Adam Smith's Invisible Hand Revisited. An Agent-Based simulation of the New York Stock Exchange

Paul Jorion, Ph.D.

IDP in Human Complex Systems, UCLA
375 Portola Plaza, Haines Hall 341
PO Box 951553
Los Angeles, CA 90095

Phone: 310 825 1360

e-mail: pauljorion@ucla.edu

http://pauljorion.com

Abstract

An agent-based simulation of the New York Stock Exchange shows that the market is more unstable when agents adopt buy/sell strategies than when they abstain. The claim is made that the relative stability observed on stock markets is not due to an "invisible hand" resulting from "the selfish pursuit by agents of their own interest" but from the practical impossibility for them to effectively learn and adapt their strategies. Their ill-fated attempts at learning fade into noise and markets settle in a mode where agents are split between potential buyers and potential sellers in proportions that don't depart significantly from 50% each, ensuring that the price curve shows a considerable amount of mean-reversion.

The settings

The results are here presented of a simulation of the *New York Stock Exchange*, the last major stock exchange with an "open outcry" where traders face each other on the "floor" around the "pit." The simulation model is realistic to the extent that it introduces, as part of an object-oriented program, [1] the actual types of agents acting on the exchange. However, a simplified approach is adopted where the market as a whole is represented as the *trading of a single stock*. [2] Another simplification adopted is that *price formation is intrinsic*: price is only driven by what is perceived by the agents as the dynamics of price itself: the only information available to clients for making a decision to buy or to sell is the historical record of all prior transactions (the "price curve"). Fundamentals of the stock's company (such as earnings, cash flow, dividends paid to investors, etc.) and fundamentals of the economy (GDP, joblessness rate, etc.) are not taken into account. In other words, the simulation offered here is of *price generated by price and by price only*.

---

[1] The simulation program is written in C# 2.0 (Visual Studio 2005).

[2] A stock exchange orchestrates of course the trading of a multiplicity of stocks and correlations develop between their prices as they reflect together the "mood" of the market at any one point in time (reflected in cross-stock co-variation). The price of each of those stocks evolves however largely independently as it is assumed by both buyers and sellers that it expresses essentially the *fundamentals* of the corporation whose stock is being traded. A stock exchange can still be justifiably regarded as a juxtaposition of stocks rather than an integrated whole and our simplification in dealing with a single stock does not denature the phenomenon being emulated.

Agents are of three types: *clients* passing buy or sell *limit orders*, *traders* executing these orders recorded in their *decks* on behalf of clients and *specialists* easing the market's operation by being prepared to both buy and sell, matching orders when traders are unable to do so. A *limit order* is an injunction to buy or to sell a certain number (the volume) of shares in the stock at a particular price, [3] called a *bid* for a buyer and an *ask* for a seller.

A *matching engine* keeps searching for such orders that match: a buy order whose *bid* price is equal to the *ask* price of a sell order. When these are found, a *transaction* takes place. A transaction is a record of a. the name of the selling client; b. the name of the selling trader/specialist; c. the name of the buying client; d. the name of the buying trader/specialist; e. the *settlement price* or *settle*; f. the volume traded. The volume traded is, out of necessity, the smaller of that of the buy limit order and of the sell limit order.

The simulation has been written so that the market can be run with or without *strategies* enacted by the clients. In the absence of strategies, an order to buy or to sell that has been fulfilled in a transaction is replaced by a similar order, based this time on the most recent settlement price. When strategies exist, clients combine a *trend-following* strategy and a *"taking your profit"/ "cutting your opportunity cost"* strategy.

Trend following introduces a positive feedback in the price curve as it is likely to materialize as "herd behavior"; as such, it feeds bubbles and crashes. Clients look back at the price curve over a period determined by their *time horizon*. [4] If prices are up, they buy; otherwise they sell. The *time horizon* is defined as a number of *n* past transactions. The difference of prices examined is between the most recent *settle* (time *t*) and the initial *settle* over the time horizon (time *t-n*).

If $Settle_t > Settle_{t-n}$ then Buy

If $Settle_t < Settle_{t-n}$ then Sell

"Taking your profit"/ "cutting your opportunity cost" introduce negative feedback in the price curve as they counter trends (they are *contrarian*). Clients check their current position (having last bought or having last sold) in the light of their *reversal level*, [5] if it has been reached either up or down, they reverse their position. The *reversal level* (RL) is expressed as a number of *ticks* (the *tick* is the smallest unit by which the stock price may rise or drop). If *p* is the time when the stock was last purchased or sold,

If $(Settle_t > Settle_{t-p})$ and $(Settle_t - Settle_{t-p}) > RL$ then Sell

If $(Settle_t < Settle_{t-p})$ and $(Settle_{t-p} - Settle_t) > RL$ then Buy

There is no *learning* of agents in the simulation: clients don't modify their *time horizon* or their *reversal level* in the light of the profits or losses they have realized.

---

[3] In its traditional definition, a *limit order* is "an order to buy or sell but only at a specific price or better." Our simulation follows an algorithm and is therefore "omniscient" of the market; therefore the "or better" qualification does not apply.

[4] Clients' time horizon is determined at inception of a session by multiplying a unit number of transactions by a randomized coefficient.

[5] Similarly, clients' reversal level is determined at inception of a session by multiplying a unit number of ticks by a randomized coefficient.

Observations

Independently from whether clients develop strategies or not, some end up accumulating large profits, some others, considerable losses. There is also a tendency to concentration, with the number of clients and traders executing their orders, diminishing regularly as a session develops. This effect has been noticed in previous market simulations (see in particular Raberto, Cincotti, Focardi, Marchesi 2001: 2).

When clients don't develop strategies, the price of the stock either fluctuates around its initial level with an apparent tendency to stabilize, or develops a slow upwards or downwards slant that remains insufficient over a 2,000 price matching session to end in a crash. In such markets, two forces are at work: *the law of averages* and the *tendency for the number of clients to drop*.

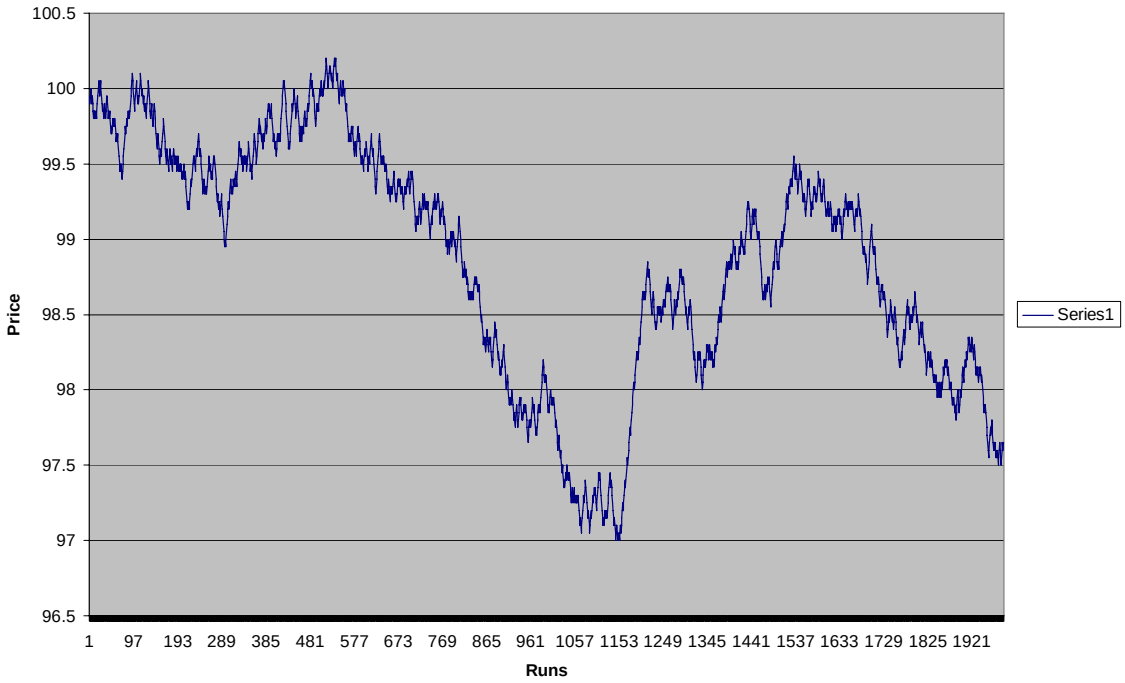
In its initial stages, the price curve is under the sole spell of the *law of averages*. This requires an explanation.

When clients don't develop strategies, the initial conditions of a session consist of a set of an equal number of buy and sell *limit order*s. Sell and buy orders that match because the *bid* and the *ask* are equal are however unlikely to have had an identical volume; a transaction leaves therefore a remainder, a number of shares in excess, either on the buyer or the seller side. This remainder fuels the dynamics of the market. Should the volume of the buy order have been higher than that of the sell order, the excess number of shares is resurrected as a new order with a *bid* higher than the last *settle* by one tick; conversely, the remainder of a sell order transforms into an order with an *ask* one tick lower than the last settle. [6]

As a buy replaces a prior order to buy and a sell replaces a prior order to sell, in the absence of any strategies by clients, no asymmetries will develop and the outcome of any matching of *asks* and *bids* amounts to a 50%/50% chance for the price to go up or down by one tick. Consequently, the empirical *frequency* of ups and downs tends to its limit with the number of transactions going to infinity, i.e. to its *probability* of 50%/50% and the market remains within a certain range as if the price curve were mean-reverting (the famous "attractive power of the mean"; see Jorion 1983). *The evolution of the price is therefore identical to that of a game where at each toss of a coin the current price is raised or lowered by one tick.* See in Figure 1, the typical profile of a price that moves by one tick up or down at the toss of a coin.

[6] The motive for these changes in *bid* and *ask* was assigned by Adam Smith in *The Wealth of Nations* to "the greatness of the deficiency, or the wealth and wanton luxury of the competitors." Here is the whole passage: "When the quantity of any commodity which is brought to market falls short of the effectual demand, all those who are willing to pay the whole value of the rent, wages and profit, which must be paid in order to bring it thither, cannot be supplied with the quantity which they want. Rather than want it altogether, some of them will be willing to give more. A competition will immediately begin among them, and the market price will rise more or less above the natural price, according as either the greatness of the deficiency, or the wealth and wanton luxury of the competitors, happen to animate more or less the eagerness of the competition" (Smith 1976 [1776]: 73).

Figure 1: Tossing a coin to get the next price...

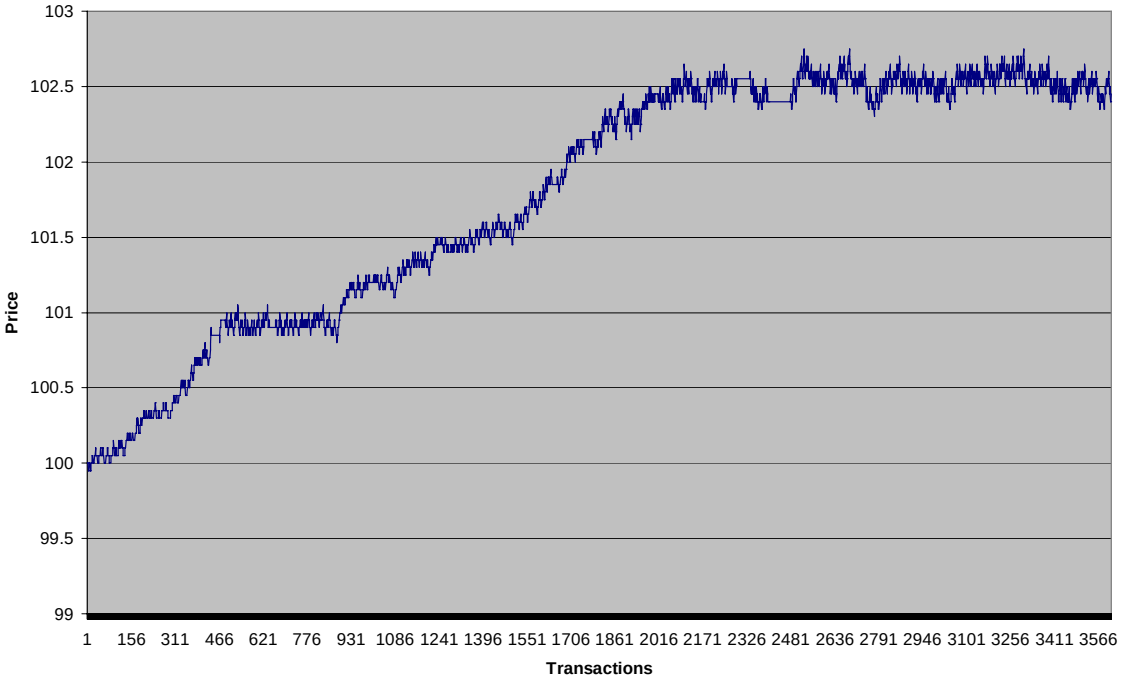


The profile is here necessarily different than that of a price curve in our simulation as several transactions may here occur when a particular settlement price is reached, adding "inertia" (apparent *auto-correlation*) to the price curve.

In its later stages, the market reflects a combination of the *law of averages* and the impact of the number of active clients having become very small. [7] In that case, settlement prices oscillate in a periodic manner. The two combined make the price curve even more stable. See Figure 2 for a session with 3610 transactions.

[7] Similarly, the disparity between the profits / losses of clients keeps widening.

Figure 2: No strategies by clients



A market where clients develop strategies shows alternations of periods where the effect of positive feedback dominates and periods where it is negative feedback that dominates. When in a positive feedback the market may then accidentally crash. See Figures 3 and 4.

Figure 3: Clients have strategies

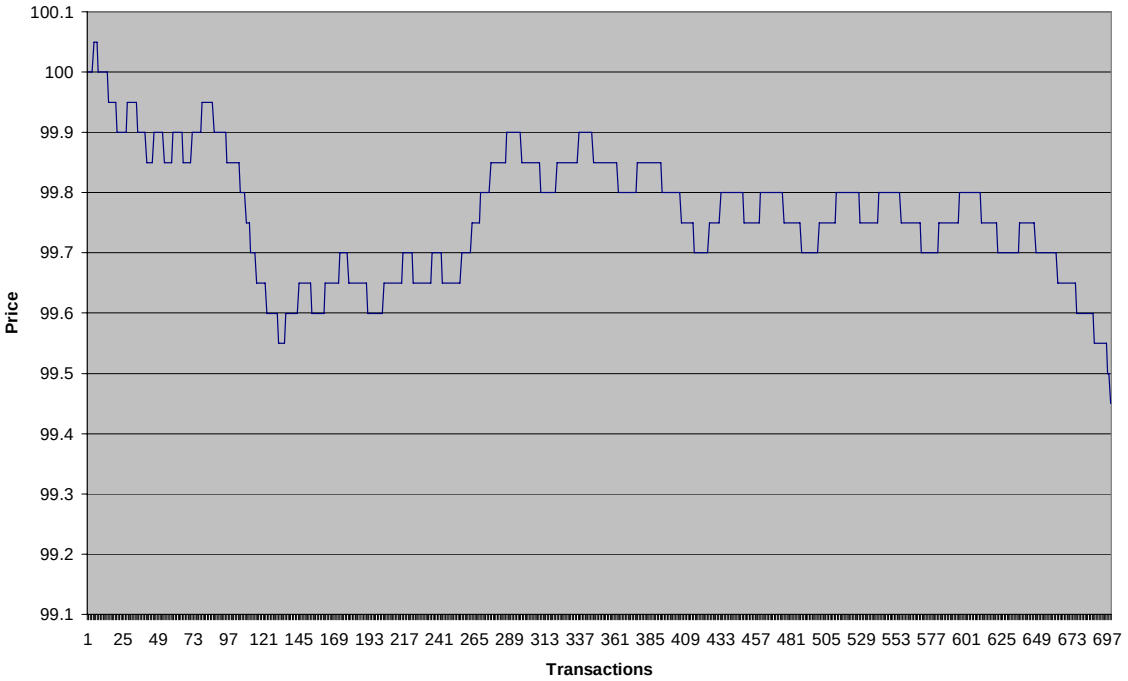
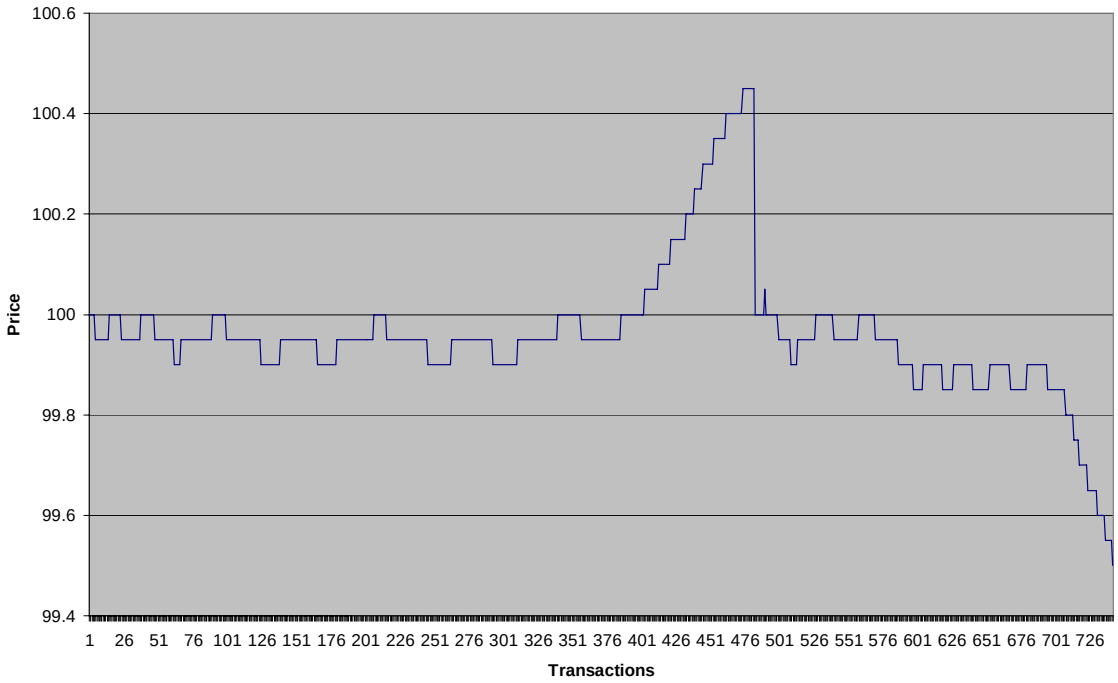


Figure 4: Clients have strategies



The tendency *for the number of clients to drop* and of the disparity in profits / losses to widen is here considerably accelerated, making it impossible to develop sessions with a number of transactions as large as observed with sessions where clients don't have strategies.

Analysis

The analysis of outcomes of simulation sessions shows that a market where clients develop strategies, that is, use information about past prices in order to make decisions about what *limit orders* to pass next, is less stable, more likely to crash, than a market where clients have no strategies, that is, where past prices have no impact on new *limit orders*.

This confirms a conclusion that could have been arrived as well from principles: that a combination of counteracting positive and negative feedbacks – induced by the clients' strategies – generates a less stable price curve than the *law of averages*.

This conclusion runs counter however to the generally held view that markets are auto-regulating, i.e. that an "invisible hand" results, in the way it is usually put, from "the selfish pursuit by agents of their own interest." The understanding is that the disorderly behavior of agents seeking their self-interest actually brings order to the markets.

It might be said that our simulation leads to the conclusion it does for the sole reason that clients don't learn, don't modify their strategies in the light of events, i.e. of their profits and losses. Let's answer this. In order for clients to learn they would have a. to decompose the current dynamics of price formation into its constituent factors, the *time horizon* and *reversal level* of all clients' strategies; b. to define for themselves rules that adapt dynamically their own *time horizon* and *reversal level* to

similar learning by the other clients. It is therefore – for all practical purposes – impossible for agents to actually learn how to adapt their strategies.

The fact that most markets don't crash most of the time suggests that their dynamics remains close to the 50% chance of price going up, 50% chance of price going down that we observed when clients have no strategies. Effective learning would mean that a proportion of clients significantly different from zero would know whether the best next move is to buy or to sell and the proportion of buyers and sellers would be significantly different than the 50% of buyers and 50% of sellers that is observed most of the time. If things were any different, markets would constantly bubble and crash. [8] Any introduction of a *learning* process in the simulation would therefore effectively only amount to introducing an additional element of randomization.

The stock markets' Regulators (the SEC in particular, the *Securities and Exchange Commission*), as far as they're concerned, as well as the stock exchanges' regulating bodies that they gently pressure, don't show an unwavering faith in the operation of the "invisible hand." Stock exchanges introduce explicit regulations of their own, like "trading halts," market interruptions that aim at preventing crashes when prices plummet. These rules seem to meet their goal. But they've only been put into place because the unfettered action of the market does not display any automatic auto-regulation. To that extent, the "hand" guiding the stock market is "visible": it is that of the markets' Regulators and of the stock exchanges' own regulating bodies.

What supports then the belief in the "invisible hand"? The *law of averages* provides in fact for most of the "invisible hand" effects observed. Strategies, as we've seen, are disruptive, as the negative feedback of the *"Taking your profit"/ "cutting your opportunity cost"* only partially counters the positive feedback of the *trend-following*. The fact that there is no *learning* possible and that there will always be therefore close to 50% of potential buyers and 50% of potential sellers maintains, as we've seen, a considerable amount of *mean-reversion* in the price curve. Unlike in our simulation, clients' strategies on an actual market amount to *noise* because they indulge in self-defeating attempts to *learn* how to best exploit the information contained in past prices. The *law of averages* remains thus the substrate of price formation even when clients develop strategies.

To conclude on the "invisible hand", one should add that, on actual markets – although it plays no role in our simulation – some self-regulating effects can be observed as a consequence of the *fair-play* displayed by the actors involved and of what Aristotle called *philia*: their goodwill, their conscious or unconscious efforts to maintain the operation of markets based on trust. Actors strive indeed at keeping the market in good condition, driven no doubt by the selfish concern of being able to pursue their trading, but still effectively acting for the benefit of all. [9] To that extent,

[8] We're reminding the reader that the context of the simulation is one where fundamentals have no impact and the only information available to clients is the historical record of prices, the "price curve." Although on the actual markets agents have access to information relative to the fundamentals, the proportion of buyers and sellers still fails to depart significantly from the 50% / 50% ratio.

[9] A compelling example of this was provided by Jack D. Schwager in an interview of Bill Lipschutz: "I got off the phone and thought about it for a few minutes. I realized that holding him to the trade would put him out of business - a development that would be bad for the exchange and terrible for the product (currency options), which we were just beginning to trade in a significant way. I called my broker and said, 'Break all the trades after the first fifty'. (...)

an agent's "selfish pursuit of his own interest" is a misnomer as however much selfish the strategy might be in the eye of its beholder, it entails an irreducible element of solidarity with all other actors present on the market to maintain it in a working condition.

The large profits observed for some of the agents, both in the simulation and in the actual world, provide sufficient motive to the clients who are winners on stock exchanges to believe that markets exist there under their ideal form and are in no need for further regulation. As, unlike the losers, the winners have access to large amounts of cash to promote their views, the opinion that markets auto-regulate because of the action of an "invisible hand" is more often heard than the opposite.

References

Jorion, Paul, "Effet attracteur de la performance économique moyenne. Un test de la théorie de l'économie paysanne de Chayanov", *Revue de l'Institut de Sociologie*, 3-4, 1983: 423-437.

Raberto, Marco, Cincotti, Silvano Focardi, Sergio M. & Marchesi, Michele, "Agent-based simulation of a financial market", arXiv:cond-mat/0103600 v2 30 Mar 2001

Schwager, Jack. D., *The New Market Wizards. Conversations with America's top traders*, New York: HarperBusiness, 1992

Smith, Adam, *An Inquiry into the Nature and Causes of the Wealth of Nations*, Oxford: Oxford University Press, [1776] 1976

-- *Schwager*: Did you decide to give the specialist a break because it was such an obvious mistake? Or because you thought it might threaten the longevity of what was then a fledgling exchange and product?
-- *Lipschutz*: It was a long-term business decision based on the opinion that it would have been bad for my business to hold him to the trade.
-- *Schwager*: Bad for the business in what way?
-- *Lipschutz*: My business in trading currency options was exploding, and the *Philadelphia Stock Exchange* was where they were traded. (The over-the-counter currency options market was only just starting at the time.)
-- *Schwager*: So you did it to protect the exchange.
-- *Lipschutz*: No, I did it to protect me.
-- *Schwager*: To protect your marketplace?
-- *Lipschutz*: That's exactly right.
-- *Schwager*: Then, hypothetically, if the exchange had been there for ten years, trading volume was huge, and this trade would not have made any difference to the survival of the exchange, you would have made a different decision.
-- *Lipschutz*: That's correct. It wasn't charity." (Schwager 1992: 34).