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Pig breeding goals in competitive markets

P.W. Knap
Genus-PIC, Schleswig, Germany

ABSTRACT: Weighting factors (**b**) derive from marginal economic values (MEVs), which derive from cost/performance parameters. Sensible approach: start with **b**=MEV, and evaluate trait responses. These may disappoint, usually resolved by modifying **b** towards acceptable response patterns. This reduces overall ΔG, but has sound reasons: overfocus on the population's weak traits (countering non-compensatory customer attitudes), and/or neutralize its genetic trait antagonisms. Breeding goal traits separate as (1) classical: growth/backfat depth; (2) high-tech: litter size/feed intake; (3) antagonistic: mortality; (4) novel: boar-taint; (5) prospective: meat quality; (6) vague-MEV: leg soundness/muscling. Monopolistic markets support unconventional breeding goals. Companies competing on particular markets may have different breeding goals due to (i) different antagonisms to neutralize, (ii) different weaknesses to compensate, (iii) creative deviations from the mainstream cost-benefit approach. Trait groups 4 and 5 will become more important in relation to animal welfare and pollution. G×E does not affect breeding goals much.

Keywords: pig; breeding goal

Introduction

The common selection criterion in commercial pig breeding is a Hazel selection index; estimated breeding values (EBVs) for traits are combined into this index with weighting factors based on the marginal economic value (MEV) of each trait following Schneeberger et al. (1992). This reflects part of a breeding goal that may include other criteria (typically anomalies and exterior traits) that are dealt with by independent culling on phenotype. Here we ignore such criteria and assume that any breeding goal trait is either (i) recorded as such and processed by multivariate BLUP, or (ii) represented by correlated traits that are recorded and processed that way.

There are three common ways to quantify and document a breeding goal: (i) the index weighting factors for the trait EBVs, usefully scaled by trait standard deviation, (ii) the predicted selection responses of the traits, usefully in standard deviation units, (ii) ditto in monetary units. Each of these has its specific pros and contras, dependent on how we want to look at things.

Economic values and index weighting factors

There are three common ways to calculate MEVs of breeding goal traits: (i) from a single profit equation, as its partial derivative with respect to each trait (e.g. Knap, 1990; Hermesch et al, 2003; Quinton et al., 2006), (ii) from a bio-economic multi-equation model, evaluated for differential values of each trait (e.g. Faust et al., 1992; Serenius et al., 2007; Houška et al., 2010), and (iii) trait by trait (e.g. Habier et al., 2004; Amer et al., 2013). Wilton et al. (2013) and Nielsen et al. (2013) describe these approaches in more detail and discuss their pros and contras. Methods (i) or (ii) get very often mixed with method (iii). We use the term "profit model" here to cover the whole range.

Regardless, MEVs derive from local cost and price parameters and from local performance levels. All of these vary across locations and over time: MEVs are not universal or constant values. For example, Hanenberg et al. (2010) present MEVs of six traits for three European countries, Brazil and USA, and show threefold ranges across these countries. Quinton et al. (2006) present MEVs that are 28 % lower (for litter size) and 100 % higher (for piglet mortality) at a mean litter size of 16 compared to 8 (a time effect).

Index weighting factors are commonly derived from MEVs. A sensible approach is to start with weighting factors that *equal* the MEVs, and evaluate the resulting trait selection responses. Very often this leads to undesirable outcomes for a few traits, and this is usually resolved by modifying the associated weighting factors away from their MEV until the pattern of responses is acceptable (or until it becomes clear that the covariance structure of the traits doesn't allow for that). Essentially, this is a desired gains approach; that approach can also be followed to set weighting factors for traits with unclear MEVs such as leg soundness, teat number, piglet weight, boar taint etc.

Commercial vs macro-economic breeding goals

Such a modification of weighting factors will by definition reduce the overall economic selection response, so there should be sound reasons for doing so.

Compensation. One reason was quantified by De Vries (1989): many pig producers make decisions to buy stock from a particular breeding company based on non-compensatory marketing models: the weakness of a product on one attribute (here: a trait) is not fully compensated by the strength of another attribute, and a product is essentially evaluated on the (unfavorable) comparison of its weakest attributes to competing products, not on its overall profitability. From that point of view, a commercial breeding company should overemphasize a line's weaker traits and underemphasize its stronger ones.

In the late 1980s this was most likely a universal truth, but this attitude in the customer base is gradually changing: with ongoing consolidation of the sector, more and more pig producers (particularly the very large vertically integrated ones) collect extensive data on anything in their farrow-to-fork production system that influences profitability, and monitor net profit per replacement gilt and/or per born piglet on a regular basis. Many of these groups have a deliberate policy to source their genetics from two or more breeding companies simultaneously, and run their own continuous in-house benchmarking programs (there is good reason to do so, because there is considerable variation in production performance, see Figure 1). This is the type of customer that the Hazel index with its implicit fully compensatory principles was, in fact, designed for – currently they feature mostly in the USA. The rest of the world still behaves generally the non-compensatory way described above, often taking decisions based on a few traits that are easily quantified (e.g. litter size and carcass lean content, as opposed to feed efficiency).

Constraints. Another reason for modification of weighting factors away from the MEVs has to do with the covariance structure of the breeding goal traits and the way this aligns with the MEVs and therefore allows for the economically optimum selection response. For example, Hermesch et al. (2000: Australian Landrace and Yorkshire), Zhang et al. (2000: a French Meishan-based synthetic), Suzuki et al. (2005: Japanese Duroc), Quinton et al. (2006: Canadian Yorkshire) and Habier et al. (2007: German Pietrain) present genetic correlation estimates among traits in a wide variety of pig populations. Treating estimates between –0.1 and +0.1 as neutral, these patterns show 7:8, 4:1, 5:4, 2:2 and 6:3 unfavorable : favorable genetic correlations, respectively. Such data structures constrain the possible response to selection, more strongly so when more traits are involved.

Walsh and Lynch (2008) consider the simple but crucial question *Is there genetic variation in the direction of selection?* and quantify this by aligning the vector of index weighting factors (**b**) with the eigenvectors of the genetic covariance matrix (**G**). We have done so with the estimates from some of the above papers, appying **b** values as derived from those papers and/or from Ierei (1995), Habier et al. (2004), and Badouard and Pellois (2010). The most representative results are in Table 1 (the results for Suzuki are between those for Habier and Quinton).

In each case, the optimum selection gradient (i.e. the **b** vector) is 68° to 131° away from the dominating eigenvectors of the **G** matrix, i.e. from most of the usable genetic variation. Eigenvectors at an angle of less than 55° from **b** cover only 7 to 21 % of the genetic variance in each population. As a consequence, although the total economic gain is by definition maximized for the optimal index, the expected genetic gains ($\Delta G = \mathbf{G}\ \mathbf{b}$) of at least half of the traits for each case deviate very seriously from their optimum (i.e. **b**) values. This illustrates the interplay between economy and biology (between **b** and **G**) in animal breeding: clearly none of these populations has the genetic makeup to fully support its breeding goal, so it should be possible to find a replacement line that does that job in a better way. This introduces an interesting trade-off between short-term and long-term strategy in commercial breeding: in the short term a line is used for a particular market because its mean performance levels match that market's MEVs (μ versus MEV) but in the long term the line's genetic covariance architecture (**G** versus MEV) should be the decisive factor. The fact that MEVs tend to change over time doesn't make it any easier.

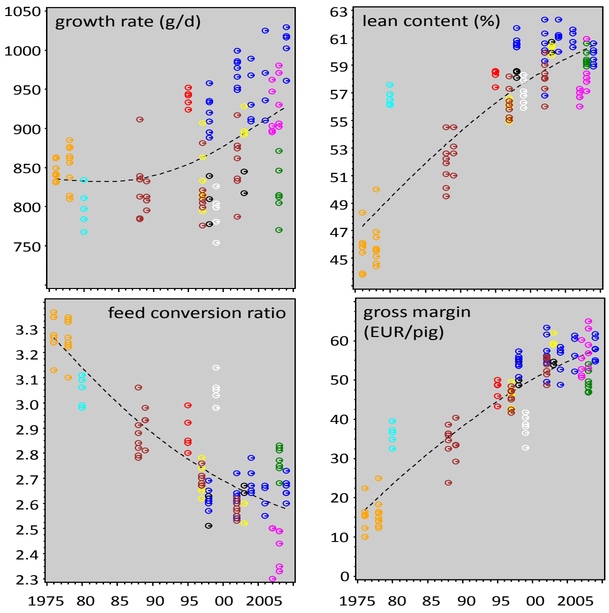

Figure 1. Results from public Commercial Product Evaluation trials of grower-finisher pigs in Denmark, France, Germany, Netherlands, UK and USA: raw phenotypic population means. Each trial is represented by a column of two to nine datapoints (i.e. commercial products locally available at that time) with the same color.

There are three common options to deal with such a constrained situation:

Option 1: Leave it as it is, and accept any unfavorable trait responses that apparently coincide with the macro-economic pattern of the MEVs. This requires a compensatory customer attitude.

Option 2: Remove some of the traits with unfavorable responses from the breeding goal, i.e. set their weighting factor to zero. Of course, this will not set their *selection responses* to zero: correlated responses will remain. So this leads to loss of control, which can be effectively neutralized by line specialization, in its most extreme form by sire and dam line formation. Less extreme are the various international sire line scenarios of companies such as Topigs (fresh pork; bacon; cured ham; high weight/high lean: De Vries and Loenen, 2005), Hypor (most pork at least cost; best pork at least cost; premium pork quality; leanest pork quality: www.hypor.com/~/media/files/hypor/maxing/english/25-mc_acn_specialized-sires.pdf) and PIC (maximum profit potential; robust lean growth; efficient lean production; outstanding carcass value: www.pic.com/images/users/1/usa/boars/boarslickfinal_small.pdf).

Variously specialized lines can be combined into a crossbred parent product that balances the various trait responses out again.

Wilton et al. (2013) stress that when a trait with economic impact is excluded from the breeding goal (their example is feed intake, a trait with expensive recording – see 'Group 2' below), then the MEVs of all other traits should be adjusted for that.

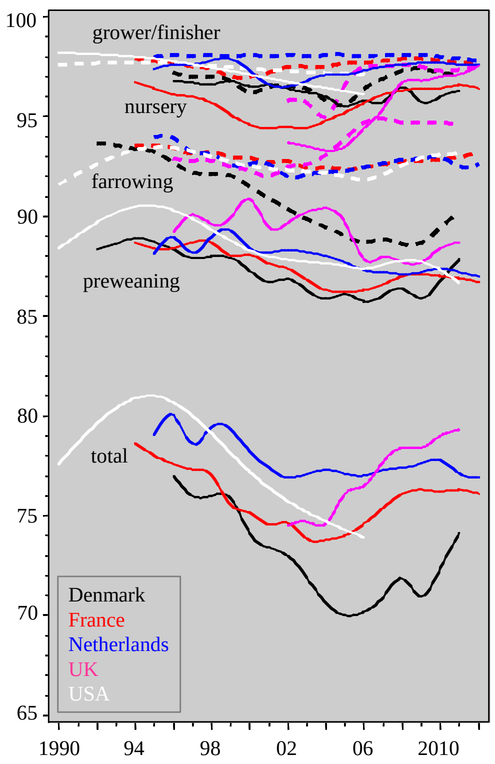

Figure 2. Phenotypic trends of pig survival (%) in four production stages. Data from VSP (DK), IFIP (FR), Agrovision (NL), BPEX (UK), USDA and PigChamp (USA).

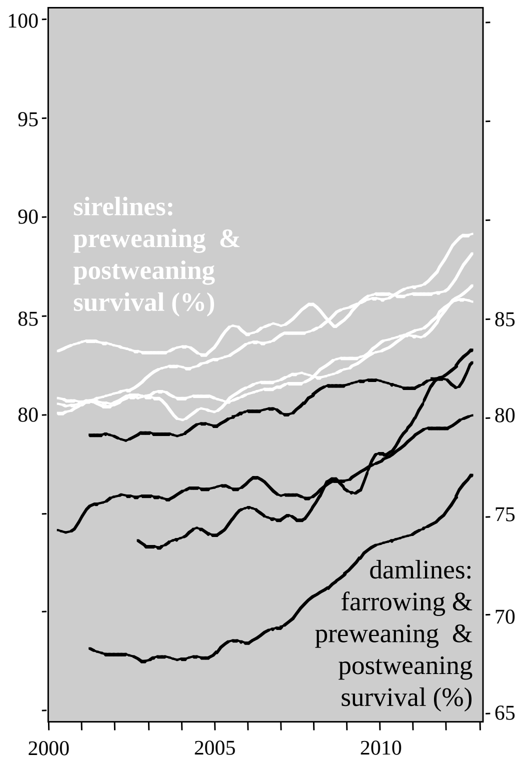

Figure 3. Genetic trends of total pig survival across various production stages, in PIC sire lines and dam lines. Compare to Figure 2 where the Y-axis has the same scale.

Option 3: Increase the weighting for any traits that show unfavorable selection responses, in an attempt to reduce these to somewhere close to zero (e.g. restricted indexes for meat quality or feed intake since the late 1980s: Morel et al., 1988; Iansen and Sehested, 1989) or even to an overall favorable pattern. In most cases this will reduce the alignment between **b** and **G** even further, so all the realized (not: predicted) selection responses will have to be closely monitored to ensure proper process control.

Because this is occurring more and more often now that breeding goals include more traits, the key issue is continuous monitoring, recording all possible traits that may turn into an unfavorable side effect, and taking corrective action whenever required.

In practice, a breeding company may apply all of these three options simultaneously in different lines, or alternate through them over time – much of this is more or less subjective: more an art than a science.

Breeding goal traits

Breeding goal traits fall apart into six groups in terms of when and why they are taken up as such.

Group 1: Traits that form an obvious part of the profit model (usually long before that model is established as such), with a large scope for uncomplicated genetic improvement: the classical production traits with medium to high h^2 and easy recording. Apart from the usual phenotypic independent culling criteria, these are the only traits seriously selected for in the typical low-tech breeding program. In pigs: growth rate and ultrasound backfat depth.

Group 2: Traits that form an equally obvious part of the profit model, but require dedicated technology for improvement: in pigs, these are production traits with low h^2 such as litter size (which require BLUP) or with complicated data recording such as feed intake (which require equipment). Those traits have been serious breeding goal traits of some European breeding systems since the late 1970s – in the sense of occupying a considerable part of the total selection effort, with elaborate schemes for creating multiple litter size records per nucleus female, or with individual housing during performance testing. But actual genetic improvement was only achieved 10 to 20 years later when the proper technology had been implemented (which always happened straight against all the cost-benefit analyses of that time). A few parties had done so and had started to report (and market) noticeable genetic gains, and in view of international competition, the rest had to follow.

Group 3: Traits as in group 2, but with an impact on profitability that becomes clear only when antagonisms appear: a good example in pigs is mortality. As soon as mortality rates are included into the profit model, it becomes obvious that they have a very large impact on profitability. This was signaled in the early 1990s (e.g. Crooks et al., 1993) and repeatedly later on (e.g. Knap, 2005; Bilbrey,

2012) but uptake in commercial breeding goals has been slow – mostly because the trait requires very large volumes of pedigreed records from diverse management conditions, which calls for complicated logistics. In that same period, phenotypic survival rates in piglets and grower-finisher pigs have been declining steadily in several parts of the world, see Figure 2. By contrast, Figure 3 shows that survival rates can be improved genetically – it just takes logistics and technology; Knol et al. (2002) discuss much of the genetic background. Comparison of Figures 2 and 3 reveals that unfavorable environmental trends can be much stronger than favorable genetic ones.

Traits in this group are usually taken up as breeding goal traits only after (sometimes: long after) the required technology has become available. In group 2, such (unsuccessful) uptake takes place *before* that point in time.

Neutralization of genetic antagonisms between production and animal robustness will be a key element of animal breeding for the coming few decades (see Neeteson et al., 2013).

Group 4: Traits that come to form part of the profit model because of novel policies in the market that create a sudden economic value. A present-day example in pigs is boar taint, preparing for the planned EU ban on surgical castration by 2018. These traits have initially unclear MEVs because their real impact on producer economics remains hard to quantify for some time. The common solution is a desired gains approach (e.g. Frieden et al., 2011).

Group 5: Traits as in group 4 that are taken up *before* any impact on profitability has occurred, driven by future expectations, and obviously in terms of desired gains. Pork quality traits (e.g. muscle pH, intramuscular fat content, fatty acid composition) are only very rarely actually *paid for* by the meat processing industry, and then mostly not on the individual carcass level (e.g. the Swiss coop IP-Suisse: www.ipsuisse.ch/web/schweine_id56). But several commercial lines have breeding goals with a considerable contribution of such traits: 20 to 37 % of the total in Norsvin Duroc; Nucléus Duroc; PrimeGro Duroc; Hypor Kanto; Suisag Duroc, Large White and Pietrain: (data from the various company websites). Most of these lines are Duroc strains, a breed with generally high meat quality levels.

Group 6: Long-standing traits that require genetic improvement because the market values them, but that do not fit into a proper profit model because their contribution to profitability at the producer level is hard to quantify. For example: leg soundness, teat number, muscle conformation, piglet weight. MEVs must then derive from ad hoc equations, or desired gains are applied again. Such traits can show good selection responses when the data are properly processed (for example, see Figure 4 for genetic trends of leg soundness and litter weaning weight in PIC lines) – the main danger is disconnecting them from the proper breeding goal by a focus on phenotypic independent culling.

Pig breeding goals in competitive markets

Breeding companies in more or less monopolistic home market countries (e.g. Danbred in Denmark, Norsvin in Norway, Suisag in Switzerland) and in vertical integrations (e.g. SPG under Smithfield in USA, PrimeGro under Rivalea in Australia) do not have to worry much about the impact of competing products on their home market and on their breeding goals (in view of non-compensatory customer attitudes, see above). This may explain the strong emphasis on meat quality traits in some of these systems ('Group 5' above), and it may explain Danbred's rather dramatic 1995 decision to double the weighting on litter size in its dam line breeding goals, resulting in this trait to account for 62% of the total ("due to the fact that the National Committee […] wishes to promote litter size": NCPBHP, 1995).

This does not hold for competition *outside* the home market of these organizations, but the general tendency is to supply export markets for breeding stock through customized sales indexes rather than to adapt the complete breeding goal. In the long term, with established international business, the weighting factors of the various breeding goals would logically be based on weighted averages of the various customers' MEVs (which may vary widely across the world, see 'Economic values and index weighting factors' above).

By contrast, a market that is supplied by several breeding companies (i.e. most of the world) must be evaluated by each of these companies to derive its MEVs. Dependent on the profit models employed and the input parameter values used (which may vary considerably, depending on who is putting them together at the local level), everyone should arrive at similar MEVs for such a market. Different sets of weighting factors would then result from

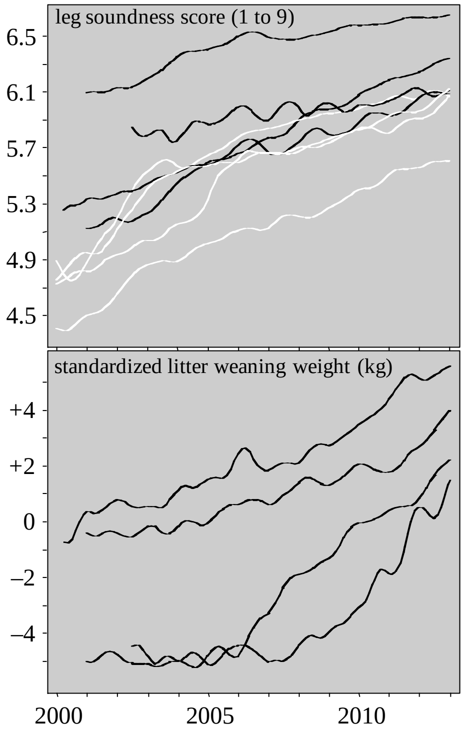

Figure 4. Genetic trends of leg soundness and litter weaning weight in PIC sire lines (white) and dam lines (black).

differences between (i) the genetic covariance structures of the various populations, and between (ii) competitive strengths and weaknesses of each population that must be compensated for, and perhaps most importantly from (iii) creative deviations from the mainstream cost-benefit approach – the non-compensatory attitude of pig producers may translate into overemphasis on an easily recorded trait (see 'Compensation' above), and any breeding company that can offer a product that excels in such a trait may temporarily overwhelm much of the market – so that its competitors will have to reconsider their stance with regard to point (ii).

Future developments

The above trait Groups 4 (novel policies in the market that create a sudden economic value) and 5 (taken up before profitability, driven by future expectations) are expected to increase in importance as the animal production sector gets under more intense scrutiny by society as a whole. The boar taint example in Group 4 came up because of that very reason: the EU ban on castration is a direct consequence of successful lobbying by animal welfare NGOs.

Another trait in that same league is the ability of gilts to cope with group housing; in view of recent regulations in this area, breeding companies are changing their data recording to that environment, and dominance behavior may be taken up explicitly as a breeding goal trait. This and other behavior traits (e.g. vices like tailbiting and piglet savaging; docility and handleability) would fall under the *adaptability* element of breeding goals described by Neeteson et al. (2013). At least in Europe and Asia, such traits are often the decisive criterion to choose for one product or another with similar production performance levels, and they can be surprisingly non-compensatory.

Other such breeding goal elements include *environmental efficiency*, which is strongly correlated to feed efficiency as quantified for growing pigs by Shirali et al. (2011). Shadow prices of greenhouse gas production inevitably lead to levies on pollution, and this will create a MEV for environmental efficiency in any livestock species; Wall et al. (2010) notice that "the prevailing emissions price becomes the relevant economic weight that should be incorporated in any breeding index that includes mitigation potential".

Genotype by environment interaction (G×E) is a potential source of inefficiency in any transnational breeding program. It can be very effectively dealt with on the individual animal level through reaction norms (e.g. Knap and Su, 2008). That would create one additional breeding goal trait (i.e. the environmental sensitivity) for each trait of interest; Hermesch and Amer (2013) describe how to derive the MEVs for such traits. But this methodology is very data-hungry and its feasibility in pig breeding is therefore dubious. Less detailed approaches such as Combined Crossbred & Purebred Selection (recording commercial performance and using the data to estimate breeding values for nucleus stock) are more realistic, most usefully for traits with a strong environmental influence such as mortality and efficiency (e.g. Knap, 2012). This does not affect the breeding goal, apart from defining it on the commercial level.

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Table 1. Upper half of each sub-table: genetic parameters (h^2 in bold; genetic correlations in green: favorable, in red: unfavorable, in grey: neutral), index weighting factors (b = MEVs) and predicted selection response (ΔG = **G b**) of various production, reproduction and robustness traits in pigs. **Lower half**: eigenvectors (EV) of the genetic covariance matrix **G** with proportional eigenvalues, correlations of the traits to each EV, and the angle between each EV and the vector of MEVs.

Zhang et al. (2000)		trait A	trait B	trait C	trait D	σ_G	b per σ_G (€)	ΔG (€)
trait A		**0.36**	+0.26	+0.03	+0.23	5.06	–1.67	–2.08
trait B			**0.73**	+0.19	+0.11	1.88	–3.28	–3.10
trait C				**0.19**	–0.66	1.42	+2.31	+0.56
trait D					**0.19**	7.51	+1.65	–0.62
EV	% of var	correlation of trait to EV				angle with b (degrees)		
1	42	+0.2	+0.0	–0.7	+0.7	99		
2	33	+0.6	+0.7	+0.3	+0.1	123		
3	18	+0.7	–0.7	+0.1	–0.1	78		
4	7	–0.2	–0.7	+0.7	+0.7	38		

Habier et al. (2007)		trait A	trait B	trait C	trait D	trait E	σ_G	b per σ_G (€)	ΔG (€)
trait A		**0.37**	–0.46	–0.42	–0.30	+0.18	42.97	+1.72	+17.33
trait B			**0.23**	–0.38	+0.44	+0.26	2.513	–36.43	–37.88
trait C				**0.59**	–0.28	–0.33	1.570	+3.24	+15.72
trait D					**0.21**	+0.06	0.0411	+0.315	–17.04
trait E						**0.43**	0.183	+1.67	–8.54
EV	% of var	correlation of trait to EV					angle with b (degrees)		
1	38	–0.2	+0.6	–0.4	+0.5	+0.3	131		
2	32	+0.7	–0.2	–0.5	–0.2	+0.4	80		
3	16	–0.3	+0.2	+0.4	–0.5	+0.7	97		
4	11	+0.1	–0.5	+0.3	+0.7	+0.4	55		
5	3	+0.6	+0.5	+0.5	+0.1	–0.1	117		

Quinton et al. (2006)		trait A	trait B	trait C	trait D	σ_G	b per σ_G ($)	ΔG ($)
trait A		**0.10**	+0.18	+0.26	+0.08	0.316	+4.59	+14.08
trait B			**0.06**	+0.45	+0.04	0.078	+0.163	+1.74
trait C				**0.02**	+0.21	0.021	+0.045	+2.97
trait D					**0.05**	0.250	–0.178	+0.178
EV	% of var	correlation of trait to EV				angle with b (degrees)		
1	42	+0.4	+0.6	+0.6	+0.3	68		
2	24	–0.1	–0.4	+0.0	+0.9	99		
3	21	+0.9	–0.4	–0.2	+0.0	25		
4	13	+0.1	+0.6	–0.7	+0.2	84		