta > 1 - \lambda\,, \tag{22b}$$

which again opens a room for public precision to have a negative impact on social welfare. In fact, it turns out that in certain cases it does.

Figure 5 demonstrates that vertical and horizontal coordination and accordingly social welfare follow similar patterns both in simultaneous and sequential versions. But there are some distinct differences between them, which depend on complementarity levels and private precision.

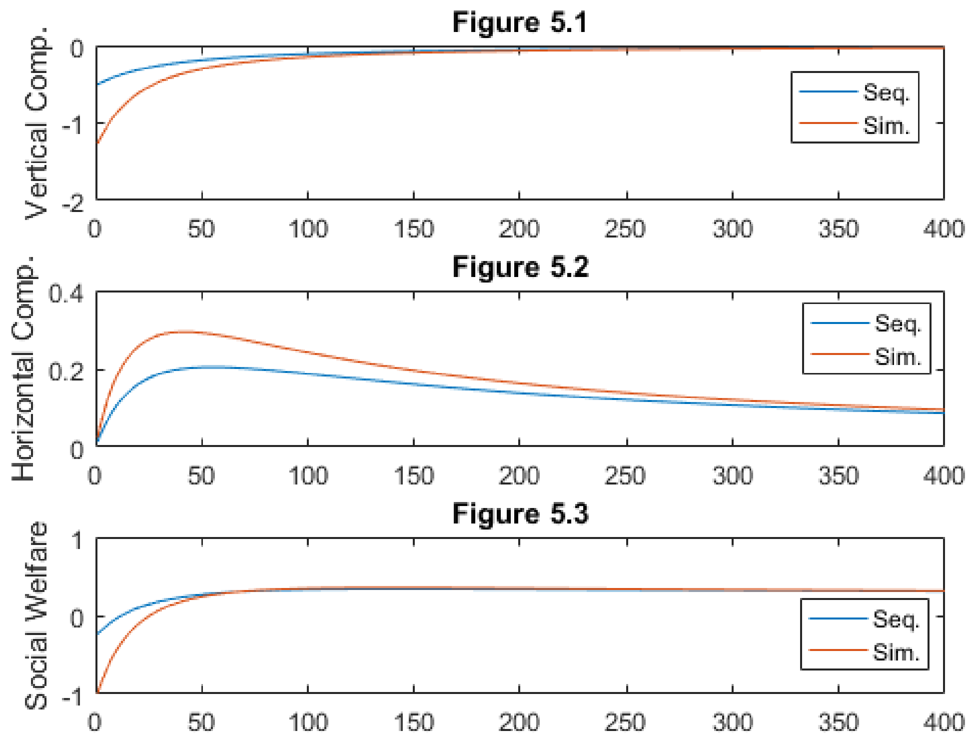

Figure 5: Social welfare function: $\theta = 0.5$, $\beta = 1$, $\lambda = \Lambda = 0.45$

Figure 5 also suggests that when private precision is sufficiently high, agents horizontally coordinate better in simultaneous game. The degree of horizontal coordination is determined by how intensively the public information is used in decisions since it is the public information that links the periods. Because agents have to simultaneously make period-one and period-two investment decisions in the simultaneous game, they choose to rely more on public information. But agents become able to determine the value of private information more accurately when the decisions are made sequentially. In this case, the private precision is one which could be considered valuable, and better usage of it improves vertical coordination but deteriorates horizontal coordination. Besides, better usage of private information causes a higher optimal level of transparency as seen from Figure 6. In other words, agents begin over-reacting public information at a higher level of transparency.

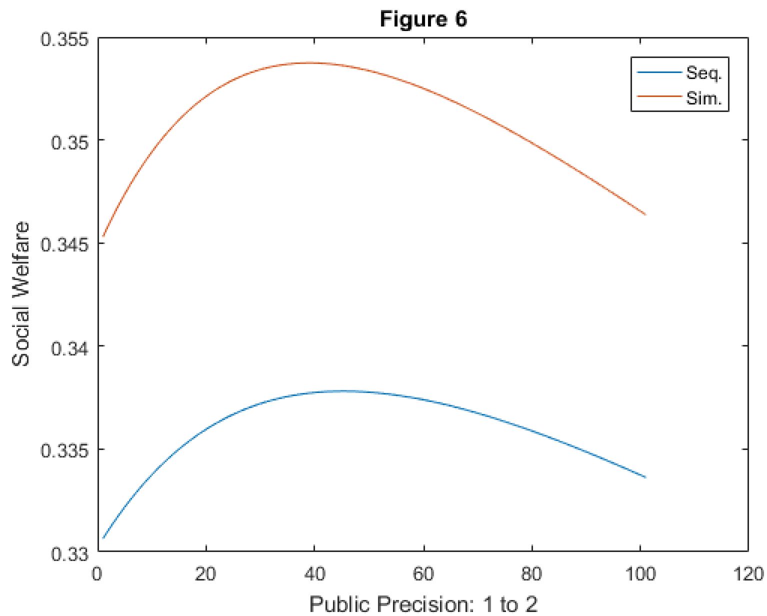

Figure 6: Social welfare function: $\theta = 0.5$, $\beta = 1$, $\lambda = \Lambda = 0.45$

However, when private information is too noisy, as in Figure 7, agents learn almost nothing from their private information. In sequential game, agents become more able to determine the so-called valueless of private information and start ignoring it at lower level of transparency. Similar to the previous case, we end up with a better vertical coordination and a worse horizontal coordination in the sequential game. Besides, less better usage of private information in sequential game causes a lower optimal level of transparency, as can be seen from Figure 7.

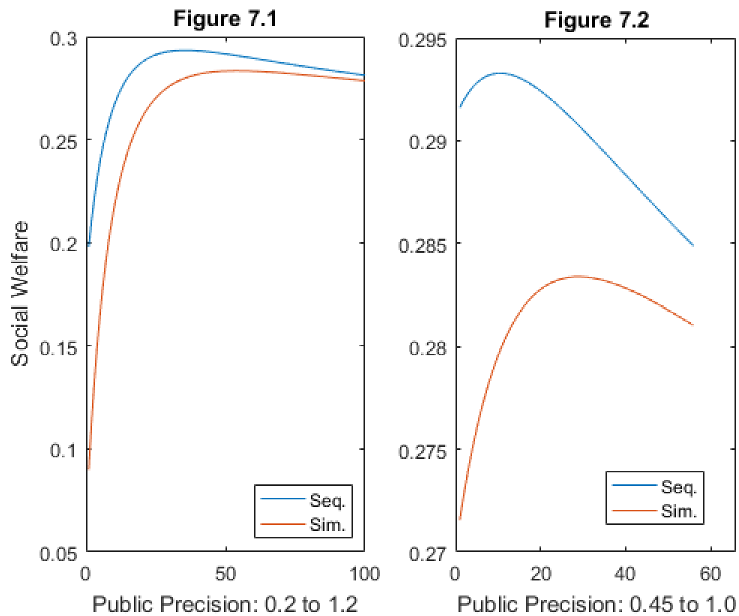

Figure 7: Social welfare function: $\theta = 0.5$, $\beta = 0.05$, $\lambda = \Lambda = 0.35$

CHAPTER 6

EXTENSIONS OF THE MAIN MODEL

The adverse impact of public information stems from the fact that it might sometimes be a very powerful tool to coordinate agents' actions. However, in order for more transparency to have a negative impact on social welfare, it must be the case that agents use the public information in an intensive and aggressive manner. Agents' decisions otherwise are not much affected by the degree of transparency. In particular, full transparency is also always optimal in our set-up as Angeletos and Pavan (2004) when agents choose to rely more on their private information when making period-one or period-two decisions or both. In order to show this, we will analyze two extreme cases in the simultaneous game.

6.1 Using Different Information Set: Case I

We will use a linear production function, $f(k_t, k_{t+1}) = A_t k_t + A_{t+1} k_{t+1}$, where period-one investments are made using only private information, but period-two investment decisions are made using both private and public information, i.e. $k_t = k_t(x)$ and $k_{t+1} = k_{t+1}(x, z)$. This structure requires that $A_t = (1 - \lambda)\theta + \lambda K_t$ and $A_{t+1} = (1 - \lambda - \Lambda)\theta + \lambda K_t + \Lambda K_{t+1}$. The optimization problem is

$$\underset{k_{i,t}, k_{i,t+1}}{\arg\max} \; A_t k_{i,t} + A_{t+1} k_{i,t+1} - \frac{1}{2}(k_{i,t}^2 + k_{i,t+1}^2) \;, \tag{23a}$$

leading to

$$k_{i,t} = E_i[A_t] := \eta_1 x_i \;, \tag{23b}$$

with

$$\theta \mid x_i \sim N(x_i, \frac{1}{\beta}) . \tag{23c}$$

The resulting optimum investment level in period one is then

$$k_{i,t} = x_i . \tag{24}$$

As for period two, we get

$$k_{i,t+1} = E_i[A_{t+1}] := \eta_2 x_i + (1 - \eta_2) z , \tag{25}$$

with

$$\theta \mid x_i, z \sim N(\frac{\alpha z + \beta x_i}{\alpha + \beta}, \frac{1}{\alpha} + \frac{1}{\beta}) .$$

The coefficient η_2 can be computed as

$$\eta_2 = 1 - \frac{\alpha(1 - \lambda)}{\alpha + \beta(1 - \Lambda)} . \tag{26}$$

It is worth stating that when $\lambda = 0$, the model simplifies to the model of Angeletos and Pavan (2004). In this set-up, expected social welfare is

$$E[W(\theta)] = \theta^2 - \frac{1}{2}\left[(1 - 2\Lambda)(1 - \eta_2)^2 \frac{1}{\alpha} + \frac{1}{\beta}(\eta_2^2 + 1)\right] . \tag{27}$$

Defining relative precision as $r = \alpha/\beta$, social welfare will be a decreasing function of public precision if and only if the condition below holds:

$$\frac{\partial E[W(\theta)]}{\partial r} \leq 0 \Leftrightarrow r \leq -\frac{(1-\Lambda+\lambda)+\lambda\Lambda\,(3-2\Lambda)}{[1-2\Lambda+\lambda]}\ . \tag{28}$$

The right hand side of the last equation is always negative which means full transparency is always optimal from a social perspective.

6.2 Using Different Information Set: Case II

The structure is exactly the same as in Section 6.1 except for the following:

$$A_t = (1-\lambda)\theta + \lambda K_t\ , \text{ and } A_{t+1} = (1-\Lambda)\theta + \Lambda K_{t+1} \tag{29a}$$

$$k_{i,t} = k_{i,t}(x_i)\ , \text{ and } k_{i,t+1} = k_{i,t+1}(z) \tag{29b}$$

That is, period-two investment decision is now made using only public information, while period-one investment still depends on only private information. Using similar arguments, the investment strategies are now given by

$$k_{i,t} = x_i\ , \text{ and } k_{i,t+1} = z\ . \tag{30}$$

The equilibrium social welfare is then

$$E\left[W(\theta)\right] = \theta^2 - \frac{1}{2}\left[(1-2\lambda)\,\frac{1}{\alpha} + \frac{1}{\beta}\right]\ , \tag{31}$$

which is monotonically increasing in public precision.

Both extensions suggest that as the role of public information as linking agents' actions loses its influence, full transparency is always optimal by allowing agents to make better decisions. However, as in our model, if public information is used to establish links between different investments decisions, transparency starts deteriorating social welfare since agents begin to ignore their private information and give too much weight to public information as compared to the weight of a social planner.

CHAPTER 7

CONCLUSION

We constructed a two-period model in the presence of investment complementarities both within periods (vertical complementarity) and between periods (horizontal complementarity) in order to examine the impact of intra- and inter-temporal investment complementarities on the incidence of coordination failure and on social welfare. In particular, the return on investment in a particular period depends both on the economic fundamental and aggregate level of investment in that period. However, other than those two, the return of investment in period two also depends on the aggregate investment made in period one.

The existence of horizontal complementarity increases strategic uncertainty and makes coordination failures more likely. The results suggest that full transparency is optimal at the social level as long as agents have an access to relatively more precise private information and complementarities are sufficiently low. More transparency otherwise reduces social welfare as the gain from better vertical coordination is outweighed by the loss that results from less horizontal coordination. We have also found that the impact of the precision of private information on welfare is ambiguous. Aside from the degrees of complementarities and relative precision, the effect of increasing precision of private information also depends on absolute precision of public information.

APPENDIX A

CONDITIONAL EXPECTATION OF THE BIVARIATE NORMAL DISTRIBUTION

Lemma 1 *Let y and x be represented as a bi-variate normal distribution*

$$\begin{bmatrix} y \\ x \end{bmatrix} \sim N\left(\begin{bmatrix} E_y \\ E_x \end{bmatrix}, \begin{bmatrix} V_y & V_{yx} \\ V_{xy} & V_x \end{bmatrix}\right).$$

The conditional expectation and variance of y are given then:

$$E[y \mid x] = E_y + \frac{V_{yx}}{V_x}(x - E_x) \quad \text{and} \quad Var[y \mid x] = V_y - \frac{V_{yx}^2}{V_x}$$

APPENDIX B

THE SIMULTANEOUS VERSION: OPTIMAL INVESTMENT STRATEGIES

Assuming investment strategies are linear in private and public signal such that

$$k_{i,1} = \eta_1 x_i + (1-\eta_1)z \text{ and } k_{i,2} = \eta_2 x_i + (1-\eta_2)z$$

the optimum capital strategies could be found as follows:

$$\arg\max_{k_{i,1}} \quad E_i\left[v_i(k_{i,1}, k_{i,2}) \mid x_i, z\right] = u_i(k_{i,1}) + \frac{1}{1+r} u_i(k_{i,2})$$

$$F.O.C. \quad k_{i,1} = E_i\left[A_1 \mid x_i, z\right] = (1-\lambda)E_i\left[\theta \mid x_i, z\right] + \lambda E_i\left[K_1 \mid x_i, z\right]$$

$$E_i\left[K_1 \mid x_i, z\right] = E_i\left[\int_0^1 k_{j,1} dj \mid x_i, z\right] = E_i\left[\int_0^1 \left(\eta_1 x_j + (1-\eta_1)z\right) dj \mid x_i, z\right]$$

$$= \eta_1 \int_0^1 E\left[x_j \mid x_i, z\right] dj + (1-\eta_1)z = \eta_1 \frac{\alpha z + \beta x_i}{\alpha+\beta} + (1-\eta_1)z$$

$$\Rightarrow k_{i,1} = (1-\lambda)\frac{\alpha z + \beta x_i}{\alpha+\beta} + \lambda\left(\eta_1 \frac{\alpha z + \beta x_i}{\alpha+\beta} + (1-\eta_1)z\right)$$

$$\Rightarrow \eta_1 = (1-\lambda)\frac{\beta}{\alpha+\beta} + \lambda\frac{\beta}{\alpha+\beta}\eta_1 \Rightarrow \eta_1 = \frac{\beta(1-\lambda)}{\alpha+\beta(1-\lambda)}$$

$$\Rightarrow k_{i,1} = \frac{\beta(1-\lambda)}{\alpha+\beta(1-\lambda)} x_i + \left(\frac{\alpha}{\alpha+\beta(1-\lambda_h)}\right)z$$

$$\arg\max_{k_{i,2}} \quad E_i\left[v_i(k_{i,1},k_{i,2}) \mid x_i,z\right] = u_i(k_{i,1}) + \frac{1}{1+r}u_i(k_{i,2})$$

$$F.O.C. \quad k_{i,2} = E_i\left[A_2 \mid x_i,z\right] = E_i\left[(1-\lambda-\Lambda)\theta + \Lambda K_1 + \lambda K_2 \mid x_i,z\right]$$

$$= (1-\lambda-\Lambda)E_i\left[\theta \mid x_i,z\right] + \Lambda E_i\left[K_1 \mid x_i,z\right] \; + \lambda E_i[K_2 \mid x_i,z]$$

$$E_i\left[K_2 \mid x_i,z\right] = E_i\left[\int_0^1 k_{j,2}dj \mid x_i,z\right] = E_i\left[\int_0^1 \left(\eta_2 x_j + (1-\eta_2)z\right)dj \mid x_i,z\right]$$

$$= \eta_2\int_0^1 E_i\left[x_j \mid x_i,z\right]dj + (1-\eta_2)z = \eta_2\frac{\alpha z+\beta x_i}{\alpha+\beta} + (1-\eta_2)z$$

$$\Rightarrow k_{i,2} = (1-\lambda-\Lambda)\frac{\alpha z+\beta x_i}{\alpha+\beta} + \Lambda\left(\eta_1\frac{\alpha z+\beta x_i}{\alpha+\beta} + (1-\eta_1)z\right)$$

$$+\lambda\left(\eta_2\frac{\alpha z+\beta x_i}{\alpha+\beta} + (1-\eta_2)z\right)$$

$$\Rightarrow \eta_2 = (1-\lambda-\Lambda)\frac{\beta}{\alpha+\beta} + \Lambda\frac{\beta}{\alpha+\beta}\eta_1 + \lambda\frac{\beta}{\alpha+\beta}\eta_2$$

$$\Rightarrow \eta_2 = \frac{\beta(1-\lambda)}{\left[\alpha+\beta(1-\lambda)\right]} - \Lambda\frac{\alpha\beta}{\left[\alpha+\beta(1-\lambda)\right]^2}$$

APPENDIX C

THE SIMULTANEOUS VERSION: SOCIAL WELFARE FUNCTION

$$W(\theta) = \sum_{t=1}^{2} \int_{0}^{1} v_i di = \sum_{t=1}^{2} \int_{0}^{1} \left(A_t k_{i,t} - \frac{1}{2} k_{i,t}^2 \right) di = \sum_{t=1}^{2} \left(A_t K_t - \frac{1}{2} \int_{0}^{1} k_{i,t}^2 di \right)$$

$$\Rightarrow E\left[W(\theta)\right] = \sum_{t=1}^{2} E\left[A_t K_t \mid \theta\right] - \frac{1}{2} \sum_{t=1}^{2} E\left[\int_{0}^{1} k_{i,t}^2 di \mid \theta \right]$$

$$= \sum_{t=1}^{2} E\left[\left((1-\lambda)\theta + \lambda K_t + \mathbb{1}_{(t=2)} [\Lambda (K_{t-1} - \theta)] \right) \cdot K_t \mid \theta \right] - \frac{1}{2} \sum_{t=1}^{2} E\left[\int_{0}^{1} k_{i,t}^2 di \mid \theta \right]$$

$$= \sum_{t=1}^{2} (1-\lambda)\theta E\left[K_t \mid .\right] + \lambda E\left[K_t^2 \mid .\right] + \Lambda \mathbb{1}_{(t=2)} \left\{ E[K_{t-1} K_t \mid .] - \theta E[K_t \mid .] \right\} - \frac{1}{2} \sum_{t=1}^{2} E\left[\int_{0}^{1} k_{i,t}^2 di \mid . \right]$$

$$E\left[K_t \mid \theta\right] = E\left[\eta_t \theta + (1-\eta_t) z \mid \theta\right] = \theta$$

$$E\left[K_t^2 \mid \theta\right] = var(K_t \mid \theta) + E\left[K_t \mid \theta\right]^2 = (1-\eta_t)^2 \frac{1}{\alpha} + \theta^2$$

$$E\left[K_{t-1} K_t \mid \theta\right] = Cov(K_{t-1}, K_t \mid \theta) + E\left[K_{t-1} \mid \theta\right] \cdot E\left[K_t \mid \theta\right]$$

$$= Cov\left[\eta_1 \theta + (1-\eta_1) z, \eta_2 \theta + (1-\eta_2) z \mid \theta\right] + \theta^2$$

$$= (1-\eta_1)(1-\eta_2) Cov(z, z \mid \theta) + \theta^2 = (1-\eta_1)(1-\eta_2) \frac{1}{\alpha} + \theta^2$$

$$
\begin{aligned}
-\frac{1}{2}\int_0^1 k_{i,t}^2 di &= \frac{1}{2}\int_0^1 \left[K_t^2 - 2k_{i,t}K_t\right] di - \frac{1}{2}\int_0^1 \left[k_{i,t}^2 + K_t^2 - 2k_{i,t}K_t\right] di \\
&= -\frac{1}{2}K_t^2 - \frac{1}{2}\int_0^1 (k_{i,t} - K_t)^2 di = -\frac{1}{2}K_t^2 - \frac{1}{2}\eta_t^2 \int_0^1 \left[x_i - \theta\right]^2 di \\
&= -\frac{1}{2}K_t^2 - \frac{1}{2}\eta_t^2 \frac{1}{\beta}
\end{aligned}
$$

$$
\Rightarrow E\left[W(\theta)\right] = \theta^2 + \gamma - \frac{1}{2}\sum_{t=1}^{2} \varkappa_t
$$

where $\gamma = \Lambda(1-\eta_1)(1-\eta_2)\frac{1}{\alpha}$ and $\varkappa_t = \eta_t^2 \frac{1}{\beta} + (1-2\lambda)(1-\eta_t)^2 \frac{1}{\alpha}$

with $\eta_1 = \frac{(1-\lambda)\beta}{\alpha + \beta(1-\lambda)}$ and $\eta_2 = \frac{\beta(1-\lambda)}{[\alpha + \beta(1-\lambda)]} - \Lambda \frac{\alpha\beta}{[\alpha + \beta(1-\lambda)]^2}$.

APPENDIX D

THE SEQUENTIAL VERSION: OPTIMAL INVESTMENT STRATEGIES

$$
\begin{aligned}
k_{i,2} &= E_i[A_2 \mid x_i, z] \\
&= (1-\lambda-\Lambda)E_i[\theta \mid x_i, z] + \lambda E_i[K_2 \mid x_i, z] + \Lambda K_1 \\
&= (1-\lambda-\Lambda)\frac{\alpha z + \beta x_i}{\alpha+\beta} + \lambda\left(\eta_0 + \eta_1 \frac{\alpha z + \beta x_i}{\alpha+\beta} + \eta_2 z\right) + \Lambda K_1
\end{aligned}
$$

$$
\begin{aligned}
\Rightarrow \eta_1 &= (1-\lambda-\Lambda)\frac{\beta}{\alpha+\beta} + \lambda\eta_1\frac{\beta}{\alpha+\beta} \\
\Rightarrow (\alpha+\beta-\lambda\beta)\,\eta_1 &= (1-\lambda-\Lambda)\beta \\
\Rightarrow \eta_1 &= \frac{(1-\lambda-\Lambda)\beta}{\alpha+\beta(1-\lambda)}
\end{aligned}
$$

$$
\begin{aligned}
\eta_2 &= (1-\lambda-\Lambda)\frac{\alpha}{\alpha+\beta} + \lambda\eta_1\frac{\alpha}{\alpha+\beta} + \lambda\eta_2 \\
\Rightarrow (1-\lambda)\eta_2 &= \frac{\alpha}{\alpha+\beta}\left[(1-\lambda-\Lambda) + \lambda\eta_1\right] \\
\Rightarrow \eta_2 &= \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha+\beta(1-\lambda)\right]}
\end{aligned}
$$

$$
\begin{aligned}
\eta_0 &= \lambda\eta_0 + \Lambda K_1 \\
\Rightarrow \eta_0 &= \frac{\Lambda}{1-\lambda}K_1
\end{aligned}
$$

APPENDIX E

THE SEQUENTIAL VERSION: SOCIAL WELFARE FUNCTION

$$K_1 = \int_0^1 \eta x_i + (1-\eta) z di = \eta\theta + (1-\eta) z$$

$$\Rightarrow E[K_1 \mid \theta] = \theta$$

$$E[K_1^2 \mid \theta] = var(K_1 \mid \theta) + E[K_1 \mid \theta]^2 = (1-\eta)^2 \frac{1}{\alpha} + \theta^2$$

$$K_2 = \int_0^1 \eta_0 + \eta_1 x_i + \eta_2 z di = \eta_0 + \eta_1\theta + \eta_2 z$$

$$E[K_2 \mid \theta] = E[\eta_0 + \eta_1\theta + \eta_2 z \mid \theta] = E[\eta_0 \mid \theta] + (\eta_1 + \eta_2)\theta$$
$$= \frac{\Lambda}{1-\lambda} E[K_1 \mid \theta] + (\eta_1 + \eta_2)\theta = \left(\frac{\Lambda}{1-\lambda} + \eta_1 + \eta_2\right)\theta$$

$$\frac{\Lambda}{1-\lambda} + \eta_1 + \eta_2 = \frac{\Lambda}{1-\lambda} + \frac{(1-\lambda-\Lambda)\beta}{\alpha + \beta(1-\lambda)} + \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]}$$
$$= \frac{\Lambda\left[\alpha + \beta(1-\lambda)\right] + (1-\lambda-\Lambda)\beta(1-\lambda) + (1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]}$$
$$= \frac{\Lambda\left[\alpha + \beta(1-\lambda)\right] + (1-\lambda-\Lambda)\left[\beta(1-\lambda) + \alpha\right]}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]}$$
$$= \frac{\left[\alpha + \beta(1-\lambda)\right](\Lambda + 1 - \lambda - \Lambda)}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]} = 1$$

$$\Rightarrow E[K_2 \mid \theta] = \theta$$

$$
\begin{aligned}
K_2 &= \frac{\Lambda}{1-\lambda}\left[\eta\theta + (1-\eta)z\right] + \eta_1\theta + \eta_2 z \\
&= \left(\frac{\Lambda}{1-\lambda}\eta + \eta_1\right)\theta + \left(\frac{\Lambda}{1-\lambda}(1-\eta) + \eta_2\right)z \\
\Rightarrow var(K_2 \mid \theta) &= \left(\frac{\Lambda}{1-\lambda}(1-\eta) + \eta_2\right)^2 \frac{1}{\alpha}
\end{aligned}
$$

$$
\begin{aligned}
\Rightarrow E[K_2^2 \mid \theta] &= var(K_2 \mid \theta) + E[K_2 \mid \theta]^2 \\
&= \left(\frac{\Lambda}{1-\lambda}(1-\eta) + \eta_2\right)^2 \frac{1}{\alpha} + \theta^2
\end{aligned}
$$

$$
\begin{aligned}
\frac{\Lambda}{1-\lambda}(1-\eta) + \eta_2 &= \frac{\Lambda}{1-\lambda}\left(1 - \frac{\beta(1-\lambda)}{\alpha + \beta(1-\lambda)}\right) + \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]} \\
&= \frac{\Lambda}{1-\lambda}\frac{\alpha}{\alpha + \beta(1-\lambda)} + \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]} \\
&= \frac{\alpha}{(1-\lambda)\left[\alpha + \beta(1-\lambda)\right]}\left(\Lambda + 1 - \lambda - \Lambda\right) = \frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]}
\end{aligned}
$$

$$
\Rightarrow E[K_2^2 \mid \theta] = \left(\frac{\alpha}{\alpha + \beta(1-\lambda)}\right)^2 \frac{1}{\alpha} + \theta^2 = (1-\eta)^2\frac{1}{\alpha} + \theta^2 := E[K_1^2 \mid \theta]
$$

$$E[K_1K_2 \mid \theta] = cov(K_1, K_2 \mid \theta) + E[K_1 \mid \theta] \cdot E[K_2 \mid \theta]$$

$$= cov(K_1, K_2 \mid \theta) + \theta^2 = cov(K_1, \frac{\Lambda}{1-\lambda}K_1 + \eta_1\theta + \eta_2 z \mid \theta) + \theta^2$$

$$= \frac{\Lambda}{1-\lambda}cov(K_1, K_1 \mid \theta) + cov(K_1, \eta_2 z \mid \theta) + \theta^2$$

$$= \frac{\Lambda}{1-\lambda}cov(K_1, K_1 \mid \theta) + cov(\eta\theta + (1-\eta)z, \eta_2 z \mid \theta) + \theta^2$$

$$= \frac{\Lambda}{1-\lambda}cov(K_1, K_1 \mid \theta) + (1-\eta)\eta_2 cov(z, z \mid \theta) + \theta^2$$

$$= \frac{\Lambda}{1-\lambda}(1-\eta)^2\frac{1}{\alpha} + (1-\eta)\eta_2\frac{1}{\alpha} + \theta^2$$

$$\frac{\Lambda}{1-\lambda}(1-\eta)^2\frac{1}{\alpha} + (1-\eta)\eta_2\frac{1}{\alpha} = (1-\eta)\frac{1}{\alpha}\left[\frac{\Lambda}{1-\lambda}(1-\eta) + \eta_2\right]$$

$$= \frac{\alpha}{[\alpha + \beta(1-\lambda)]}\frac{1}{\alpha}\left[\frac{\Lambda}{1-\lambda}\frac{\alpha}{[\alpha+\beta(1-\lambda)]} + \frac{(1-\lambda-\Lambda)\alpha}{(1-\lambda)\,[\alpha+\beta(1-\lambda)]}\right]$$

$$= \frac{1}{[\alpha+\beta(1-\lambda)]}\left[\frac{\Lambda\alpha + (1-\lambda-\Lambda)\alpha}{(1-\lambda)\,[\alpha+\beta(1-\lambda)]}\right]$$

$$= \frac{1}{[\alpha+\beta(1-\lambda)]}\left[\frac{(1-\lambda)\alpha}{(1-\lambda)\,[\alpha+\beta(1-\lambda)]}\right]$$

$$= \frac{\alpha}{[\alpha+\beta(1-\lambda)]^2}$$

$$\Rightarrow E[K_1K_2 \mid \theta] = \frac{\alpha}{[\alpha+\beta(1-\lambda)]^2} + \theta^2$$

$$W = \int_0^1 \left(A_1 k_{i,1} + A_2 k_{i,2}\right) di - \frac{1}{2}\int_0^1 \left(k_{i,1}^2 + k_{i,2}^2\right) di$$

$$= A_1 K_1 + A_2 K_2 - \frac{1}{2}\left[\left(K_1^2 + \eta^2 \frac{1}{\beta}\right) + \left(K_2^2 + \eta_1^2 \frac{1}{\beta}\right)\right]$$

$$\left[(1-\lambda)\theta + \lambda K_1\right] K_1 + \left[(1-\lambda-\Lambda)\theta + \lambda K_2 + \Lambda K_1\right] K_2 - \frac{1}{2}\left(K_1^2 + K_2^2\right) - \frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right)$$

$$= (1-\lambda)\theta K_1 + \lambda K_1^2 + (1-\lambda-\Lambda)\theta K_2 + \lambda K_2^2 + \Lambda K_1 K_2 - \frac{1}{2}\left(K_1^2 + K_2^2\right) - \frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right)$$

$$= (1-\lambda)\theta K_1 + \left(\lambda - \frac{1}{2}\right) K_1^2 + (1-\lambda-\Lambda)\theta K_2 + \left(\lambda - \frac{1}{2}\right) K_2^2 + \Lambda K_1 K_2 - \frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right)$$

$$E\left[W(\theta)\right] = (1-\lambda)\theta^2 + \left(\lambda - \frac{1}{2}\right)\left[(1-\eta)^2 \frac{1}{\alpha} + \theta^2\right] + (1-\lambda-\Lambda)\theta^2$$

$$+ \left(\lambda - \frac{1}{2}\right)\left[(1-\eta)^2 \frac{1}{\alpha} + \theta^2\right] + \Lambda\left[\frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]^2} + \theta^2\right] - \frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right)$$

$$= (1-\lambda)\theta^2 + \left(\lambda - \frac{1}{2}\right)\theta^2 + (1-\lambda-\Lambda)\theta^2 + \left(\lambda - \frac{1}{2}\right)\theta^2 + \Lambda\theta^2$$

$$-\frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right) + 2\left(\lambda - \frac{1}{2}\right)\left[(1-\eta)^2 \frac{1}{\alpha}\right]$$

$$+\Lambda\left[\frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]^2}\right]$$

$$= \theta^2 - \frac{1}{2\beta}\left(\eta^2 + \eta_1^2\right) - \frac{1}{2}\left[2(1-2\lambda)(1-\eta)^2 \frac{1}{\alpha}\right] + \Lambda\left[\frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]^2}\right]$$

$$= \theta^2 - \frac{1}{2}\left[\frac{1}{\beta}\left(\eta^2 + \eta_1^2\right) + 2(1-2\lambda)(1-\eta)^2 \frac{1}{\alpha}\right] + \Lambda\left[\frac{\alpha}{\left[\alpha + \beta(1-\lambda)\right]^2}\right]$$

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