Should Speculators be Taxed?

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SHOULD SPECULATORS BE TAXED?*

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ABSTRACT

A number of economists have supported the taxation of speculation in ¯nancial markets. We examine the welfare economics of such a tax in a model of trading in a ¯nancial market where some agents have superior information. We show that in some cases a tax on speculators may actually increase speculative pro¯ts. This occurs if the speculators' bene¯t from less informative prices o®sets the costs of the tax. The e®ect on the welfare of other agents depends on how revelation of information changes risk-sharing opportunities in the mat

1. Introduction

A number of economists have promoted taxes on speculation in ¯nancial markets, for example Tobin (1978), Stiglitz (1988), and Summers and Summers (1988). The main thrust of their arguments is that speculation is largely a rent-seeking activity that either has little or no economic bene¯t, as in Hirshleifer's analysis of private \foreknowledge" of information that will soon become public (Hirshleifer (1971), or is even positively harmful, as in Tobin's critique of \destabilizing speculation" (Tobin has generally concentrated on foreign exchange speculation, but has also criticized equity markets (Tobin (1984)). Of course, the opposite point of view has been articulated as well, for example by Miller (1991) and Schwert and Seguin (1993) who view speculative trading in ¯nancial markets as a productive economic activity that promotes e±ciency and innovation, and by Scholes (1981) who argues that securities taxes are distortionary and self-defeating as they can be largely avoided by tax-minimizing trading strategies.

Various taxes are levied on securities trading (see Campbell and Froot (1995) and Schwert and Seguin (1993) for a general description). For example, the UK imposes stamp duty of 1/2% on share sales (this is due to be abolished when transactions become dematerialized). Sweden had a 1% transactions tax until 1984, which was increased to 2% in 1986 before being abolished in 1992 (Umlauf (1993)). In the US, mutual funds that derive more than 30% of gross income from securities sold after being held for less than three months are subject to the \short-short rule," a disadvantageous tax regime (Miller (1991)). Although some countries have tended to reduce these taxes (e.g. Sweden and the UK), others such as France and the US have recently proposed to introduce or increase them: for example \la Taxe Tobin" was one of the elements of Lionel Jospin's election manifesto \Propositions pour la France" (Jospin (1996)). A similar proposal has been actively considered in the US. Both the US and French proposals were speci¯cally intended to target speculation as opposed to trading for other motives.

Since this is an important practical problem in the economics of ¯nancial markets, it is desirable to investigate it analytically using the standard methods of welfare economics. This has not been done before, probably because of the technical complexity of modelling ¯nancial market equilibrium with asymmetric information and rational, utility maximizing agents.

However, the problem does not seem intractable. In this paper we investigate it in a very simple framework of a single-period exchange economy. The model is intended to describe an equity market, although in principle the analysis could be applied to other assets such as foreign exchange. We study the following question: does a tax on speculators always make them worse off in equilibrium? The answer is negative. We show that speculators themselves may be better off as a result of a tax. Next, we extend the analysis to address the related question: can a tax on speculators be beneficial? In fact, it is straightforward to show that a tax may be Pareto improving. Both speculators and agents who trade for other motives may be made better off as a result of the tax. This is true even if the tax revenues are wasted.

We investigate these questions in a standard rational expectations model similar to Kyle (1985) and Rochet and Vila (1991), but with competitive agents. Speculators receive private information about an asset value, and they trade with agents whose initial risk exposures give them a hedging motive to trade the asset. The intuition for the result is as follows: the tax reduces the informativeness of prices as speculators scale back their trades. Speculators, other things being equal, prefer less information revelation; in this case the benefits of reduced informativeness must be weighed against the costs of paying the tax but the balance may be favourable to the tax. Hedgers, on the other hand may prefer either more or less revelation depending on whether the "Hirshleifer effect" (early revelation of the risk that hedgers wish to insure makes hedging impossible, as in Hirshleifer (1971)) dominates the "dynamic spanning" effect (early revelation of an extraneous risk factor makes the asset a better hedging instrument). See Dow and Rahi (1996) and Marín and Rahi (1995) for a description of how these effects operate.

In this paper we analyze the costs and benefits of taxes on speculation in a static model without a production sector. Clearly, if asset prices can influence productive activities (for example, by improving the allocation of investment resources), this would tend to offset the effects studied here. Depending on the parameters of the economy this effect could be arbitrarily large or arbitrarily small (see Dow and Rahi (1996)). The more interesting question concerns the extension to a model with long-term and short-term informed trading. A tax on short-term trading may encourage speculators to focus on long-term information which may have superior economic value. An analytically complete study of this question remains an open problem (but see Subrahmanyam (1995)).

In this paper we study the impact of a tax on speculators. Although in practice it is impossible to distinguish perfectly between speculators and other traders, the short-short rule in the US, Jospin's proposed tax, and others are designed to target speculators by using short holding periods as a proxy for speculative motives. This is one reason why in this paper we study the e®ects of a tax on speculators only. The other reason is to separate analytically the e®ect of a tax on speculation from a more general tax.

The paper proceeds as follows. To study the welfare e®ects of informed trading, we consider the rational expectations equilibrium of a parametric model with price-taking agents. We start by showing the result in a simple case where an informed trader interacts with uninformed liquidity traders, but the uninformed trade is treated as an exogenous random variable. This device for modelling uninformed trade is standard in the literature and allows the results to be derived simply. However, since the exogenous liquidity trader device is unsatisfactory for a proper welfare analysis, we then considi Tj 5.52 ² d the net aggregate order flow from the speculators and liquidity traders, and sets the price equal to the expected value of the asset, conditional on θ.

Definition 1. An equilibrium is a price function $p(\theta)$ and a trade θ_S such that:

(a) $\theta_S \in \arg\max E[U_S(w_S)|s;p]$, and

(b) $p = E(v|\theta)$.

Before computing the equilibrium and proceeding to the analysis of the model, we make two remarks on the features of the model. First, the quadratic form of the tax payment may not appear natural as a description of actual taxes which are generally approximately linear. However, a linear function of the magnitude of the trade would not be differentiable at zero, since trading positions can be positive or negative. The quadratic form of the tax payment that we have used here is the standard way to circumvent this problem, since it preserves differentiability and linearity of the solution. See, for example, Subrahmanyam (1995) for a similar application to a tax problem.

Secondly, the model presented here is similar to the standard models that have been used in the literature to analyze security market trading with asymmetric information. On the one hand, it is the same model as in Kyle (1985), except that the informed trader can condition his demand on the price and behaves competitively. Rochet and Vila (1991) also modified Kyle's model to allow for conditioning on the price, although retaining a monopolistic informed trader. Allowing conditioning on price (generalized limit orders) seems desirable as, in practice, traders do not face a significant amount of execution risk (the risk that their orders will be executed at a price different from the current market price); and in any case they are able to use limit orders to prevent execution risk. Furthermore the execution risk in Kyle's framework is capable of significantly influencing traders' optimal strategies. This is particularly relevant when exogenous liquidity trades are replaced by optimal endogenous trades, as we do later in the paper. As shown in Spiegel and Subrahmanyam (1992), execution risk can distort hedging demands perversely.

On the other hand, the model used here is precisely a rational expectations model of the kind studied by Grossman (1977) and Grossman and Stiglitz (1980), with an additional agent who is uninformed and risk-neutral.

We now proceed to solve and analyze the model. We look for a linear equilibrium of the form

$$p = \lambda s + \mu\eta; \qquad (2)$$

for some parameters λ and μ that will be determined below. Since the speculator has constant absolute risk aversion and normally distributed wealth (conditional on knowing s and p), his optimization problem reduces to choosing a position θ_S to maximize the mean-variance criterion $E(w_S|s;p) - \frac{r_S}{2}\mathrm{Var}(w_S|s;p)$. His optimal trade is given by

$$\theta_S = \frac{s - p}{r_S V_\epsilon + \tau} = \frac{(1-\lambda)s - \mu\eta}{r_S V_\epsilon + \tau}. \tag{3}$$

Hence the total order flow is

$$\theta = \frac{(1-\lambda)s + (r_S V_\epsilon + \tau - \mu)\eta}{r_S V_\epsilon + \tau}.$$

We conjecture that the order flow is proportional to $(\lambda s + \mu\eta)$. Then the coefficients on s and η in the above expression must lie in the proportion

$$\frac{\lambda}{\mu} = \frac{1-\lambda}{r_S V_\epsilon + \tau - \mu}.$$

Therefore,

$$\frac{\mu}{\lambda} = r_S V_\epsilon + \tau. \tag{4}$$

Furthermore,

$$\begin{aligned} p &= E(v|\theta) \\ &= E(v|\lambda s + \mu\eta) \\ &= \frac{\lambda V_s}{\lambda^2 V_s + \mu^2 V_\eta} \cdot (\lambda s + \mu\eta). \end{aligned}$$

Given the conjectured form of the price function (2), it follows that

$$\lambda^2 V_s + \mu^2 V_\eta = \lambda V_s. \tag{5}$$

From (4) and (5), one can solve directly for λ and μ. This shows:

Proposition 2.1. *There exists a unique linear equilibrium. The price function is*

$$p = \lambda s + \mu\eta;$$

the equilibrium holding of the speculator is

$$\theta_S = \frac{(1-\lambda)s - \mu\eta}{r_S V_\epsilon + \tau};$$

and the order flow is

$$µ = (r_S V_{²} + ¿)V_{´} V_s^{i\,1}(¸s + ¹´);$$

where

$$¸ = \frac{V_s}{V_s + (r_S V_{²} + ¿)^2 V_{´}}$$

and

$$¹ = \frac{V_s(r_S V_{²} + ¿)}{V_s + (r_S V_{²} + ¿)^2 V_{´}}:$$

The market-maker learns (¸s + ¹x) from observing the order °ow and sets the price equal to it. The ratio $\frac{¸}{¹}$ is strictly decreasing in ¿: a tax on informed trading makes the order °ow less revealing.

We now co

Hence

$$\operatorname{sgn}\left(\frac{\partial EU_S}{\partial \tau}\right) = \operatorname{sgn}\left[V_s - (r_S V_\epsilon + \tau)^2 V_\eta\right]:$$

Evaluating this at $\tau = 0$, we get the following result:

Proposition 2.2. Introducing a small tax on speculators will make them better off if and only if

$$V_s > r_S^2 V_\epsilon^2 V_\eta:$$

We can also solve for the tax rate that is optimal for the speculators. Setting $\frac{\partial U_S}{\partial \tau} = 0$ and solving for τ; we obtain

$$\tau = \sqrt{\frac{V_s}{V_\eta}} - r_S V_\epsilon:$$

The intuition underlying the result is not difficult to see. If one regards the information of all agents in the economy as given, then a tax on any one class of agents will tend to make them worse off. However, in this case there is the offsetting effect that taxing the speculators makes them reduce the scale of their trades, resulting in a less informative price in equilibrium and increasing their informational advantage over other agents. The condition on the parameters in Proposition 2.2 can be interpreted as follows: if the order flow reveals "too much" information, either because speculators trade aggressively (low risk aversion r_S or low residual risk ϵ) or because the noise trade is small in magnitude (low V_η), a tax can benefit speculators by making the order flow less revealing.

The result would not hold if there were a monopolistic informed trader, since unlike competitive speculators he could optimally control the informativeness of prices regardless of taxes. In our model, there is an externality since an individual informed trader does not consider the effect his trade will have on increasing information revelation and thereby lowering the profits of others. With oligopolistic informed traders (for example with Cournot oligopoly) one could presumably derive a similar result. However we have not explored this case since it is well-known that with imperfect competition one can easily obtain effects that would be perverse in the perfectly competitive case.

3. A Model with Rational Traders

In this section we describe a modified version of the model in which all traders maximize utility and have rational expectations. As before there is a privately informed speculator with terminal wealth given by (1). There are two other agents who trade for hedging reasons. The initial endowment of hedger 1 is $e_1 = xz$, where z is a random variable representing a risk factor that is correlated with the asset payo®, and x is the exposure to this risk factor. We assume that x is unknown to other agents, hence it is itself a random variable. After privately observing x, the hedger trades an amount μ_1 which results in net wealth

$$w_1 = xz + \mu_1(v \text{ ¡ } p):$$

Hedger 2's endowment is simply $e_2 = z$; and he trades μ_2 to realize terminal wealth

$$w_2 = z + \mu_2(v \text{ ¡ } p):$$

Agent i $(i = S; 1; 2)$ has a von Neumann-Morgenstern utility function U_i with constant absolute risk aversion r_i. All agents take prices as given.

In this model, the \noise" that prevents equilibrium from being fully revealing arises from the trading of hedger 1. This agent trades a random amount which depends on his privately observed endowment shock x. The endowment shock could be interpreted as a liquidity shock su®ered by the agent, resulting in a need to rebalance his portfolio. Unlike the noise trade in the model of the previous section, this hedging trade results from hedger 1 maximizing utility and making inferences like any other rational trader. Hedger 2 also trades rationally.

The model presented here, with two hedgers, one with a stochastic risk exposure and one with a ¯xed exposure, is similar to the model used by Dow and Rahi (1996) to study the feedback e®ect of stock prices on real investment. This formulation is chosen because it is the simplest one for computational purposes that is also rich enough analytically. If hedger 2 were dropped from the model, the only hedging trade would come from hedger 1 and he would be perfectly informed in equilibrium. On the other hand if hedger 2's risk exposure were also stochastic, it would be impossible to solve the model in closed form.

We assume that s; ²; z and x are jointly normally distributed with mean zero. The endowment shock x is independent of all the other random variables, while by construction the signal s and the residual ² are mutually independent. The endowment risk factor z is correlated with the asset payo® v. We take the covariance of z with the signal s to be nonnegative (without loss of generality) and its covariance with the residual ² to be nonzero (otherwise, equilibrium is necessarily fully revealing). To simplify the exposition we assume the latter covariance is positive.

We denote the variance of a random variable g by V_g, its covariance with another random variable h by V_{gh}, its regression coefficient on h (the "beta" of g with respect to h) by $\beta_{gh} := V_{gh}V_h^{-1}$, and their correlation by ρ_{gh}. To summarize our assumptions on correlations, $V_{zs} \geq 0$ and $V_{z\varepsilon} > 0$. We also assume that

$$r_1^2 V_x V_z < 1. \tag{7}$$

This turns out to be a necessary and sufficient condition for the expected utility of hedger 1 to be well-defined.

The market-maker observes the aggregate order flow $\theta = \theta_S + \theta_1 + \theta_2$, and sets the price equal to the conditional expectation of the asset payoff given the order flow,

$$p = E(v|\theta).$$

For agents $i = S, 1, 2$, we define I_i to be the information observed by i, i.e. his private information together with the price p. Accordingly, $I_S = (s, p)$, $I_1 = (x, p)$ and $I_2 = p$.

Definition 2. An equilibrium is a price function $p(\theta)$ and a trade θ_i for each agent $i = S, 1, 2$, such that:

(a) $\theta_i \in \arg\max E[U_i(w_i)|I_i]$; and

(b) $p = E(v|\theta)$.

We look for an equilibrium with a linear price function

$$p = \lambda s + \mu x.$$

Note that (provided λ and μ are both nonzero) the speculator and hedger 1 have the same information in equilibrium: knowing p and his own signal s, the speculator can infer hedger 1's risk exposure x, and similarly hedger 1, who knows x, can infer s. The market-maker and hedger 2, on the other hand, are unable to isolate s from x.

Analogous to (6) agent i's expected utility is

$$E[-\exp(-r_i w_i)] = -E[\exp(-r_i E_i)],$$

where

$$E_i := E(w_i|I_i) - \frac{r_i}{2}\mathrm{Var}(w_i|I_i).$$

In general we can write

$$w_i = e_i + \theta_i(v - p) - \frac{\tau_i}{2}\theta_i^2;$$

where the endowment e_i is zero for the speculator, xz for hedger 1, and z for hedger 2; and the tax rate τ_i is τ for the speculator and zero for the hedgers. Then,

$$E_i = E(e_i|I_i) + \theta_i\left[E(v|I_i) - p\right] - \frac{\tau_i}{2}\theta_i^2 - \frac{r_i}{2}\left[Var(e_i|I_i) + \theta_i^2 Var(v|I_i) + 2\theta_i cov(v; e_i|I_i)\right]:$$

Differentiating with respect to θ_i we obtain the optimal portfolio:

$$\theta_i = \frac{E(v|I_i) - p - r_i cov(v; e_i|I_i)}{r_i Var(v|I_i) + \tau_i}: \qquad (8)$$

Proposition 3.1. There exists a unique linear equilibrium. The price function is

$$p = \lambda s + \mu x;$$

the equilibrium holdings of the agents are given by

$$\theta_S = \frac{(1-\lambda)s - \mu x}{r_S V_\epsilon + \tau};$$

$$\theta_1 = \frac{(1-\lambda)s - (\mu + r_1 V_{z\epsilon})x}{r_1 V_\epsilon};$$

$$\theta_2 = -\frac{(1-\lambda)V_{zs} + V_{z\epsilon}}{(1-\lambda)V_s + V_\epsilon};$$

and the order flow is

$$\theta = \theta_2 - (1-\lambda)\mu^{-1}\beta_{z\epsilon}(\lambda s + \mu x);$$

where

$$\lambda = \frac{V_s[(r_S + r_1)V_\epsilon + \tau]^2}{V_s[(r_S + r_1)V_\epsilon + \tau]^2 + r_1^2 V_{z\epsilon}^2 V_x (r_S V_\epsilon + \tau)^2}$$

and

$$\mu = -\frac{r_1 V_s V_{z\epsilon}(r_S V_\epsilon + \tau)[(r_S + r_1)V_\epsilon + \tau]}{V_s[(r_S + r_1)V_\epsilon + \tau]^2 + r_1^2 V_{z\epsilon}^2 V_x (r_S V_\epsilon + \tau)^2}:$$

The proof is in the Appendix. Since θ_2 is nonstochastic, the order flow is linear in $(\lambda s + \mu x)$. The market-maker learns $(\lambda s + \mu x)$ from observing the order flow and sets the price equal to it. The price and the order flow are informationally equivalent, so that the uninformed hedger has the same information in equilibrium as does the market-maker. Note that $|\frac{\lambda}{\mu}|$ is strictly decreasing in τ: a tax on informed trading makes the price less revealing.

For convenience, we study agents' welfare in equilibrium in terms of their certainty-equivalent wealth, i.e. the certain amount of money that gives the same expected utility as their equilibrium ex ante distribution of terminal wealth:

$$
\begin{aligned}
U_i &:= -\frac{1}{r_i}\ln\left[-EU_i(w_i)\right] \\
&= -\frac{1}{r_i}\ln\left[E[\exp(-r_i w_i)]\right].
\end{aligned}
$$

Notice that this does not require wealth to be normally distributed ex ante.

Proposition 3.2. The payoffs of the agents are:

$$
\begin{aligned}
U_S &= \frac{1}{2r_S}\ln\left[1 + \frac{r_S(1-\lambda)V_s}{r_S V_\epsilon + \tau}\right] \\
U_1 &= \frac{1}{2r_1}\ln\left\{(1 - r_1^2 V_x V_z)[1 + (1-\lambda)^2 V_s V_\epsilon^{-1}] + (\mu + r_1[(1-\lambda)V_{zs} + V_{z\epsilon}])^2 V_x V_\epsilon^{-1}\right\} \\
U_2 &= \frac{r_2}{2}\left[\frac{[(1-\lambda)V_{zs} + V_{z\epsilon}]^2}{(1-\lambda)V_s + V_\epsilon} - V_z\right].
\end{aligned}
$$

This result mirrors Proposition 4.1 in Dow and Rahi (1996), and the proof is a straightforward adaptation. We are now in a position to carry out comparative statics with respect to the tax rate τ, and prove the main result of this section.

Proposition 3.3. There is an open set of parameters for which a tax on speculative transactions leads to a Pareto improvement.

The proof, which appears in the Appendix, proceeds by identifying restrictions on the parameters under which each of the agents, the speculator and the two hedgers, are individually better off in equilibrium when a small tax is introduced on the speculator's transactions. These restrictions are then shown to be consistent.

The speculator's welfare can be improved for the same reason as in Proposition 2.2. If the speculator and hedger 1 (who perfectly infers the signal s from the price) are not very risk-averse, they speculate too aggressively. A tax on the speculator ameliorates this externality. A necessary condition for the speculator to benefit from a tax is that he be less risk-averse than hedger 1 (see (11)).

The uninformed hedger benefits from the tax if (and only if) he prefers to be less informed in equilibrium, which is the case when $\beta_{z\epsilon} \leq 2\beta_{zs}$: Observing a signal that is highly informative about endowments reduces risk-sharing opportunities in the market (the

Hirshleifer effect). This occurs when β_{zs} is large. Conversely, information about s is valuable when β_{z^2} is large, because it allows the trader to hedge endowment risk more accurately. If β_{z^2} is relatively small compared to β_{zs}, the Hirshleifer effect dominates: imposing a tax is favourable for the hedger as it reduces informed trading and makes the price less informative, mitigating the Hirshleifer effect.

4. Conclusions

In this paper, we have suggested a simple framework for analyzing the consequences of a tax on financial market speculation. We have studied the comparative-statics effects of a change in the tax rate on the welfare of speculators and hedgers in the market. In some cases, the tax can make all agents better off. Of course, we do not suggest that in reality such a tax would actually benefit the speculators themselves. The main contribution of the paper is applying a rigorous analytical framework for assessing the effects of a tax.

The analysis here considers only the impact of the tax on speculative profits and on risk-sharing opportunities for hedgers. We ignore all other economic effects of the tax, among them doubtless many that are as important as, if not more important than, the ones considered here. The most important extension would seem to be to consider also the effect of a tax on incentives to produce long-term and short-term information, and the implications for economic investment and production. We are pursuing this extension in our current research.

APPENDIX

We ¯rst state a useful result (see, for example, Dow and Rahi (1996)):

Lemma A.1. Suppose A is a symmetric m £ m matrix, b is an m-vector, c is a scalar, and w is an m-dimensional normal variate: w » $N(0;$ §$)$; § positive de¯nite. Then $E[\exp(w^{>}Aw + b^{>}w + c)$ is well-de¯ned if and only if $(I$ ¡ 2§$A)$ is positive de¯nite, and

$$E[\exp(w^{>}Aw + b^{>}w + c) = jI \text{ ¡ } 2\text{§}Aj^{\text{i}\frac{1}{2}} \exp[\frac{1}{2}b^{>}(I \text{ ¡ } 2\text{§}A)^{\text{i}1}\text{§}b + c]:$$

Proof of Proposition 3.1. Using (8) we get

$$\mu_S = \frac{(1 \text{ ¡ } \text{¸})s \text{ ¡ } {}^{1}x}{r_S V}$$

Substituting into (9) gives the desired formula for μ_2. It is straightforward to compute the equilibrium order flow. ∎

Proof of Proposition 3.3.

Using the expression for the speculator's payoff in Proposition 3.2, it is easy to show that $\left(\frac{\partial U_s}{\partial \tau}\right)_{\tau=0} > 0$ if and only if

$$V_s > \frac{r_1^2 r_S^2 V_x V_{z\epsilon}^2}{r_1^2 - r_S^2}. \tag{11}$$

Similarly for hedger 1, $\left(\frac{\partial U_1}{\partial \tau}\right)_{\tau=0} > 0$ if and only if

$$\begin{aligned} &2r_1 r_S^3 (r_1 + r_S) V_x V_s V_{z\epsilon}^2 (1 - r_1^2 V_x V_z) \\ &+ \left(r_1 r_S^2 V_x V_{z\epsilon}(V_{z\epsilon} + V_{zs}) + V_s(r_1 + r_S) \right) \\ &\cdot \left(r_1^2 r_S V_x V_{z\epsilon}[2(r_1 + r_S)V_{zs} + r_S V_{z\epsilon}] - (r_1 + r_S)^2 V_s \right) > 0. \end{aligned}$$

Recalling that $V_{z\epsilon}$ and V_{zs} are positive, and using (7), $\left(\frac{\partial U_1}{\partial \tau}\right)_{\tau=0} > 0$ if

$$V_s < \frac{r_1^2 r_S V_x V_{z\epsilon}[2(r_1 + r_S)V_{zs} + r_S V_{z\epsilon}]}{(r_1 + r_S)^2}. \tag{12}$$

Since λ is strictly decreasing in τ, we can deduce from Proposition 4.2 in Dow and Rahi (1996) that the uninformed hedger's payoff U_2 is strictly increasing in τ if $|\beta_{zs} - \beta_{z\epsilon}| \le \beta_{zs}$, which is equivalent to

$$V_s \le \frac{2V_{zs}V_\epsilon}{V_{z\epsilon}}. \tag{13}$$

It remains to show that there is an open set of parameters which satisfy the three inequalities above, (11), (12), and (13), as well as (7), while preserving positive definiteness of the covariance matrix of the models's random variables. Positive definiteness is equivalent to requiring that all variances are nonzero and that

$$\rho_{zs}^2 + \rho_{z\epsilon}^2 < 1. \tag{14}$$

There is an open interval of possible values for V_s consistent with (11) and (12) if and only if

$$\frac{r_1^2 r_S^2 V_x V_{z\epsilon}^2}{r_1^2 - r_S^2} < \frac{r_1^2 r_S V_x V_{z\epsilon}[2(r_1 + r_S)V_{zs} + r_S V_{z\epsilon}]}{(r_1 + r_S)^2}$$

or, equivalently,

$$r_S^2 V_{z\epsilon} < (r_1^2 - r_S^2)V_{zs}.$$

Inequality (13) can simultaneously be satisfied if V_ϵ is sufficiently large. Inequality (14) holds for V_z sufficiently large, and finally (7) can be satisfied by choosing V_x sufficiently small. ∎

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