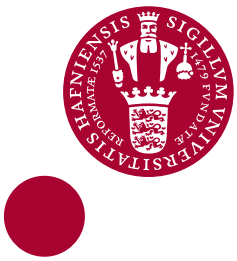

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Tracing the 'Swan-groups' of Physics and Economics in the Key Publications of Nobel Laureates

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Abstract: Following the 'black-white swan' interaction metaphor introduced in an earlier study, we now trace and observe a new 'swan-group' pattern. Our motivation for introducing the "swan group" is based on the fact that 'black-white swan' interactions are observed primarily in physics, which belongs to science. We extend a newer model called the 'swan-group' model and test its applicability to the field of economics, which belongs to the social sciences. The primary feature of this model is that the 'black swan' represents an important scientific discovery or contribution that has been awarded Nobel Prize, while the 'white swans' are highly cited publications by the 'black swan'. Together the two types of swans form a group, though unlike the original 'black-white swan' interaction pattern, the 'swan-groups' do not necessarily interact in a way where we see a marked decrease in citations to white swans. Our findings show that the new 'swan-group' pattern covers about 50% of key Nobel prize-winning physics papers and about 40% of key Nobel prize-winning economic papers. This allows us to identify important academic achievements both qualitatively and quantitatively, not only in science where major breakthroughs can cause paradigm shifts, but also in the social sciences where progress often remains open to multiple discoveries and doctrines.

Keywords: *Swan-group; white swan; black swan; scientific metrics; Nobel Prize*

1.Introduction

The 'sleeping beauty' phenomenon (van Raan, 2004), based on citation curves (Avramescu, 1979), is an interesting discovery with new and related findings in recent years (Braun et al., 2010; Li & Ye, 2012; Du & Wu, 2018). It refers to research papers that are cited long after publication; thus 'awakened' after some time, because they are suddenly influential, or useful for scientific innovation (van Raan, 2017). The 'sleeping beauty' is recognized from pure statistical patterns related to a sleeping period, sleeping depth, awaking

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period, and awaking intensity (van Raan, 2004), while little consideration is given to its scientific content, or the content of the publication that has led to its 'awakening'.

We propose another interesting pattern called the 'swan' (Zeng et al, 2017), which differs from the 'sleeping beauty' in that the qualitative content of 'swan' papers is considered in addition to scientometric (citation) data. Unlike 'sleeping beauties' the 'swan' pattern in science is not concerned with 'delayed recognition', but with the known recognition of a scientific paper, and then all preceding papers' role in bringing that recognized paper to fruition. In this way, there are actually two types of swans, a ‘black swan’, which is a research publication consisting of a breakthrough that changes scientific views and promotes scientific progress, and a ‘white swan’, which denotes quality publications that are highly cited prior to the appearance of the 'black swan', but later also cited by the 'black swan'.

Since ‘black swans’ and ‘white swans’ are interrelated, and may be defined at both a qualitative and quantitative level, the overall ‘swan’ pattern is a special citation phenomenon. In contrast to the sleeping beauty, where a dormant publication's quality is not as definitive, the swan pattern first identifies 'black swan' publications that are already considered to be of high quality (i.e., Nobel prize winning research). Previously we investigated 'black swans' and 'white swans' in the fields of physics, chemistry, and physiology/medicine (Zeng et al., 2017; Zhang et al., 2017). What we found with physics specifically is that a "black-white swan" interaction pattern corresponds to approximately 20% of Nobel prizes in the field.

In this paper, we extend our analysis to include the social sciences. Here, we draw comparisons between physics and economics, to see if there is a representative difference between white swans and black swans within the sciences and social sciences. Again, we develop our method of identifying ‘swans’, by focusing on Nobel prize-winning research. But this time, we modify our original model from that of a ‘black-white swan interaction’ pattern to a new model for recognizing ‘swan groups’.

2. Methodology

In an earlier ‘black-white swan interaction’ pattern (Zeng et al., 2017), white swans and black swans were defined as follows.

Definition 1. Black swan: Qualitatively, a black swan is a publication that presents a breakthrough discovery in a particular field of science. Quantitatively, it is a publication that receives more than Cb citations (Cb denotes citations of black swan) within five years of its publication, during which time its citations increase and the corresponding citations of the white swans decrease.

Definition 2. White swan: Qualitatively, a white swan or ‘swans’ comprise a group of publications that have been highly cited in the scientific field prior to the publication of the black swan. Quantitatively, each white swan is a publication that receives more than Cw citations (Cw indicates citations of white swan) in the five years prior to the publication of the black swan.

With physics in particular, we found that following the publication of a black swan, citation rates to white swans tend to decrease. Black and white swans relate to one another, with the publishing event of the black swan serving as the primary link. With every black-white swan pairing, we can therefore focus on this publishing event and examine the five years prior to it and the five years following it. Since there might be many white swans

related to a black swan, we choose the top two highly cited publications for a more feasible and simple analysis.

Suppose a 'black swan' was published in the year T_S, and we have two top 'white swans', where 'white swan 1' was published at T_1 and 'white swan 2' at T_2. Let $T_W = \min\{T_1, T_2\}$. The setting condition means $T_S - T_W \geq 5$. Examining the five years prior we discover the two white swans that have the highest number of citations and compare them with the black swan. The swan-index (Sw) can thus be introduced as

$$Sw = \frac{Cb}{Cw_1 + Cw_2} \quad (1)$$

where Cb is the total expected citations of the black swan in the first five years following its publication (the publishing year is Ts), and Cw_i (i=1,2…) is the citations of white swan *i* five year prior to Ts. The Ts also designates the scientific finding breakthrough year. In every case we search for the top two white swans. As Cb increases and Cw_i decreases, we expect that $Cb > Cw_i$.

When Sw = 1 there is a standard black swan. When Sw > 1, Cb is larger than (Cw_1+Cw_2), i.e. the integral area of the citation curve of the black swan is larger than those of the top two white swans, then the black swan is strong or "plump". When 0.5 < Sw < 1, the Cb is smaller than (Cw_1+Cw_2), i.e. the integral area of citation curve of black swan is smaller than those of the top two white swans, then the black swan is weak or "thin". When Cb << (Cw_1 + Cw_2), Sw << 1. When Sw < 0.5, or $T_S - T_W < 5$, the black swan is called as a grey-black swan (or a grey swan briefly, which also belongs to black swan).

Combining the qualitative and quantitative definitions, the black-white swan metaphor is supported by both the scientific contents of publications and their scientometric data, most notably for scientific discoveries that have received a Nobel prize in the fields of physics, chemistry, physiology or medicine.

However, when we extend the metaphor in order to see if the same black-swan/white swan pattern applies to the field of economics, where economic discoveries are also eligible to win Nobel prizes, we find that an improvement is needed. Since 'breakthroughs' tend not to exist as 'black swans' in economics, the pattern of the 'black-white swan interaction' is rarely observed. This constitutes a difference between the natural sciences and social science; hence the application of a new 'swan-group' metaphor can be used to unite the disciplines in a more meaningful way, by modeling their discovery processes together.

For practical purposes we set Cb > 100 and Cw > 50 in order to account for the 'sleeping beauty' phenomenon, because a 'sleeping beauty' may also receive 10 citations during a five-year sleeping period and then receive > 20 citations in the four years after it wakes up. With these two settings we are enlarging by five times the difference between typical white swans and the black swan during the five-year period. If during the five-year period the number of citations to the black swan is not higher than those of the white swans, the black swan merges into the swan group. This is where a new 'swan group' has potential to emerge in the field of economics.

(1) Indicator

To quantify a swan-group, we use a swan-group indicator

$$Gs = (Cb, Cw_1, Cw_2) \quad (2)$$

where Gs denotes the swan-group indicator, Cb is the total expected citations of the black swan in the first five years following its publication (the publishing year is Ts), and Cw_i (i=1,2…) is the citations of white swan *i* in the same five years.

On Eq. (2), we can classify swan-groups as three types:

- Type I: $Cb > Cw_1$ and $Cb > Cw_2$. In this case, Cb is always larger than Cw_1 or Cw_2.
- Type II: $Cb \leq Cw_1$ and $Cb \leq Cw_2$. In this case, Cb is always less than or equal to Cw_1 or Cw_2.
- Type III: Others, including $Cb > Cw_1$ and $Cb \leq Cw_2$, or $Cb \leq Cw_1$ and $Cb > Cw_2$.

Type I shows that black swan of a swan-group *is* stronger than any white swan, and type II indicates that the black swan in a swan-group *is not* stronger than any white swan. In addition, the type III covers *all other cases*.

In this three-type classification system, type I is close to the original black-white swan interaction pattern, where a black swan instigates a breakthrough in scientific research. Type II and type III are special patterns of swan-groups, where both black and white swans look like they are the same swans in a group. In the swan-group indicator Gs, different Cb, Cw_1 and Cw_2 indicate different type of swan-groups.

The Ts also designates the breakthrough year of the scientific finding. To test for similarities or differences between physics and economics, we use the same model for both. The earlier physics pattern, which we call the black-white swan interaction still holds true for sciences in general, but we want to see if there can be a new pattern for both physics and economics.

In contrast to both the h-index (Hirsch, 2005) and B-coefficient (Ke et al., 2015), which are based on pure quantitative studies, we use a swan-index and swan-group indicator for both qualitative and quantitative considerations. First, we selected the high quality publications (our qualitative approach), and then we applied the simple indices to measure the ‘swan’ shapes (our quantitative approach).

(2) Modeling

In the framework of citations (C) and publishing years (T), a swan-group model is shown as Figure 1.

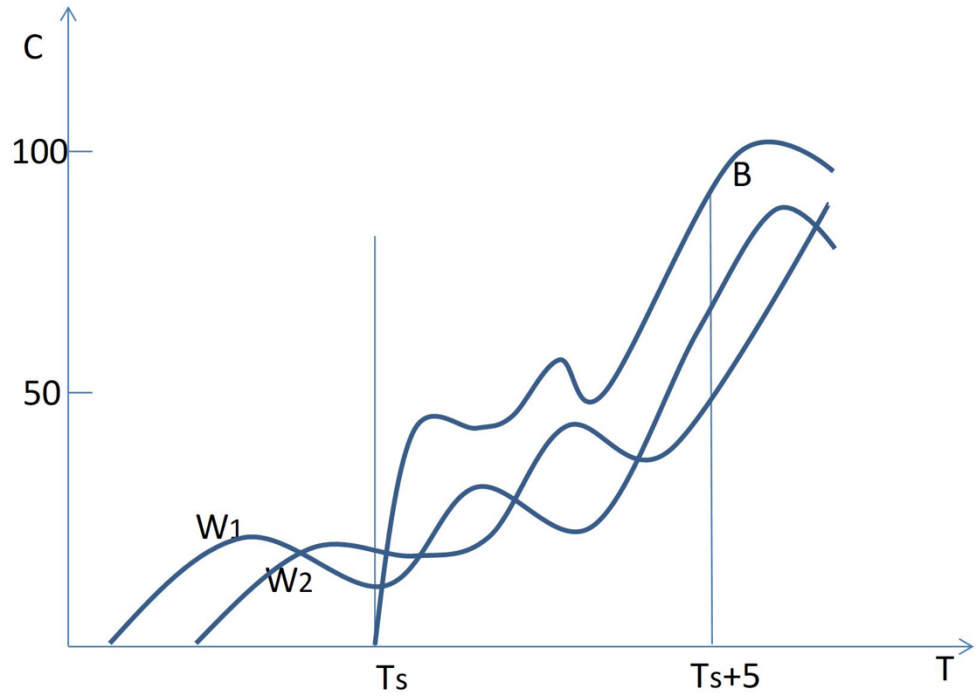


Figure 1. Modeling the swan-group

In Figure 1, the black swan (B) is published at Ts, which is a high-quality paper that has been awarded a Nobel prize represents the breakthrough scientific discovery or contribution. The two white swans (W_1 and W_2) are highly cited papers published before B and cited by B. Then B, W_1 and W_2 become a group of highly cited articles during Ts to Ts+5 years. This pattern overall could be suitable for both physics and economics.

Different fields possess different average citations. Thus, in accordance with the Essential Science Indicators Baselines and Average Citation Rates recorded from January 1, 1999 to December 31, 2009, the averages for physics and economics are 8.82 and 5.72, respectively. Average citation rates in physics are clearly higher than that of economics, if not almost double. For practical purposes, and in correspondence to an earlier observed 'black-white swan' interactive pattern (Zeng et al., 2017), we set $Cb \geq 50$ and $Cw_i \geq 50$ in physics, and $Cb \geq 25$ and $Cw_i \geq 25$ in economics.

(3) Data and data processing

Our method of data processing requires the following additional definitions.

Definition 3. Key paper(s) of Nobel Laureates. The key paper(s) that was the awarded a Nobel prize, and mentioned in the Nobel Laureates' lectures.

Definition 4. Key publications. The key publications of Nobel Laureates are defined the key paper and its own references, as well as all references mentioned in the Laureates' Nobel lectures.

In order to explore typical swan examples in both physics and economics, we follow three steps: (i) examine the list of Nobel Prizes in Physics and Economics awarded during the period 1995–2010 (http://www.nobelprize.org/nobel_prizes/physics/laureates/; http://www.nobelprize.org/nobel_prizes/economics/laureates/), (ii) analyze the references of

the key publications in the Nobel lecture of each Nobel laureate, and (iii) search for the citations to the key paper and its references using Web of Science (WoS). This key paper then becomes a black swan and the two most-highly cited references in the key papers are the white swans.

During 1995-2010, there are total 33 key papers in physics and 27 key papers in economics. For the 33 key papers in physics, we were unable to collect 5 items from the WoS. And, for the 27 key papers in economics, 3 items could not be collected from the WoS.

3. Results

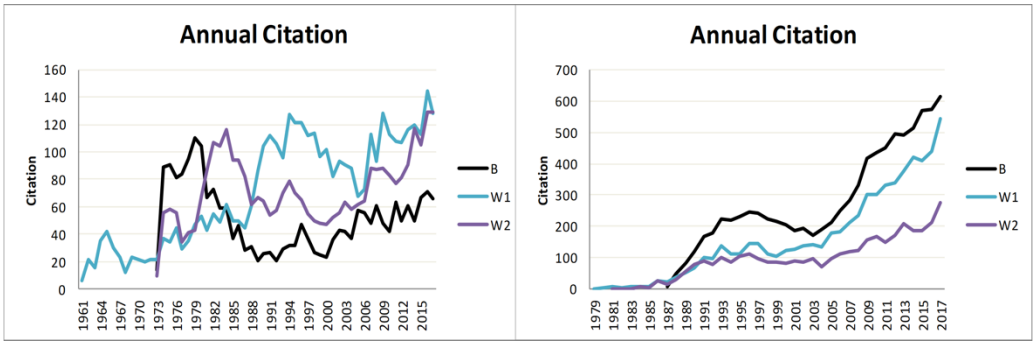
Since the Nobel prize in economics was first awarded in 1968, (unlike the first Nobel prize physics awarded in 1901), and since earlier and newer citation records from the WoS are not complete, we selected the years of 1995 to 2010 for our comparative analysis. The two different but visible swan-groups are shown in Table 1.

Table 1. Swan-groups in physics and economics

Field/Statistics	Physics		Economics	
	Number	Portion (%)	Number	Portion (%)
Key paper	33	100	27	100
Swan-group	17	51.52	11	40.74

From 1995 to 2010, there are total 33 key papers in physics, and it is within this set that we found 17 swan-groups, or in terms of percentage, 51.52% discoveries that were awarded a Nobel Prize. Note also that for the field of economics, also from 1995 to 2010, we found a total of 27 key papers, with 11 swan-groups, or, 40.74% of discoveries that were awarded a Nobel Prize.

At an individual level, we show two type I 'swan group' examples in the figures below, one for a Nobel prize in physics 2004 (Figure 2a) and another for a Nobel prize in economics 2003 (Figure 2b). Note specifically in Figure 2b, that the 'black swan' in economics has received more citations than its related 'white swans'.



(a) (b)

Figure 2. Typical swan-groups in physics and economics

Figure 2a, shows how highly cited research has contributed to the discovery of asymptotic freedom in the theory of the strong interaction, where the 'black swans' is:

- **B:** Politzer H D. Reliable perturbative results for strong interactions? *Physical Review Letters*, 1973, 30(26), 1346.

Here, the two 'white swans' are:

- **W_1:** Nambu Y, Jona-Lasinio G. Dynamical model of elementary particles based on an analogy with superconductivity.I. *Physical Review*, 1961, 122(1), 345.
- **W_2:** Coleman S, Weinberg E. Radiative corrections as the origin of spontaneous symmetry breaking. *Physical Review D*, 1973, 7(6), 1888

Its swan-group indicator is Gs= (440, 180, 245), where the 'black swan' has received more citations than the 'white swans'.

Figure 2b shows how highly cited research has contributed to new methods of analyzing economic time series with time-varying volatility (ARCH), where the black swan is

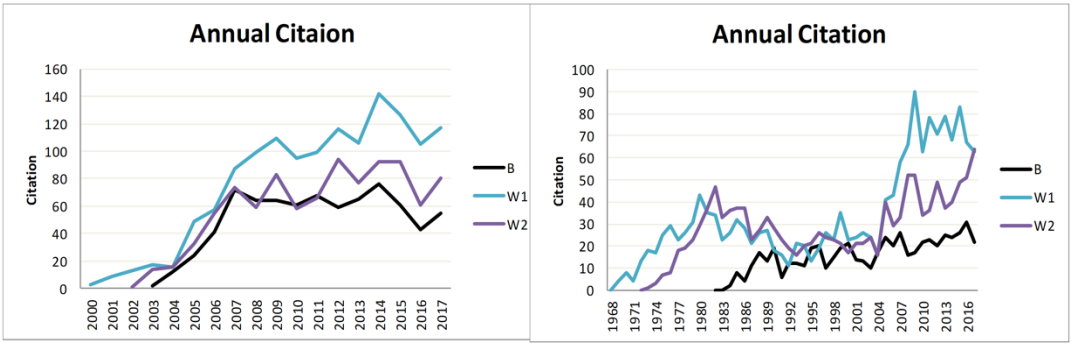
- **B:** Engle R F & Granger C W J. Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society,* 1987, 251-276.

The top two white swans are

- **W_1:** Dickey D A, Fuller W A. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American statistical association*, 1979, 74(366a), 427-431.
- **W_2:** Dickey D A, Fuller W A. Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: Journal of the Econometric Society*, 1981, 1057-1072.

Its swan-group indicator is Gs= (592, 353, 333).

Further in our analyses, we found some type II 'swan groups' whereby the 'black swan' had lower citations than its preceding 'white swans'. Figures 3a and b show two examples for 2010 both in physics (Figure 3a) and economics (Figure 3b).



(a) (b)

Figure 3. Special swan-groups in physics and economics

Figure 3a, shows how highly cited research has contributed to groundbreaking experiments regarding the two-dimensional material graphene, where the black swan is

- **B:** Geim A K, Dubonos S V, Grigorieva I V, et al. Microfabricated adhesive mimicking gecko foot-hair. *Nature materials*, 2003, 2(7), 461.

Here, the top two white swans are:

- **W_1:** Autumn K, Liang Y A, Hsieh S T, et al. Adhesive force of a single gecko foot-hair. *Nature*, 2000, 405(6787), 681.
- **W_2:** Autumn K, Sitti M, Liang Y A, et al. Evidence for van der Waals adhesion in gecko setae. *Proceedings of the National Academy of Sciences*, 2002, 99(19), 12252-12256.

Its swan-group indicator is Gs= (213, 308, 237), where we see that the two 'white swans' have received more citation than the 'black swan'.

Figure 3b shows how highly cited research has contributed to the analysis of markets with search frictions, where the black swan is

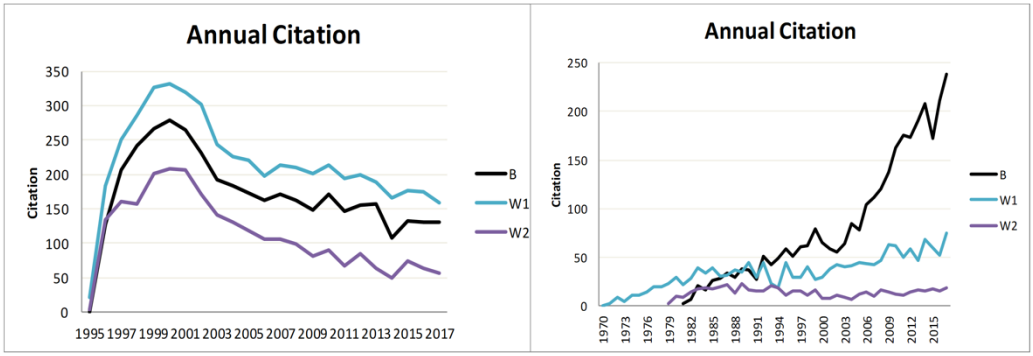
- **B:** Diamond P A. Aggregate demand management in search equilibrium. *Journal of political Economy,* 1982, 90(5): 881-894.

The top two white swans are

- **W_1:** Friedman, M. Role of monetary policy. *American Economic Review*, 1968, 58(1), 1-17
- **W_2:** Lucas Jr R E. Expectations and the Neutrality of Money. *Journal of economic theory*, 1972, 4(2), 103-124.

Its swan-group indicator is Gs= (25, 130, 166). Although the two 'white swans' had higher citations than the 'black swan', note that the 'black swan' was awarded a Nobel prize.

As for the swan-group, which we call type III, we provide two examples, one in Figures 4a and another in 4b, where a 'black swan' can have either a higher or lower citations than 'white swans'. Figure 4a shows a 2001 example in physics (left) and Figure 4b shows a 2001 example in economics (right).



(a) (b)

Figure 4. The swan-groups of type III in physics and economics

Figure 4a, shows how highly cited publication contributed to the discovery of Bose-Einstein condensation, where the black swan is

- **B:** Davis K B, Mewes M O, Andrews M R, et al. Bose-Einstein condensation in a gas of sodium atoms. *Physical Review Letters*, 1995, 75(22), 3969.

The top two white swans are:

- **W1:** Anderson M H, Ensher J R, Matthews M R, et al. Observation of Bose-Einstein condensation in a dilute atomic vapor. *Science*, 1995, 269(5221), 198-201.
- **W2:** Bradley C C, Sackett C A, Tollett J J, et al. Evidence of Bose-Einstein condensation in an atomic gas with attractive interactions. *Physical Review Letters*, 1995, 75(9), 1687.

Its swan-group indicator is Gs= (1119, 1379, 862), where we see two 'white swans' that have received almost the same citations as the 'black swan'.

Figure 4b shows the highly cited publications that have contributed to the analysis of markets with asymmetric information where the black swan is

- **B:** Stiglitz J E, Weiss A. Credit rationing in markets with imperfect information. *The American Economic Review*, 1981, 71(3): 393-410.

The top two white swans are

- **W_1:** Rothschild M, Stiglitz J E. Increasing risk: I. A definition. *Journal of Economic*

Theory, 1970, 2(3), 225-243

- **W_2:** Shavell S. Risk sharing and incentives in the principal and agent relationship. *The Bell Journal of Economics*, 1979, 55-73.

Its swan-group indicator is Gs= (99, 171, 89). We also see two 'white swans' that have received almost the same rate of citations as the 'black swan'.

In sum, with the 17 swan-groups in physics and the 11 swan-groups in economics, we now present the three types in Table 2.

Table 2. Three types of swan-groups with their ratios in physics and economics

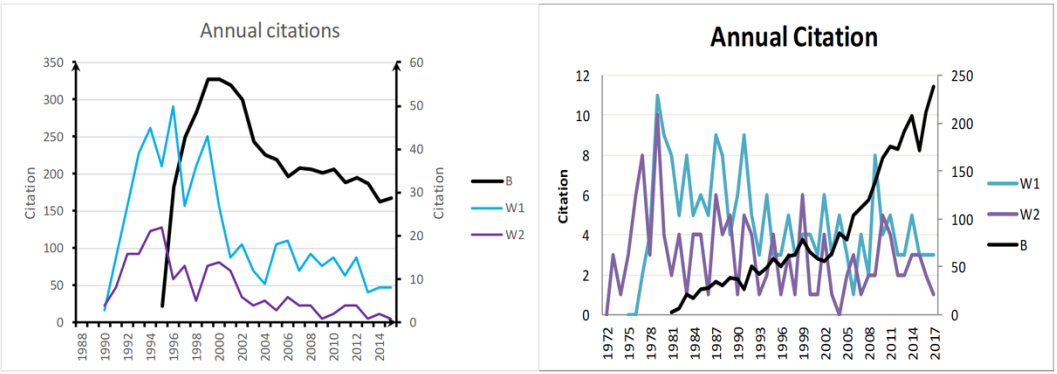
Type\Field	Physics		Economics	
	Number	Ratio (%)	Number	Ratio (%)
Type I	5	29.41	1	9.09
Type II	7	41.18	8	72.73.
Type III	5	29.41	2	18.18
Total	17	100	11	100

In Table 2, we see that both physics and economics, each selected for our science and social science field comparison have the highest proportion of 'swan-group' patterns that fit the type II category.

4. Discussion

The 'black-white swan' metaphor provides an interesting interpretation of key scientific findings or contributions, by considering their scientific content as well as their scientometric (citation) data. Our new model of the 'swan-group' allows us to verify the 'black swan' and its relational 'white swans' in both science and social science, based on Nobel prize-winning research from both physics and economics. Since this scientometric pattern focuses on Nobel prize-winning publications, it is clearly rare and thus not prevalent. Nevertheless, the type I, type II and type III swan-group patterns revealed in this paper convey something of interest about how the process of discovery works in physics and economics.

Earlier we note that in physics we see a somewhat rare (20%) black swan-white swan interaction pattern, but if we try to apply the original 'interaction' model to economics, there is almost no fit (less than 1%). Figure 5 presents a comparison between the 2001 Nobel physics prize, awarded to E. A. Cornell and the 2001 Nobel economics prize, awarded to J. E. Stiglitz. Note that the left vertical coordinate indicates the number of black swan citations and the right vertical coordinate denotes the number of white swan citations because of their larger differences.



(a) (b)

Figure 5. Strong and weak fit to the back-white swan interaction in physics and economics.

In Figure 5, we see that the case for physics possesses a strong fit to the pattern of the black-white swan interaction model, while the case in economics is comparatively weak. Also, this is the only example that we could find in economics.

The black-white interaction model is clear about breakthrough discoveries, and seems to reflect what Kuhn (1962) refers to as paradigm shifts in science. However, in the absence of dramatic paradigm shifts, which are less prevalent and said to occur during a period of 'crisis' in science, there are still a number of high quality or prize-winning discoveries in both science and the social sciences, which fit better with the second "swan group" model.

This does not mean that in a field like economics there is no such thing as a paradigm shift. In fact paradigm shifts are discussed in economics (Erdem, 2016) due to the many observed crises in this field, but if a shift occurs it is recognized mainly in terms of a change in doctrine. For this reason, old ways of thinking and new ways of thinking about economics may still be combined (cited together) over time in further research, which makes sense in light of our observed black-white swan group, where 'white swans' can receive almost the same rate of citations as the 'black swan'. This is unlike a paradigm shift in science, where an earlier scientific truth may be considered no longer useful or relevant.

5. Conclusion

Our introduction to the 'black-white swan' metaphor supports the measurement of key scientific discoveries and traces the effects of scientific progress both qualitatively and quantitatively. This metaphor is one of few introduced in scientometrics; hence we compare it to the "sleeping beauty" metaphor, which also tries to show a pattern related to significant discoveries in science. The primary issue with sleeping beauty publications is that scientometric patterns must be traced forwards. As a result, they can be difficult to find and depending on the parameters set for a dormant 'beauty' there can be relatively few of them in science. The beauty of the 'swan' metaphor is that there is a relatively higher ratio of swans and the process of analysis is implemented backwards, starting from a known but small dataset of high-quality (highly cited) papers from which we can observe different patterns: the black-white swan interaction pattern, or the type I, II or III 'swan group' pattern.

The original black-white swan interaction model proposed in Zeng et al. (2017) and

studied further in Zhang et al. (2017) is most apparent in medicine and in physics; while the 'swan-group' has been found to exist in both physics (a science) and economics (a social science). With the case of economics, in particular, the patterns for 'black swan' and 'white swans' tend to be similar and often mixed together, where mixed 'black-white swans' become a 'swan-group'. The 'swan-group' pattern covers about 50% key Nobel papers in physics and about 40% of key Nobel papers in economics. Overall, this means that the newly proposed model is much more meaningful and unites the disciplines in a more meaningful way.

Finally, we wish to note one small limitation to this study concerning the use of books, particularly because it is normal for scholars in economics to publish seminal books in addition to key research papers. We actually found two references to Nobel prize-winning books in economics; however we chose not including them in our analysis. Scientometric research pertaining to books is difficult when using data from the WoS because of how they are indexed, and it is well known that certain indexing problems can lead to inaccurate citation patterns (Gorraiz et al., 2013). Again, we conclude that this is a small limitation, even though it may be accounted for in the future, if indexing processes change for books (Zuccala et al., 2018). Since the 1990s, more and more original Nobel prize-winning contributions in economics have appeared in journals; hence the data that we have used from the WoS is the most accurate and relevant for observing and verifying different types of swan-group patterns in this field, as well as physics.

Author contributions

H.H.Z. collected data and processed data, A.A.Z checked the research and wrote the paper, F.Y.Y. initiated the idea and wrote the paper.

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