A Partial Equilibrium Analysis in the Markets with Social Interactions

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Abstract

This paper analyzes a demand side of a two-good economy where the demand of one good is affected by social interactions between consumers. We focus on two types of interactions: a spillover effect in the form of a positive externality from other consumers' choices, and a conformity effect representing a need for making similar choices as other people. We show that a positive spillover effect shifts the demand curve for the good with interactions upwards, and the conformity effect makes the demand curve to pivot around the average market demand

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1. Introduction

Economic approach to human behavior that assumes a single decision maker is sometimes criticized as an example of excessive abstraction leading to un-informative behavioral implications and inaccurate predictions. One reason economic researchers have avoided models with interdependent agents is complexity and no generally accepted theoretical framework for examining interdependent economic agents (Manski 2000, Moffitt 2001, Durlauf and Young 2001). Empirically, researchers would need to construct econometric models that can be tested, and available data sets are typically short on information concerning economic interactions among persons or firms. Still, economic interactions among persons are a fact of life and both microeconomic models and data become more informative by taking greater account of the individual's social group connections in decision making. Our research focuses on the partial market analysis with two goods and examines the qualitative, and in some cases quantitative, importance of two types of interactions in utility: spillover from others' decisions and conformity with others' choices.

Researchers have identified wide-ranging, economically meaningful policy relevant social interactions including effects on the high school dropout and teen pregnancy rates (Crane 1991), future adult wages of the children (Rosenbaum 1991, Corcoran et al. 1992), the economic status of blacks (Datcher 1982), crime (Glaeser et al. 1996), and school dropout rates (Case and Katz 1991). Many studies recognize that to identify social interactions the researcher must account for the fact that the interdependent behavior potentially creates the problem of simultaneity in the data. The social interactions variable may be endogenous so the use of conventional OLS regression yields biased parameter estimates. Therefore, the empirical researcher and policymaker must be cautious when considering evidence of interaction effects. Many empirical studies may not be informative concerning the reference group identity and in turn not identify the underlying structure of interactions, such as whether it is endogenous, exogenous, or both (Manski 1993, 2000; Morgan and Ó Gráda 2000; Moffitt 2001).

Once the interdependence is identified, social interactions are of much policy relevance for taxation programs or policies directed toward improving the well-being of the unemployed if the social reference group's mean value affects the outcome of interest to the individual (Blomquist 1993). When there is a substantial amount of interdependence, then an optimal policy design needs to consider a social multiplier effect because individuals will react to the actions of others (Becker and Murphy 2000, Glaeser, Sacerdote, and Scheinkman 2002). When evaluating policies based on their predicted outcomes the applied economist may need to consider the existence and size of social interaction effects. For example, if workers care about their relative positions in the income distribution because position is a measure of social status over and above absolute purchasing power, then regulatory policy that does not disturb relative incomes receives too low a benefit in conventional cost-benefit calculations (Frank and Sunstein 2001, Kniesner and Viscusi 2003).

It has long been hypothesized that a person's utility depends not only on his or her own choices but also on the actions and utility of others with whom a person interacts socially or economically (Becker 1974). Economic theory formally considered many forms of interactions: spillovers (Roback 1982), positional goods (Frank 1985), peer group effects (de

Bartolome Charles 1990), fairness (Rabin 1993), conformity effects (Bernheim 1994), neighborhood effects (Durlauf 1996), externalities (Chamley 1999), social norms (Lindbeck, Nyberg, and Weibull 1999), herding (Smith and Sorensen 2000), social capital (Glaeser, Laibson, and Sacerdote 2000, Becker and Murphy 2000), identity (Akerlof and Kranton 2000), and contagion (Rigobon 2001). The basic theoretical setup generally differs across applications, ranging from overlapping generations considerations to Bayesian learning as the feature. All theoretical exercises involving household economic interactions share one common feature: the utility of the individual is somehow affected by either utility or choices made by members of the individual's reference group, which is comprised of persons with whom the individual somehow interacts or relates.

One well tested theoretical model is the Linear Expenditure System (LES) with interactions which was first introduced by Gaertner (1974), Pollak (1976), and Pollak and Wales (1992). The specification imbeds the interdependence in the parameter indicating necessary consumption and thus one obtains a linear expenditure function where social interactions are represented by the average consumption in the individual's reference group. Kapteyn et al. (1997) provide evidence for the presence of social interactions in the LES model; Soetevent and Kooreman (2002) use numerical simulations to determine the magnitude of the potential welfare loss relative to the case without interdependence; and Kooreman and Schoonbeek (forthcoming) prove conditions for the existence of welfare improvements over the market equilibrium with social interactions present. LES with interactions is one of many examples for the testable specification of the social interactions.

The present paper attempts to generalize the results for a particular class of models with social interactions. We follow the approach introduced by Brock and Durlauf (2001a,b), and we use the concepts of the total utility and the social utility that represent interactions. This paper contributes to the literature by demonstrating how interactions affect the market demands for a general utility function and presenting comparative statics results for various forms of interdependence. We analyze spillover (externality from other consumers' behavior) and conformity (there is a penalty for people behaving different from the norm), where social interactions are directly embedded into the utility function in the form of the social utility. Generally, positive spillover effect shifts the demand curve upwards and the conformity pivots the demand curve around the expected market demand to make the demand more inelastic.

2. Model

Using the specification suggested by Brock and Durlauf (2001a,b), suppose we have the total utility function

$$V(x,y;\alpha,\mu_x) = V(u(x,y),S(x;\mu_x,\alpha)) \tag{1}$$

$$\text{st. } p_x x + p_y y = M \tag{2}$$

where x and y are actions/choices made by an individual with the corresponding prices p_x and p_y, $u(x,y)$ is the private utility associated with a choice bundle (x,y), μ_x is the conditional probability measure of choices (expectation/belief) that a person places on the choices of others in the reference group[1] at the time of decision making, $S(x;\mu_x,\alpha)$ is the social utility associated with the choice of individual and his or her expectation of the choices of others, α is the parameter indicating the importance of social utility in total utility (for $\alpha = 0$ we have $S(x; \mu_x, \alpha) = 0$), and M is the total resource available to the individual. The individual maximizes the total utility (1) subject to the budget constraint (2). The approach has been used with much success and the recent example includes Hopkins and Kornienko (2004).

We assume that $u(\bullet)$ is strictly quasi-concave function (to guarantee satisfaction for the utility maximization conditions) with $u_x > 0, u_{xx} < 0, u_y > 0, u_{yy} < 0$ (subscripts denote partial derivative) which implies that both x and y are goods with increasing but diminishing marginal utility. We also assume the positive sign on the derivative $V_u > 0$, however, the derivative V_S has an uncertain sign and depends on the form of interactions.

We consider two forms of social interactions: positive spillover and conformity. Positive spillover is characterized by the positive contribution to the total utility, $V_S > 0$ (for example increased human capital of the members of the reference group increases everybody's human capital). The conformity is associated with the negative contribution to the utility because there is a disutility for being different, $V_S < 0$ (for example usually alcohol drinkers expect their colleagues to drink as well and the outcasts may not be accepted). Note that the analysis can easily be extended to negative spillover by assuming $V_S < 0$, or non-conformity by taking $V_S > 0$.

Spillover is generally defined as an externality effect relative to the behavior of the reference group. For example, in the labor supply setting the spillover effect can be viewed as a positive externality generated by the labor supplied in the reference group, where a higher mean of hours worked in the reference group decreases the individual's disutility from working. A way to interpret the spillover effect in the labor market is that one feels less pain from working if one knows that others also work. Therefore, the forms like $S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$, $S^{s2}(x;\mu_x,\alpha) = \alpha\mu_x x^2$, $S^{s3}(x;\mu_x,\alpha) = \alpha\mu_x\sqrt{x}$ all could be called a spillover effect. However, even though all functions are strictly increasing the impact of the spillover effect on the individual behavior may be different depending on the specific form. For example, we show in this work that the derivative S_{xx} determines the slope of the demand curve. Because $S^{s1}_{xx} = 0$, $S^{s2}_{xx} > 0$, $S^{s3}_{xx} < 0$, the effect of the spillover on the demand for good x is different depending on the assumed form of interactions. Full results of the derivatives for selected functional forms of interactions are presented in table 1A.

Conformity in behavior and attitudes is one of the fundamental building blocks that historically contributed to the emergence of the field of social psychology (Sherif 1935). The general idea is that individuals tend to conform to broadly defined social norms and the magnitude of the response depends on the cohesiveness, group size, and social support. For example, in the labor supply setting we can think that the person feels penalized when working a different amount of hours than what is typical in the reference group. More formally, the definition of the conformity in the Longman dictionary is defined as the "agreement with established rules, customs." The definition implies that the individual who conforms first recognizes the existence of norms or forms the expectation about the norms using deduction and observation, and second, the individual responds to the norms. In particular, one could model conformity as $S^c(x;\mu_x,\alpha) = \frac{1}{|x-\mu_x|}$ where the individual is rewarded for behaving according to the norm. However, the form of social utility in S^c is difficult to work with analytically, and we would need to impose at least a restriction on $x \neq \mu_x$. Thus, without the loss of generality (the signs on the critical derivatives are the same), we assume conformity as a quadratic loss of utility as in $-S^{c1}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^2$, $-S^{c2}(x;\mu_x,\alpha) = -\frac{\alpha}{12}(x-\mu_x)^4$, $-S^{c3}(x;\mu_x,\alpha) = -\frac{\alpha}{4}(x^2-\mu_x^2)^2$ (notice that we put the negative sign on $-S$ to indicate the fact that $V_S < 0$). Again, depending on the form of conformity the effect of interactions on the demands for x and y may differ in a non-trivial way (note that $S_{xx}^{c1} = 0$, $S_{xx}^{c2} > 0$, $S_{xx}^{c3} < 0$). Complete results for the derivatives are presented in table 1A.

Of course the analytic forms of social interactions for the spillover and the conformity can vary more than our limited set of examples, and interactions may operate through different channels: budget constraint, parameters, or else. However, we believe that the forms we choose will help us uncover the common effects associated with generally defined spillover and conformity interdependence even though the magnitudes of the changes may differ.

Also, we acknowledge that there are many other possible forms for interactions represented by the social utility $S(\bullet)$ besides spillover and conformity variations. However, we believe that the spillover and conformity may exhaust most of the real life interactions problems. Note that the spillover interactions are often modeled in urban economics in agglomeration studies, human capital studies as knowledge spillovers, and many other applications. On the other hand, conformity reflects modeling strategy for the analysis of social norms and can be crudely said to be the foundation of the Social Psychology.

3. Results

We now turn to the comparative statics results and examine the impact of different forms of interactions on the general utility problem stated in (1) and (2). The results are derived by setting up a constrained maximization problem, taking the total differential of the first order conditions, and solving for the endogenous differentials, dx, dy, and $d\lambda$ (where λ is the marginal utility of income M), in terms of the exogenous differentials dp_x, dp_y, dM, $d\alpha$, and $d\mu_x$. We analyze the partials $\frac{d(\text{endogenous})}{d(\text{exogenous})}$ to examine the behavior of the endogenous changes around the equilibrium due to the change in one of the exogenous factors while holding other exogenous variables constant (differentials are set to zero). See derivations in the appendix for details.

3.1. Exogenous interactions

In equation (1) interactions are represented by the expectation of the demand for good x by a particular consumer, μ_x. In a perfect world or in a small community the individual may be able to observe other people's demands for good x and make sensible inferences about the expected demand by way of computing the sample mean, median, or mode. However, there are often cases where the market is so large that the individual has no means to infer about others' behavior and may resort to using existing norms. For example, one norm may be that a full-time status for a working person means that an individual is working 40 hours per week. Sometimes such norm can even be enforced by the law.

When the interactions are exogenous the variable μ_x is exogenous and thus taking the total differential of $S(x;\mu_x,\alpha)$ becomes:

$$dS = S_{xx}dx + S_{x\mu_x}d\mu_x + S_{x\alpha}d\alpha \tag{3}$$

We can see that the difference between non-interactions case and any case with interdependence is exhibited by the presence of the partials S_{xx}, $S_{x\mu_x}$, and $S_{x\alpha}$.

3.1.1. Demand for good with interactions, *x*

The change of the demand for good *x* around equilibrium, approximated by *dx*, is

$$\begin{aligned} dx = {} & \frac{(p_y u_{xy} - p_x u_{yy})V_u dM + (\lambda p_x p_y - y p_y V_u u_{xy} + y p_x V_u u_{yy})dp_y}{\det H} \\ & + \frac{(x p_x V_u u_{yy} - x p_y V_u u_{xy} - \lambda p_y^2)dp_x}{\det H} \\ & + \frac{p_y^2 V_S S_{x\alpha} d\alpha + p_y^2 V_S S_{x\mu_x} d\mu_x}{\det H} \end{aligned} \tag{4}$$

where the matrix H is the Hessian from the maximization of (1) subject to (2)

$$\det H = 2p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{xx}) > 0. \tag{5}$$

Notice that if the function $u(\bullet)$ is concave and $V(\bullet)$ is without interactions, the concavity of $u(\bullet)$ guarantees $\det H > 0$ (determinant of the bordered Hessian). However, with interactions present we still need to determine the sign of $p_y^2 V_S S_{xx}$. For example, with social utility $S(\bullet)$ having positive contribution to the total utility $V(\bullet)$, and having diminishing marginal utility, the condition for maximization is satisfied because $V_S > 0, S_{xx} < 0$. However, the condition may need to be checked for specific forms of the social utility function because there are known cases of social interactions models exhibiting multiple equilibria (Brock and Durlauf

2000a,b, 2002).

First we analyze what happens to the slope for good x, $\frac{\partial x}{\partial p_x}$, for different interactions forms. Setting all exogenous variables besides dp_x to zero, we get

$$\frac{dx}{dp_x} = \frac{\overbrace{-\lambda p_y^2}^{\text{substitution effect part}} \quad \overbrace{-x(p_y V_u u_{xy} + p_x V_u u_{yy})}^{\text{income effect part}}}{2p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{xx})} \tag{6}$$

Notice that without social interactions the slope is negative as long as the function $V(\bullet)$ is concave. However, introduction of social interactions affects the slope $\frac{dx}{dp_x}$ in a significant way through the term $-p_y^2 V_S S_{xx}$. The effect of the interdependence on the slope of the demand function for good x differs depending on the form of social interactions.

Suppose that we have the **spillover** effect in the form of $S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$. Thus, $V_S > 0$, $S_{xx} = 0$, and the slope of the demand curve for x does not change. However, when the spillover effect takes the form $S^{s2}(x;\mu_x,\alpha) = \alpha\mu_x x^2$ we get $S_{xx} = 2\alpha\mu_x > 0$ and the slope becomes steeper because the term $-p_y^2 V_S S_{xx}$ makes the denominator less positive and the whole expression becomes larger in the absolute value. Finally, if the spillover takes the form $S^{s3}(x;\mu_x,\alpha) = \alpha\mu_x\sqrt{x}$, we get $S_{xx} = -\frac{1}{4\sqrt{x^3}}\alpha\mu_x < 0$, and the slope becomes flatter but as the demand for x increases the slope becomes closer to the baseline case. Note that, as we show later, even though the demand for good x shifts upwards for each spillover form assumed, the effect is different for individuals consuming different levels of good x. We present the results on figure 1.1. Notice that the axes are reversed in order to accommodate the standard way of presenting a demand and supply curves with prices on the vertical axis and quantity on the horizontal axis.

Consider the **conformity** effect in the form $-S^{c1}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^2$, meaning, there is a disutility whenever the individual demand is different from the norm. The social utility have a negative effect on the total utility, $V_S < 0$, and we have $S_{xx} = \alpha > 0$. Therefore the expression $-p_y^2 V_S S_{xx} > 0$ makes the slope of the demand curve for x less negative, flatter (positive denominator becomes more positive), and thus more inelastic. When the conformity takes the form $-S^{c2}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^4$ the effect on the demand curve for good x depends on the demand for good x because $S_{xx} = \alpha(x-\mu_x)^2 > 0$. Therefore when $x = \mu_x$ the slope in the conformity case is the same as the no-interactions case. But the more different (larger or smaller) is the demand for x from μ_x, the slope becomes less negative. When the conformity takes the form $-S^{c3}(x;\mu_x,\alpha) = \frac{\alpha}{4}(x^2-\mu_x^2)^2$ we have $S_{xx} = \alpha(3x^2-\mu_x^2) \gtrless 0$. The slope for the demand for x not only depends on the value of x but also on the location of x. Note that for the demand $x = \frac{\mu_x}{\sqrt{3}}$, the slope is exactly the same as for the baseline case, for $x > \frac{\mu_x}{\sqrt{3}}$ the slope becomes flatter, and for $x < \frac{\mu_x}{\sqrt{3}}$ the slope becomes steeper. We demonstrate the changes to the slope on figure 1.2. Notice that the axes are reversed in order to accommodate the standard way of presenting a demand and supply curves with prices on the vertical axis and quantity on the horizontal axis.

Now we examine what happens to the demand curve for x as the magnitude of interactions changes where the magnitude is represented by the value of the parameter α. Compute $\frac{dx}{d\alpha}$ as

$$\frac{dx}{d\alpha} = \frac{p_y^2 V_S S_{x\alpha}}{\det H} \tag{7}$$

Thus, in the **spillover** $S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$ we have $V_S > 0$ and $S_{x\alpha} = \mu_x > 0$ so the demand curve is shifted upwards by a constant amount because $p_y^2 V_S S_{x\alpha} > 0$ does not depend on x. However, when the spillover effect takes the form $S^{s2}(x;\mu_x,\alpha) = \alpha\mu_x x^2$ we get $S_{x\alpha} = 2x\mu_x$, and the demand curve shifts upward and the effect increases with higher values of the demand for x. Notice that the result is consistent with the result above that the slope is steeper than the baseline demand curve, and thus the demand curves diverge (spillover diverges from the baseline). Finally, if the spillover takes the form $S^{s3}(x;\mu_x,\alpha) = \alpha\mu_x\sqrt{x}$, we get $S_{x\alpha} = \frac{1}{2\sqrt{x}}\mu_x > 0$. There is an upward shift of the demand curve and the shift is getting smaller for higher levels of x. Notice that the result is consistent with the previous conclusion that the slope is flatter for smaller x. We summarize findings for the spillover effect on figure 1.1.

Suppose now that we have the **conformity** effect in the form $-S^{c1}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^2$, so $V_S < 0$ and $S_{x\alpha} = x - \mu_x \lesseqgtr 0$, and thus the final outcome of $\frac{\partial x}{\partial \alpha}$ is uncertain. We can see that the effect of the exogenous social interactions on the demand curve for good x is different depending on the location of the individual choice of x. For $x > \mu_h$ we have $S_{x\alpha} > 0$ and thus the demand for good x is lower when the conformity is present ($\frac{\partial x}{\partial \alpha} < 0$) because $p_y^2 V_S S_{x\alpha} < 0$. For $x < \mu_h$ we have $S_{x\alpha} < 0$ and thus the demand for good x is higher when the conformity is present relative to the baseline case ($\frac{\partial x}{\partial \alpha} > 0$) because $p_y^2 V_S S_{x\alpha} > 0$. For $x = \mu_h$ we have

$S_{x\alpha} = 0$, we can see that under the conformity the demand curve pivots around the average of the demand for good x equal to μ_x. Notice that the result is consistent with the previous finding that the conformity effect makes the demand curve for good x flatter. However, now we can explicitly state how exactly the shape of the demand curve changes.

For $-S^{c2}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^4$ there is $V_S < 0$ and $S_{x\alpha} = \frac{1}{3}(x-\mu_x)^3 \gtrless 0$, and thus the demand curve shifts up for low x, and the demand curve shifts down for high x. Qualitatively the changes are alike the case S^{c1} but the magnitudes are exaggerated, and the curve with interactions becomes non-linear. In the case of S^{c3} we have $S_{x\alpha} = x(x^2-\mu_x^2) \lessgtr 0$ and again when $x = \mu_x$ there is no shift of the demand curve. The demand curve with interactions pivots around μ_x because for $x > \mu_x$ the shift is down and when $x < \mu_x$ the shift is up. However, notice that for x close to zero and μ_x the demand curve with the conformity almost resembles the baseline case (no shift). It turns out that when the demand for good x is below the market demand μ_x the maximum shift of the demand curve with interactions occurs for $x = \frac{\mu_x}{\sqrt{3}}$. We present the results for the conformity case on figure 1.2.

To sum up, the general result for the spillover is that the demand curve shifts up and in the conformity case the demand curve pivots around the market demand for good x. However, the functional form of interactions affects the exact shape for the demand curve in a non-trivial way and has a profound impact on the effects of certain policy changes. For example when a researcher needs to calculate the deadweight loss associated with the fiscal policy such as taxation, the results may be dramatically different for different shapes of the demand curve.

Notice that for spillover 1 the deadweight loss is the same as for the baseline case. But for spillover 2, the deadweight loss is higher, and for spillover 3 the deadweight loss is lower than the baseline case of no interactions.

Now we analyze what happens to the demand for x when the expectation of the market demand for x changes, meaning μ_x changes around the equilibrium. The change is equivalent to the change of norms. For example in the labor supply setting we can think of the changes in law to define full-time status workers as individuals working 40 hours per week.

After setting other exogenous variables to zero the effect is

$$\frac{\partial x}{\partial \mu_x} = \frac{p_y^2 V_S S_{x\mu_x}}{\det H} \tag{8}$$

Thus, in the **spillover,** $S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$, we have $V_S > 0$ and $S_{x\alpha} = \alpha > 0$, so the demand curve is shifted upwards by a constant amount because $p_y^2 V_S S_{x\alpha} > 0$ does not depend on x. For other forms of exogenous spillover the changes are qualitatively the same as for the change in α (see table 1A.). In **conformity** we have the upward shift of the demand curve for all three cases, though again, the magnitudes are somewhat different for each form of interdependence.

The cross-price derivative $\frac{\partial x}{\partial p_y}$ and the derivative with respect to income $\frac{\partial x}{\partial M}$ are only affected by the presence of S_{xx} in the denominator. However, because we do not know what was the effect in the first place, we cannot tell how interactions affect the final outcome. For full set of comparative statics results see table 1.

3.1.2. Demand for good without interactions, *y*

We also analyze how interactions present in good *x* affect second good that does not have interactions, *y*. The motivation for the following analysis is that if the budget constraint is binding then any change to the demand for good *x* shall also change the demand for good, *y*. The change of the demand for good *y* around equilibrium, approximated by *dy*, is

$$\begin{aligned} dy = & \frac{(p_x V_u u_{xy} - p_y V_u u_{xx})dM + (-yp_x V_u u_{xy} - \lambda p_x^2 + yp_y V_u u_{xx})dp_y}{\det H} \\ & + \frac{(\lambda p_x p_y - xp_x V_u u_{xy} + xp_y V_u u_{xx})dp_x}{\det H} \\ & + \frac{-p_y V_S S_{xx} dM + xp_y V_S S_{xx} dp_x + yp_y V_S S_{xx} dp_y - p_x p_y V_S S_{x\alpha} d\alpha - p_x p_y V_S S_{x\mu_x} d\mu_x}{\det H} \end{aligned} \tag{9}$$

Notice that interactions are present in any partial derivative we may consider and thus the presence of a good with interactions, *x*, has a profound impact on the non-interactions good. The finding underlines the importance of the study of social interactions at least with respect to the commodities that have a high proportion in the consumers bundle. It is likely that the researcher may identify certain effects for non-interactions goods that actually may be attributed to the interdependence in good *x*.

When we set to zero changes of all exogenous variables besides dp_y we get the slope for the demand for good *y* as:

$$\frac{dy}{dp_y} = \frac{\overbrace{-\lambda p_x^2}^{\text{substitution effect part}} \overbrace{-(p_x V_u u_{xy} - p_y V_S S_{xx} - p_y V_u u_{xx})}^{\text{income effect part}}}{2p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{xx})} \tag{10}$$

Notice that without social interactions (V_S) the slope is negative, as expected. However, social interactions significantly affect $\frac{dy}{dp_y}$ through the term S_{xx} that is present in both the nominator and the denominator.

Suppose social interactions have the form of a **spillover** effect $S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$. Because $V_S > 0$ and $S_{xx} = 0$ the slope for good y does not change when there are interactions in good x. However, when the spillover effect takes the form $S^{s2}(x;\mu_x,\alpha) = \alpha\mu_x x^2$ we get $S_{xx} = 2\alpha\mu_x > 0$ and we cannot determine what happens to the slope because the term $-p_y^2 V_S S_{xx}$ makes the denominator less positive, but the term $yp_y V_S S_{xx}$ makes the nominator less negative, and thus the expression can go either way in the absolute value. By the same token when the spillover takes the form $S^{s3}(x;\mu_x,\alpha) = \alpha\mu_x\sqrt{x}$ we cannot determine what happens to the slope of the demand curve for y because negative $S_{xx} = -\frac{1}{4\sqrt{x^3}}\alpha\mu_x < 0$ increases both the nominator and the denominator in the absolute value.

Consider any form of a **conformity** effect in good x. From the previous calculations, we know that in most cases $V_S < 0$ and $S_{xx} > 0$, and thus there are two opposing forces affecting the shape of the demand curve for y. On the one hand the demand curve for y becomes steeper because the nominator becomes more negative ($yp_y V_S S_{xx} < 0$), but on the other hand the denominator becomes more positive ($-p_y^2 V_S S_{xx} > 0$) making the demand curve for good y flatter. We can see that in the absolute value both the nominator and the denominator increase and we can not determine how ultimately the slope of the demand curve for y is affected due to the interdependence in good x. The result is true for all forms of conformity.

Now we examine what happens to the demand curve for y as the magnitude of interactions changes, where the magnitude is represented by the value of the parameter α. Compute $\frac{dy}{d\alpha}$ as

$$\frac{dy}{d\alpha} = \frac{-p_x p_y V_S S_{x\alpha}}{\det H} \tag{11}$$

When there is a **spillover** effect of any form, as before, we have $V_S, S_{x\alpha} > 0$, and thus $\frac{dy}{d\alpha} = \frac{-p_x p_y V_S S_{x\alpha}}{\det H} < 0$. The demand for good y decreases due to the increase in the spillover effect in good x. Intuitively, we can interpret it as the consumer substitutes away from good y because he or she attaches higher utility value to good x due to interactions (there is more utility derived from good x and the imbalance of the marginal products and prices, $\frac{\partial V/\partial x}{\partial V/\partial y} > \frac{p_x}{p_y}$, needs to be established again by an individual consuming less of good y and more of good x).

In a **conformity**, due to the algebraic complications, we discuss only $-S^{c1}(x;\mu_x,\alpha) = -\frac{\alpha}{2}(x-\mu_x)^2$ but the discussion is relevant for all forms of interactions as the effects are qualitatively the same whereas the magnitudes are more difficult to determine. Thus, if we focus on S^{c1}, we know that $V_S < 0, S_{x\alpha} = x - \mu_x \lesseqgtr 0$, and thus $\frac{dy}{d\alpha} = \frac{-p_x p_y V_S S_{x\alpha}}{\det H} \lesseqgtr 0$. We can see that the effect of the exogenous social interactions on the the demand curve for good y is different depending on the location of the individual choice of x. For individuals with $x > \mu_h$ we have $S_{x\alpha} > 0$ and thus the demand for good y is higher when the conformity is present for good x, relative to the baseline case[3]. For $x < \mu_h$ we have $S_{x\alpha} < 0$ and thus the demand for good y is lower when the conformity is present in commodity x because more of good x is consumed ($\frac{\partial x}{\partial \alpha} > 0$).

It is not obvious what happens to the entire demand curve for good y when the conformity is present in good x relative to the baseline case of no interdependence because there is no reference point like μ_x on the demand schedule for good y. However, as an illustration we can think of an extreme case when the demand for good x becomes perfectly inelastic due to the conformity and then the demand for good y becomes $\frac{M_x}{p_y}$, where $M_x = M - p_x\mu_x$ and μ_x represents a constant demand for good x. Depending on whether goods x and y are complements or substitutes the change to the demand curve for good y is different.

We present the effect of the interactions in good x on the demand curve for good y in figure 2. If without the presence of social interactions goods x and y are substitutes ($\frac{\partial x}{\partial p_y} > 0$, and on figure 2 the offer curve is downward sloping), we can see on the figure 2 that the resulting demand curve for good y is less elastic than the demand curve for good y when there is no interdependence in good x. Intuitively we can think that with the presence of the substitute for y the demand for y was more elastic because consumers could demand more of x to substitute for the higher price of y. On the other hand, when goods x and y are complements without the interdependence in good x ($\frac{\partial x}{\partial p_y} < 0$, and on the figure 2 the offer curve is upward sloping), the resulting demand for good y becomes more elastic relative to case of no interactions in good x. Intuitively we can think that when there were no social interactions in x, both x and y were relatively tightly connected by being complements. However, when x is fixed and certain part of the income is spent on good y, mechanically the demand for good y becomes more elastic.

We can see that the effect of interactions in good x on the demand for good y is dependent on the relationship between the two goods. When we make certain assumptions about the two goods in some cases we can make the inference, but as we demonstrated, the analysis becomes more involved and due to the complications the results may be less useful and intuitive.

Nevertheless, we show that interactions in only one good affect the behavior of the goods in the entire market as long as the goods are in the same expenditure bundle for the consumers.

3.2. Endogenous interactions

Until now we analyzed exogenous interactions, meaning the consumer takes the expectation of the market demand μ_x as given. We turn to the case where the individual not only is able to correctly observe the expected market demand but also affects it when he or she makes a choice about the consumption of x. Therefore we suppose that μ_x is endogenous and it is a function of x, as $\mu(x)$. Thus, $d\mu_x$ becomes $\mu_x' dx$ (where $\mu_x' = \frac{\partial \mu(x)}{\partial x}$), and when we take the total differential of $S(x; \mu_x, \alpha)$ we get:

$$dS = S_{xx}dx + S_{x\mu_x}\mu_x' dx + S_{x\alpha}d\alpha \tag{12}$$

Due to the complexity of endogenous interactions we only examine the simplest interactions forms of spillover and conformity, $S^{s1}(x; \mu_x, \alpha) = \alpha x \mu_x(x)$ and $-S^{c1}(x; \mu_x, \alpha) = -\frac{\alpha}{2}(x - \mu_x(x))^2$ respectively. However, most likely the conclusions of the following sections are applicable to other forms of interdependence.

3.2.1. Demand for good with interactions, *x*

The change of the demand for good x around equilibrium, approximated by dx, is

$$dx = \frac{(p_y u_{xy} - p_x u_{yy})V_u dM + (\lambda p_x p_y - y p_y V_u u_{xy} + y p_x V_u u_{yy})dp_y}{\det H} \tag{13}$$
$$+ \frac{(x p_x V_u u_{yy} - x p_y V_u u_{xy} - \lambda p_y^2)dp_x}{\det H}$$
$$+ \frac{p_y^2 V_S S_{x\alpha} d\alpha}{\det H}$$

where the matrix H is the Hessian from the maximization of (1) subject to (2):

$$\det H = 2p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{x\mu_x}\mu_x' - p_y^2 V_S S_{xx}) > 0 \tag{14}$$

Notice that in endogenous, relative to exogenous interactions, the term associated with μ_x disappears because it is affected directly by the variable x. Also, the interactions enter into the maximization criteria with both $-p_y^2 V_S S_{x\mu_x}\mu_x'$ and $-p_y^2 V_S S_{xx}$, and thus the effect of the interdependence on the slopes for x and y may be more complicated than in the case when the interactions are exogenous.

After setting all differentials but dp_x to zero we get the slope for the demand curve for x as

$$\frac{dx}{dp_x} = \frac{\overbrace{-\lambda p_y^2}^{\text{substitution effect part}} \quad \overbrace{-x(p_y V_u u_{xy} - p_x V_u u_{yy})}^{\text{income effect part}}}{2p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{x\mu_x}\mu_x' - p_y^2 V_S S_{xx})} \tag{15}$$

Suppose that we have the **spillover** effect in the form of $S(x; \mu_x(x), \alpha) = \alpha x \mu_x(x)$. Thus, as before $V_S > 0$ but now $S_{xx} = \alpha(\mu_x'' x + 2\mu_x') \gtrless 0$, and $S_{x\mu_x} = \frac{\partial}{\partial \mu_x}(\alpha(\mu_x' x + \mu_x)) \gtrless 0$. Notice that even though we assume a particular form for the spillover effect the signs of both S_{xx} and $S_{x\mu_x}$ are not obvious. The difficulty is to sign the derivatives μ_x'' and μ_x' and without prior knowledge we can not determine the effect of endogenous interactions on the slope for the demand of good x. However, when we assume $\mu_x' = 1$, meaning that there is a global change in the demands in the economy that shifts everyone's demand for good x by the same amount[2], the derivatives become $S_{xx} = 2\alpha > 0$, and $S_{x\alpha} = 2\alpha > 0$. Thus both $-p_y^2 V_S S_{xx} < 0$ and $-p_y^2 V_S S_{x\mu_x} \mu_x' < 0$ make the slope for the demand of good x more negative and more elastic (because positive denominator becomes smaller).

Consider further a **conformity** effect in the form of $-S(x; \mu_x(x), \alpha) = -\frac{\alpha}{2}(x - \mu_x(x))^2$, meaning, there is a disutility whenever the individual demand is different from the norm. We have now $V_S < 0$ with the derivatives $S_{xx} = \alpha\left((1 - \mu_x')^2 - \mu_x''(x - \mu_x)\right) \gtrless 0$ and $S_{x\mu_x} = \frac{\partial}{\partial \mu_x}(\alpha(x - \mu_x)(1 - \mu_x')) \gtrless 0$. Again, unless we know the signs of the derivatives μ_x' and μ_x'' we can not determine the signs on S_{xx} and $S_{x\mu_x}$. However, when we assume a global change in the demand for good x, as above $\mu_x' = 1$, we have $S_x = \alpha(x - \mu_x)(1 - 1) = 0$ and thus both S_{xx} and $S_{x\mu_x}$ are zero. Therefore endogenous conformity interactions do not make the slope to change and the interdependence case is observationally equivalent to the baseline case of no interactions.

Now we examine what happens to the demand curve for x as the magnitude of interactions changes. Compute $\frac{dx}{d\alpha}$ as

$$\frac{dx}{d\alpha} = \frac{p_y^2 V_S S_{x\alpha}}{\det H} \tag{16}$$

In the **spillover** $S(x; \mu_x, \alpha) = \alpha \mu_x(x) x$ we have $V_S > 0$ and $S_{x\alpha} = \mu_x' x + \mu_x > 0$. Assuming $\mu_x' > 0$ the demand curve is shifted upwards because $p_y^2 V_S S_{x\alpha} > 0$. Notice that without endogeneity the derivative $S_{x\alpha}$ is $\mu_x(x)$, the same as in the case of exogenous interactions.

Thus, with the endogeneity the shift of the demand curve for good x is more pronounced by the amount $\mu_x'(x)x$, and the shift depends positively on the demand for good x. Note that the results is consistent with the above derivation that the slope for the demand curve with endogenous interdependence is steeper than the baseline case.

When we assume global changes to the demand for x (everyone's demand changes by the same amount) we again have $\mu_x'(x) = 1$, and thus $S_{x\alpha} = x + \mu_x > 0$. Therefore the change in the demand for good x due to the change in the level of interactions α linearly increases with the level of x. Notice that the finding is consistent with already derived result that the slope is steeper in endogenous spillover than in both cases of the baseline and the exogenous spillover. The effect is presented in Figure 3.1 where the demand for good x becomes more elastic than both the cases without the interdependence and with exogenous interactions. The intuition of the result is similar to the logic in the macroeconomic multiplier where each consumer's behavior produces the feedback effect that changes the total demand and in turn affects every individual's demands again. The process continues until the circular feedback effect fades away.

Under the **conformity** $-S(x;\mu_x(x),\alpha) = -\frac{\alpha}{2}(x - \mu_x(x))^2$ we have $V_S < 0$ and $S_{x\alpha} = (x - \mu_x)(1 - \mu_x')$. Notice that the form of $S_{x\alpha}^{endogenous}$ is $(1 - \mu_x')S_{x\alpha}^{exogenous}$, which suggests that the effect of endogenous interactions on the demand for x has the same form as the exogenous conformity (pivot around μ_x), but the magnitude shall differ. Again, the sign on the derivative μ_x' needs to be determined.

If we assume that $\mu_x' > 0$ and there are only local interactions, meaning that there are demand changes only for one individual due to some exogenous change, we may further reasonably assume that $\mu_x' < 1$ (see Glaeser et al, 2002, for a thorough discussion of local interactions). Therefore $(1 - \mu_x') < 1$ and the demand curve for good *x* becomes flatter than the baseline case (see discussion in the exogenous conformity), but the demand curve is steeper than in the case of exogenous interactions. In the extreme case of global interactions (everybody's price change by the same amount and the demand also changes by the same amount) we have $\mu_x' = 1$, and therefore observationally the demand curve for *x* is the same as the demand curve for *x* in the baseline case. We present the result in figure 3.2 by showing that first with exogenous conformity the demand curve for *x* becomes less elastic, and then with endogenous conformity the demand for *x* approaches the baseline case.

Note that "no change" endogenous conformity result (demand curve does not change from the baseline case) is experienced in all three forms of conformity that we assume. The observational equivalence of endogenous conformity interactions and no interdependence cases not only underlines the complexity of the models with social interactions, but also the difficulty with the identification of the exact effects of interactions on individual choices and the sources of observed effects.

3.2.2. Demand for good without interactions, *y*

Now we analyze how interactions present in good *x* affect another good that does not have the interactions, good *y*. When we solve for *dy* using the Cramer's rule we get:

$$dy = \frac{(-p_y V_S S_{xx} - p_y V_S S_{x\mu_x} \mu_x')dM + (\lambda p_x p_y - x p_x V_u u_{xy} + x p_y V_u u_{xx})dp_x}{\det H} + \frac{(-y p_x V_u u_{xy} - \lambda p_x^2 + y p_y V_u u_{xx})dp_y}{\det H} + \frac{-p_x p_y V_S S_{x\alpha} d\alpha}{\det H} \tag{17}$$

We can see that again every change in any of the exogenous variables is affected by the presence of social interactions because of the omnipresent derivatives of the social utility function.

We compute the slope of the demand for good y as

$$\frac{dy}{dp_y} = \frac{\overbrace{-\lambda p_x^2}^{\text{substitution effect part}} \overbrace{-y(p_x V_u u_{xy} - p_y V_u u_{xx} - p_y V_S S_{xx} - p_y V_S S_{x\mu_x} \mu_x')}^{\text{income effect part}}}{2 p_x p_y V_u u_{xy} - p_x^2 V_u u_{yy} - p_y^2 V_u u_{xx} + (-p_y^2 V_S S_{x\mu_x} \mu_x' - p_y^2 V_S S_{xx})} \tag{18}$$

Notice that interactions affect the slope both through the nominator and the denominator and the difference with the exogenous interactions case is the presence of the term $V_S S_{x\mu_x} \mu_x'$.

If we assume global **spillover** interactions ($\mu_x' = 1$), we have $S_{xx}^{endogenous} = 2\alpha > 0 = S_{xx}^{exogenous}$ and $S_{x\mu_x} = 2\alpha$, and as in exogenous interactions, we can not determine what happens to the slope for the demand of good y. The nominator becomes less negative and the denominator becomes less positive and thus the result of the expression in the absolute value is uncertain. By the same token if we assume global **conformity** interactions ($\mu_x' = 1$), we have $S_x = 0$ and thus $S_{xx} = S_{x\mu_x} = 0$, meaning that there is no effect on the slope for good y. The result is straight forward because we showed that with endogenous global conformity the demand for x does not change and thus because there is no change in income or prices there is no reason for the demand for good y to change.

By setting all partials but $d\alpha$ to zero we get

$$\frac{dy}{d\alpha} = \frac{-p_x p_y V_S S_{x\alpha}}{\det H} \tag{19}$$

If we assume global **spillover** interactions ($\mu_x' = 1$), we have $S_{x\mu_x}^{endogenous} = x + \mu_x > \mu_x = S_{x\mu_x}^{exogenous}$, and thus the effect will be the same as in the case of exogenous spillover, a negative shift of the demand curve for good y, with the effect becoming more pronounced. On the other hand, as in the case of exogenous conformity, we can not determine how exactly the slope for the demand for good y changes with the global **conformity** interactions present in good x. The final effect depends on whether x and y are substitutes or complements, and we still need to determine the derivatives μ_x' and μ_x''.

4. Conclusion

We analyze social interactions in the partial market equilibrium study with two goods where for each individual the choice of one good is affected by the interdependence with choices of other consumers in the market, whereas the other good's demand is not influenced by the social interactions between individuals. Interactions in one good are imbedded directly in the utility function and affect the demands for both goods. We analyze cases of spillover where individuals experience positive externality from other individuals' demands in the market, and conformity where individuals experience penalty for having demands different from other individuals in the market. We perform comparative statics on the demand side of the market where we select several functional forms for the part of the utility function representing interdependence. The results of our study are useful for policy changes and welfare analysis because even though the qualitative effects to the demand curves are relatively clear, the quantitative outcomes may have profound consequences on the correct measurement of the deadweight loss or behavioral effects of taxation.

Generally, a positive spillover effect shifts the demand curve upwards, however, specific functional forms for the social utility part of the total utility make the slope for the demand curve to change in a non-trivial way. Therefore the magnitude of the effect of interactions is important because in some cases part of the population in the market (say, low-demand consumers) may be much strongly affected by the interactions then the rest of the consumers in the economy. When the conformity is present in good x the demand curve pivots around the expected market demand, μ_x, and the demand curve becomes less elastic. However, selection of the specific functional form can exaggerate or diminish the general changes to the demand curve.

We also show that interactions in one good, x, significantly affect the demand for good that does not have interactions, y, however, it is much more difficult to determine the direction and the magnitude of the changes for y. The results hinge upon relationship between goods x and y as being complements or substitutes. Therefore, we can not analytically provide answers as to how non-interactions good is affected by the presence of the interactions type good without some prior knowledge about the relationship between two commodities. Numerical analysis with carefully selected functional forms and properly calibrated parameters may potentially aid in more comprehensive study of the market changes when the consumers' demands are interdependent.

Finally, we show that the partial market analysis with the present endogenous social interactions is more difficult because one needs to determine exactly how an individual affects the expectation of the market demand. However, in most cases the changes mimic the effects derived for exogenous interactions but the magnitudes are exaggerated.

Endnotes

[1] The reference group is any set of individuals in the population (including the entire population) to which the individual refers when making a demand decision. For example members of the reference group may be neighbors, family members, or co-workers depending on the phenomena studied.

[2] For example suppose that $\mu_x = \frac{\sum_{i=1}^{n} x_i}{n}$, and then if $\forall i$ we have $\Delta x_i = \Delta_x$, we also have $\Delta\mu_x = \Delta_x$. Therefore $\frac{\partial \mu_x}{\partial x} \approx \frac{\Delta \mu_x}{\Delta x_i} = \frac{\Delta_x}{\Delta_x} = 1$.

[3] Notice that for $x > \mu_h$ we have $\frac{\partial x}{\partial \alpha} < 0$, and thus the individual consumes less of good x, there is more resources for good y, and thus the individual consumes more of y because the budget constraint is binding and the prices and incomes do not change.

Figure 1.1. Demonstration of the effect of the spillover interactions on the demand for good x with different functional forms.

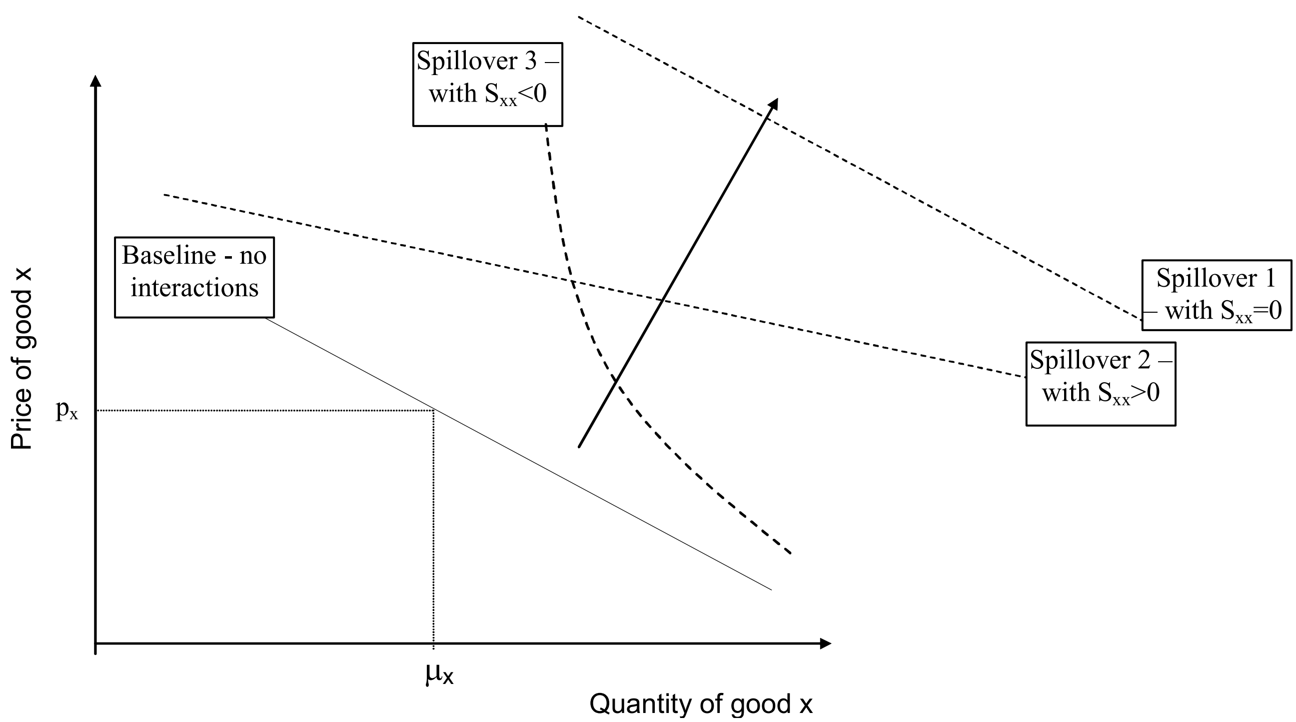

Figure 1.2. Demonstration of the effect of the conformity interactions on the demand for good x with different functional forms.

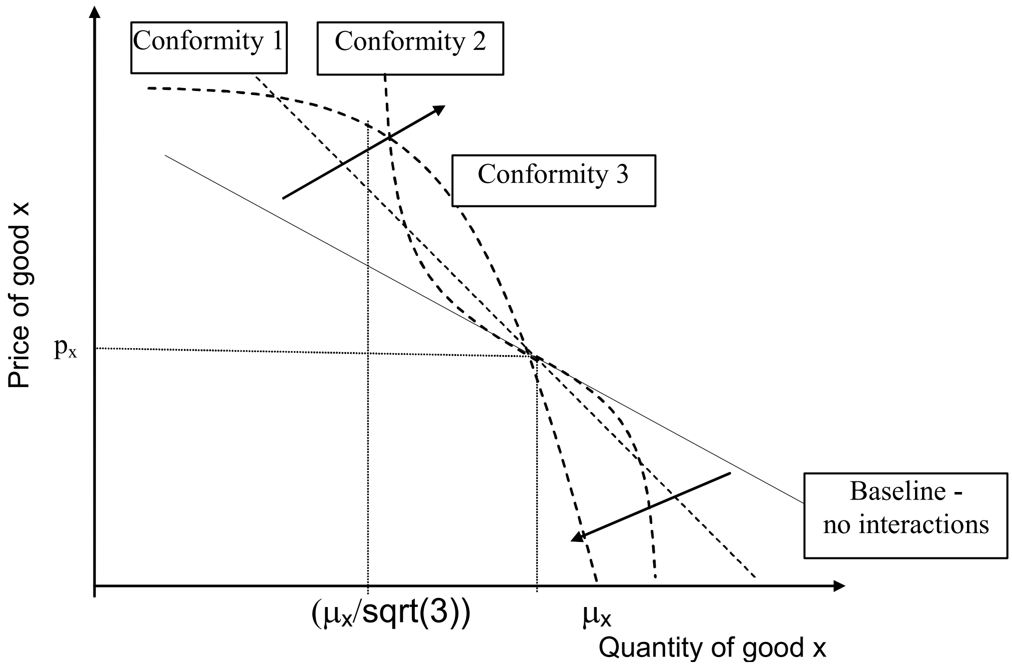

Figure 2. Demonstration of the effect of the conformity in good x on the demand for good y when there is an extreme conformity in good x (consumer consumes fixed amount of good x); graphs represent relationship between offer curves and demand curves (for good y).

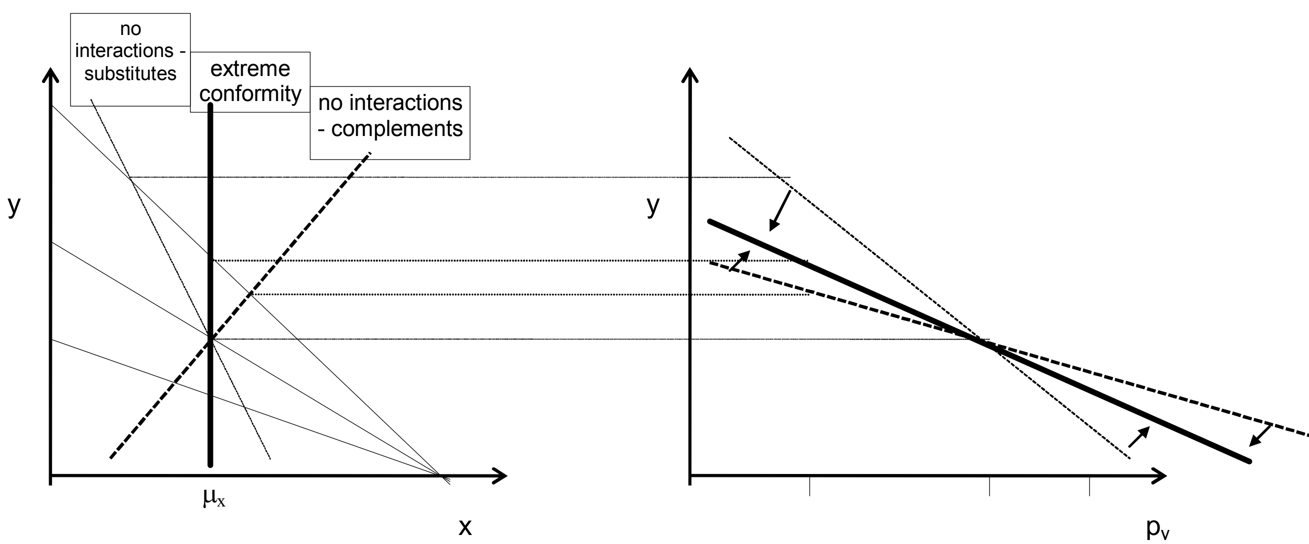

Figure 3.1. Demonstration of the effect of the global endogenous and exogenous spillover interactions on the demand for good x.

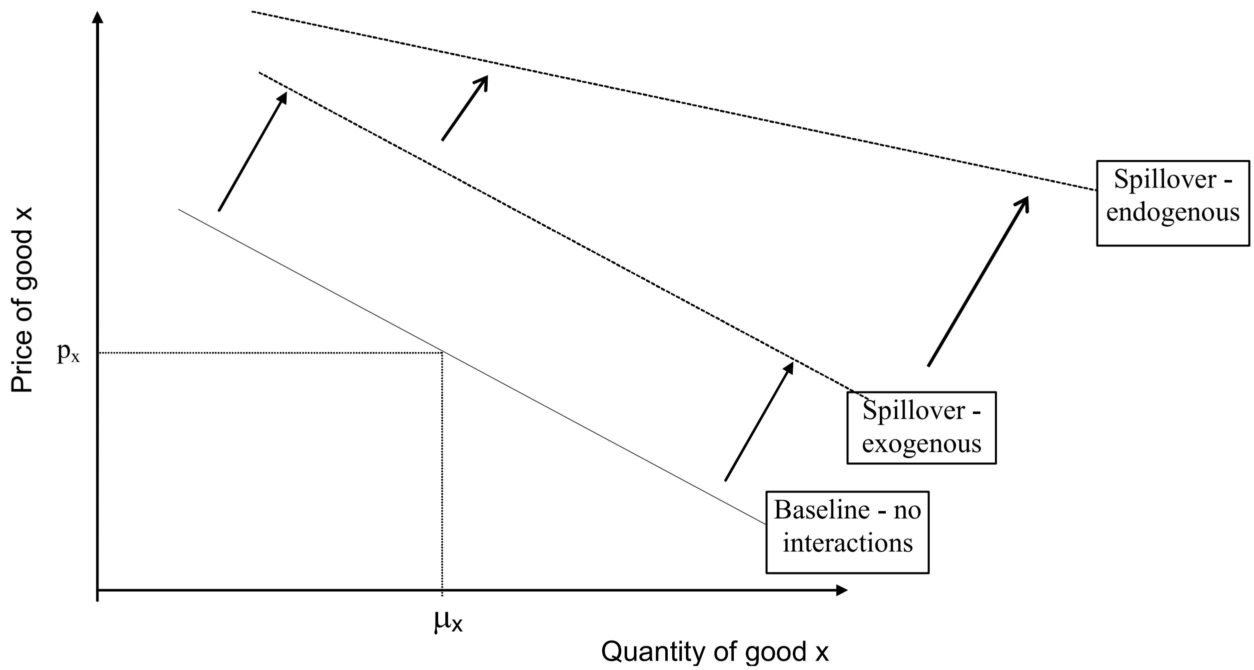

Figure 3.2. Demonstration of the effect of the global endogenous and exogenous conformity interactions on the demand for good x.

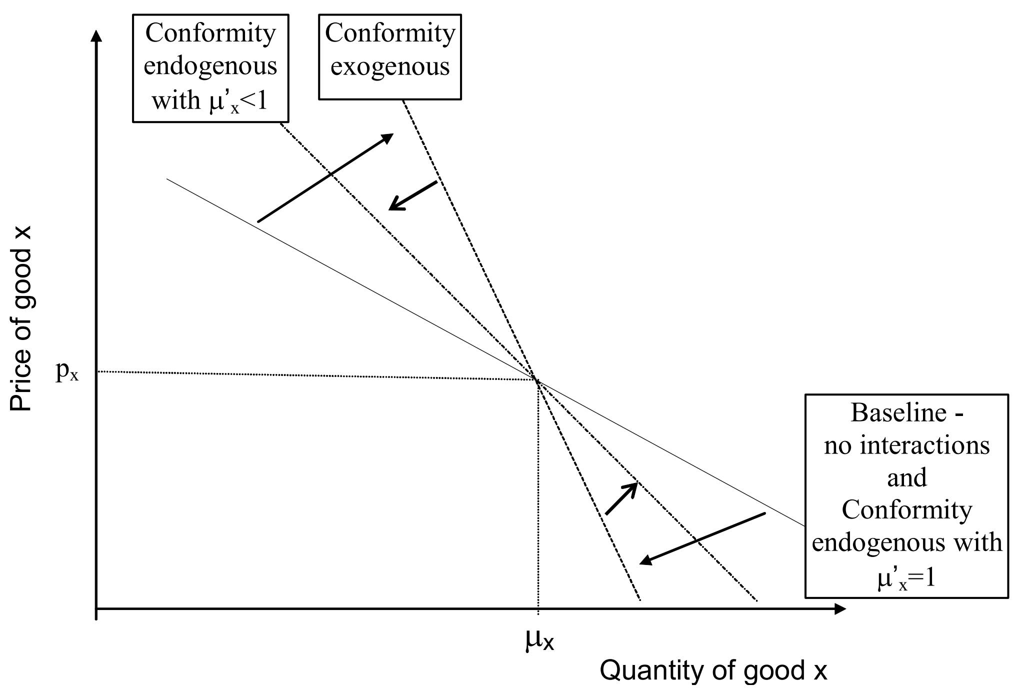

Table 1. Results of the comparative statics for different interactions functional forms when interactions are exogenous relative to the case of no interactions.

	Partials					
Interactions Effect	dx/dp_x	$dx/d\alpha$	$dx/d\mu_x$	dy/dp_y	$dy/d\alpha$	$dy/d\mu_x$
None-baseline	-	0	0	-	0	0
Spillover						
$\alpha\mu_x x$	-	+	+	-	-	-
$\alpha\mu_x x^2$	- -	++	++	-?	--	--
$\alpha\mu_x ?x$	- +	+-	+-	-?	-+	-+
Conformity						
$\alpha(x-\mu_x)^2/2$	- +	+ / -	+	-?	?	?
$\alpha(x-\mu_x)^4/12$	- ++	+ +/- -	++/+-	-?	?	?
$\alpha(x^2-\mu_x^2)^2/4$	- -/- +	+ - / - -	++	-?	?	?

Notation:

All symbols are relative to baseline case.

0 – derivative is zero.

? – uncertain / can not determine.

\- – negative derivative

\- - – negative derivative and the change is more than the baseline case

\- + – negative derivative and the change is less than the baseline case

\+ – positive derivative

\+ + – positive derivative and the change is more than the baseline case

\+ - – positive derivative and the change is less than the baseline case

/ – lists various cases when the derivative is changing signs.

APPENDIX

Table 1A. Partial derivatives for various forms of spillover and conformity.

	Partial		
	S_{xx}	$S_{x\mu_x}$	$S_{x\alpha}$
Spillover			
$S^{s1}(x;\mu_x,\alpha) = \alpha\mu_x x$	0	$\alpha > 0$	$\mu_x > 0$
$S^{s2}(x;\mu_x,\alpha) = \alpha\mu_x x^2$	$2\alpha\mu_x > 0$	$2x\alpha > 0$	$2x\mu_x > 0$
$S^{s3}(x;\mu_x,\alpha) = \alpha\mu_x\sqrt{x}$	$-\frac{1}{4\sqrt{x^3}}\alpha\mu_x < 0$	$\frac{1}{2\sqrt{x}}\alpha > 0$	$\frac{1}{2\sqrt{x}}\mu_x > 0$
Conformity			
$S^{c1}(x;\mu_x,\alpha) = \frac{\alpha}{2}(x-\mu_x)^2$	$\alpha > 0$	$-\alpha < 0$	$x-\mu_x \lessgtr 0$
$S^{c2}(x;\mu_x,\alpha) = \frac{\alpha}{12}(x-\mu_x)^4$	$\alpha(x-\mu_x)^2 > 0$	$-\alpha(x-\mu_x)^2 < 0$	$\frac{1}{3}(x-\mu_x)^3 \lessgtr 0$
$S^{c3}(x;\mu_x,\alpha) = \frac{\alpha}{4}(x^2-\mu_x^2)^2$	$\alpha(3x^2-\mu_x^2) \lessgtr 0$	$-2x\alpha\mu_x < 0$	$x(x^2-\mu_x^2) \lessgtr 0$

Table 2A. Summary of partial derivatives from comparative statics when the interactions are present (to accompany table 1). In order to obtain no-interactions case set S_{xx}, $S_{x\alpha}$, and $S_{x\mu_x}$ to zero. ($\det H$ is the denominator from the first two derivatives)

	Partial derivative $\frac{\partial(x \text{ or } y)}{\partial(variable)}$	
variable	Good with interactions, x	Good without interactions, y
p_x	$\frac{xp_xV_uu_{yy}-xp_yV_uu_{xy}-\lambda p_y^2}{2p_xp_yV_uu_{xy}-p_y^2V_SS_{xx}-p_x^2V_uu_{yy}-p_y^2V_uu_{xx}}$	$\frac{\lambda p_xp_y-xp_xV_uu_{xy}+xp_yV_SS_{xx}+xp_yV_uu_{xx}}{2p_xp_yV_uu_{xy}-p_y^2V_SS_{xx}-p_x^2V_uu_{yy}-p_y^2V_uu_{xx}}$
p_y	$\frac{\lambda p_xp_y-yp_yV_uu_{xy}+yp_xV_uu_{yy}}{2p_xp_yV_uu_{xy}-p_y^2V_SS_{xx}-p_x^2V_uu_{yy}-p_y^2V_uu_{xx}}$	$\frac{yp_yV_SS_{xx}-yp_xV_uu_{xy}-\lambda p_x^2+yp_yV_uu_{xx}}{2p_xp_yV_uu_{xy}-p_y^2V_SS_{xx}-p_x^2V_uu_{yy}-p_y^2V_uu_{xx}}$
α	$\frac{p_y^2V_SS_{x\alpha}}{\det H}$	$\frac{-p_xp_yV_SS_{x\alpha}}{\det H}$
μ_x	$\frac{p_y^2V_SS_{x\mu_x}}{\det H}$	$\frac{-p_xp_yV_SS_{x\mu_x}}{\det H}$
M	$\frac{(p_yu_{xy}-p_xu_{yy})V_u}{\det H}$	$\frac{p_xV_uu_{xy}-p_yV_SS_{xx}-p_yV_uu_{xx}}{\det H}$

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