Women and Innovation: The Missing Link

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Abstract

Ethnic and gender diversity is purported to be critical for innovation success, yet scant empirical evidence exists to support this claim. Surveys of executive perceptions, simulations under controlled conditions and field research through proxy metrics point to a positive relationship between diversity and innovation but suffer from significant limitations. The paucity of data-driven studies on the linkage between diversity and innovation is due to the fact that innovators are almost invisible in innovation research, in sharp contrast to entrepreneurs who figure prominently in entrepreneurship studies. The objective of this paper is to examine the issue of gender in innovation through an analysis of patent application data from geographical regions with intense innovative activity. (The issue of ethnicity is difficult to approach with publicly available data.) Patent application data are a direct -although not fully complete- metric of innovation output as they (mostly) capture technological innovations. A comprehensive analysis of the 31 top innovation hotspots in the US reveals that the percentage of women innovators is weakly correlated with the total patent output of innovation hotspots. While the correlation does not appear to be statistically significant, further equivalency tests suggests that the admittedly small effect is not negligible. The results of this exploratory study thus set the stage for a more comprehensive one that will have to be designed with a richer set of data.

Keywords
Diversity, Innovation, Gender, Patents.

1. Introduction
The process of innovation evolves through several phases, such as identifying opportunities, screening ideas, testing concepts, developing products and services, and finally bringing them to the marketplace. The ever-present pressure to accelerate time-to-market means that there is always phase-overlapping in the innovation process and cross-functional teams must always work in tandem. The complexity of the information flows involved as well as the diversity of knowledge represented in the creative teams, requires sophisticated management skills (Anderson et al., 2014). Indeed, value creation in new product and service development is almost exclusively based on the effective management of knowledge and of the social dynamics of the innovative teams (Mueller-Seeger 2015; Tsakalerou 2016).

The study of creativity and innovation has occupied a broad spectrum of experts across the fields of behavioral science, human cognition, and organizational behavior. In recent years, diversity has emerged as a factor of interest in the innovation process (Massaro et al. 2015). After years of incentives and targeted initiatives to increase diversity in organizations, there is some empirical evidence from a range of industries around the world that diversity produces better outcomes. Specifically, it appears that the financial performance of firms with greater gender and ethnic diversity in their corporate leadership significantly exceeds that of their respective national industry medians (Hunt et al. 2015).

While there is a broad agreement that diversity improves financial performance, there are very few papers in the literature examining the link between diversity and innovation performance. An early experiment in a controlled setting demonstrated that a problem-solving team with members randomly selected from a diverse population of intelligent agents outperforms a team comprised of the best-performing agents (Hong & Page 2004). A later simulation in a controlled setting demonstrated that while there is little correlation between a group's collective

intelligence and the IQs of its individual members, if a group includes more women, then its collective intelligence rises (Woolley & Malone 2011).

Furthermore, a survey of executives at large multinationals revealed that most of them believe that there is strong linkage between talent diversity and innovation (Forbes Insights 2011). It is unclear whether these beliefs were expressed because of the need for political correctness or whether there was available data to back such beliefs. The lack of diversity perspective in innovation studies is explained to some extent by the fact that for most empirical studies and surveys the individuals involved in the innovation process are invisible (Belghiti-Mahut et al. 2016).

As innovation challenges have become more complex requiring scientific knowledge and methods from different fields, collaborative research has become increasingly more important. The emphasis on research conducted by more than one individual in an interdependent fashion has led to the concept of team science and focused research on the group dynamics of scientific teams working towards a common objective (Hall et al. 2018; National Research Council 2015).

This, in turn, generated empirical research on the impact of gender on innovation activities related to software development (Ortu et al. 2017), small businesses (Zastempowski & Cyfert 2021), and academic entrepreneurship (Mickey & Smith-Doerr 2022). Ethnicity, on the other hand, has received scant attention since it is difficult to assess with publicly available data. There is anyway little fact-based research on women's entrepreneurship and on the female perspectives and practices in innovation. A better understanding of women success factors, its distinctive features and constraints remains a priority.

1.1 Objectives

In this context, the motivation of this paper is to contribute to the research on gender and innovation via a data-informed assessment. The originality of the research described herein lies in its use of patent application data as a proxy for measuring innovation productivity. The research question of this exploratory study is to determine whether gender diversity in innovation teams has a measurable effect on innovative output and to examine the presence of possible moderating factors.

The paper is organized as follows. In Section 2, a review of the issue of women in innovation is presented through relevant data from around the world. In Section 3, the concept of innovation hotspots is articulated, and the methodology followed is outlined. In Section 4, a complete gendered analysis is performed to address the issue at hand. Finally, in Section 5 the conclusions of the current research are presented along with the limitations of the approach followed as well as suggestions for future research.

2. Literature Review

Women represent half of the world's population and, therefore, also half of its potential. Gender equality, besides being a fundamental human right, is essential to achieve full human potential. Gender equality in science is a key tenet of the 2030 Agenda for Sustainable Development of the United Nations. Despite global efforts over the past 15 years to inspire and engage women in science, the gender gap was painfully present -only one in three researchers worldwide are women (UNESCO 2019).

The World Intellectual Property Organization (WIPO) estimated that far more men than women gain patents for their inventions. While there has been considerable improvement over the years (with the percentage of female patent holders rising from 17% in 1995 to 29% in 2015), gender parity is a few decades away (WIPO 2018).

Long-standing biases, gender stereotypes and work conditions are steering girls and women away from science related fields at various stages of their life. Increasing the proportion of women in science and technology tertiary education does not necessarily translate into a greater presence in research. Indeed, while the number of women enrolling in university and studying science is increasing, many opt out at the highest levels required for a research career. Female students are actively pursuing bachelor's and master's degrees, but their numbers drop off abruptly at the PhD level. And, increasingly, women are more prone to abandon a research career than men. Numerous studies have found that women in in science and technology fields publish less, are paid less for their research, and do not progress as far as men in their careers. This "leaky pipeline phenomenon" is being actively discussed in public fora and has generated numerous calls for action (Fara 2018; Tsakalerou et al. 2022).

A wide range of arguments on the connection of gender and innovation have been articulated within theoretical frameworks, with resultant policy recommendations to increase competitiveness via gender diversity (Danilda & Thorslund 2011). These arguments support six fundamental themes on the positive impact of gender diversity to innovation performance:

Additional ability to recruit experienced employees;
Improved decision making at all organizational levels;
Enhanced creativity;
Facilitation of user-driven design innovation; and
Better image shaping in the marketplace.

While these arguments are certainly plausible and there is sufficient empirical evidence in their support, they are all indirectly related (if at all) to improved innovation performance. The paucity of data-driven studies on the linkage between diversity and innovation is due to the fact that innovators are almost invisible in innovation research, in sharp contrast to entrepreneurs who figure prominently in entrepreneurship studies.

Recently, the European Commission issued a report with statistics and indicators regarding gender in research and innovation (European Commission 2021). The report sought to integrate the gender dimension in the research context and analyzed gender differences in patent output. It identified that between 2015-2018 women were significantly under-represented among inventors at the European level, holding just one inventorship for every 10 inventorships held by men. While this broad trend disguises underlying variations and disparities at the regional or country level, it served as the inspiration point to design the present exploratory study.

3. Methods

Innovative activities tend to be concentrated in geographical areas linked to a city or a set of neighboring cities (Dutta & Lanvin (WIPO 2013). Global innovation hotspots are identified through their intense patent filing activities. While patent data offer rich information on the localization of innovation, they provide only an incomplete and imperfect perspective as they (mostly) capture technological innovations omitting sectors of the economy where patents are not necessary or useful (Tsakalerou   2018). With these caveats in mind, the World Intellectual Property Organization (WIPO) introduced a coherent methodology to identify innovation hotspots around the based on their patent activity and showcased it as a special section in its Global Innovation Index 2017 report (Dutta et al. (WIPO 2017).

The methodology is based on patent application data of the Patent Cooperation Treaty (PCT) which account for more than 98 percent of patent filings worldwide. PCT data are considered high quality because they are collected based on uniform filing standards. Seeking an international PCT patent is a costly and lengthy process, to be followed only when there is reasonable expectation of sufficiently high return. Thus, PCT data are more likely to capture the most commercially valuable inventions. On the downside, not all international patent applications go through the PCT system, and not every PCT application will eventually result in a granted patent.

The PCT data collected are processed with the Density-Based Spatial Clustering of Application of Noise (DBSCAN) algorithm with the baseline density parameters of 13km (radius) and 2,000 (minimum number of data points), corresponding to a density of approximately 5 listed inventors per square kilometer, a relatively high-density threshold. The WIPO 2017 report identified the top 100 innovation hotspots around the world representing 23 countries and accounting for 60% of all PCT filings during the 2011-2015 period (Table 1).
Data from the WIPO 2017 report are used in this paper because they include the share of women inventors among all inventors located in a particular hotspot. (Subsequent editions of the annual WIPO report omit this very important information.) For each hotspot, the following pieces of information are included:

the total number of PCT filings;
the largest applicant (in terms of its share of the total PCT filings);
the main field of technology (in terms of its share of the total PCT filings);
the share of total PCT filings attributed to all public research organizations; and
the share of women inventors.

The report is thus unique in that it introduces the gender perspective, which is often ignored in innovation studies. (Although, inexplicably, this perspective is missing from later annual reports.) Attributing gender to inventors is dictionary-based and deemed effective for more than 90% of listed inventors, with the remaining 10% being case where inventor gender could not be determined. The share of women inventors is calculated based on listed inventors, so inventors listed in multiple applications are counted multiple times. As can be seen from Table 1, women inventors account for fewer than one-third of all inventors across all top innovation hotspots.

It is apparent that innovation output around the world is concentrated in very few economies possessing the requisite skills, knowledge, and market acumen to capitalize on emerging technologies (Akhmadi & Tsakalerou 2022). This global innovation divide increases the gap between developed and developing economies. Even within this group of 23 intensely innovative countries, there are discernible differences in their innovation intensity and output.

Table 1. Top innovation hotspots worldwide

COUNTRY	Innovation hotspots	Total hotspot PCT applications	Average share of women inventors (%)
China	7	67,911	29.1
Korea	4	42,249	26.5
Malaysia	1	1,049	25.5
Spain	2	3,799	25.5
Singapore	1	2,996	23.0
France	5	19,525	18.4
Belgium	1	1,994	17.6
Denmark	1	2,613	17.2
United Kingdom	3	9,666	15.9
Italy	1	1,909	15.6
USA	31	157,068	14.7
India	3	4,497	14.7
Switzerland	3	7,999	14.6
Canada	4	7,140	14.6
Finland	1	3,045	14.0
Australia	2	4,179	13.9
Russia	1	1,915	13.8
Israel	2	6,957	13.2
Austria	1	1,403	12.7
Netherlands	3	10,520	12.3
Sweden	3	8,409	10.4
Germany	12	52,261	9.2
Japan	8	139,804	7.9

According to WIPO data, female participation in the IP system has been improving, albeit slowly, over the recent decades (Cutura, 2019). The improvement is seen in all technical fields, although at different rates and across most countries, with Asian ones consistently emerging at the top. Interestingly, standard economic indicators such as GDP per capita do not explain the gender gap in women inventors with many middle-income countries, such as Malaysia, outperforming by an almost 2 to 1 factor high-income ones, such as Japan, Germany, or Sweden (Lefeuvre et al. 2018).

The participation of women in the IP system varies across technological fields, with women more likely to apply for patents in biotechnology, pharmaceuticals and food engineering (with over 55% of all applications having at least one woman inventor) and less likely to apply for patents in related to engineering, construction or transport (with less than 17% of all applications having at least one woman inventor). While this differentiation may explain, in part, regional and national differences it has been theorized that the innovation divide is cultural, in the sense that perceptions about innovation affect innovation performance innovation (Ocampo-Wilches et al. 2020). For instance, a societal culture that induces fear of consequences has been shown to be detrimental to innovation (Clark 2020).

The view that perceptions about innovation differ substantially due to societal norms has been somewhat challenged for EU countries but does remain a distinct issue (Akhmadi & Tsakalerou 2022). Thus, in the sequence, the focus is on the 31 top innovation hotspots of the US to control for cultural factors in the illumination of the gender perspective in innovation.

4. Data Collection

Table 2 tabulates the information for the top 31 innovation hotspots in the US. Each hotspot is named according to the city or a metropolitan area it is associated with and ranked according to its total PCT filings identified in the WIPO 2017 report. For each hotspot, the record includes the total number of PCT filings, the share of women inventors (WI), and the total population (POP) of the geographical area identified by the DBSCAN algorithm (and not of the city or metropolitan area the hotspot is named after).

Table 2. Top innovation hotspots in the US (adapted from WIPO 2017)

Rank	Innovation Hotspot	Total filings PCT	Women inventors WI (%)	Area population POP
1	San Jose–San Francisco, CA	34,324	15.0	6,056,626
2	San Diego, CA	16,908	16.9	3,552,659
3	Boston–Cambridge, MA	13,819	17.4	4,029,151
4	New York, NY	12,215	20.0	15,539,937
5	Houston, TX	9,825	11.6	5,227,899
6	Seattle, WA	8,396	13.2	2,315,154
7	Chicago, IL	7,789	13.1	5,777,498
8	Los Angeles, CA	5,027	15.0	11,851,722
9	Minneapolis, MN	4,422	12.1	2,545,762
10	Portland, OR	4,146	14.0	2,073,296
11	Irvine, CA	3,965	12.7	866,871
12	Philadelphia, PA	3,172	19.6	4,023,359
13	Plano, TX	3,147	11.9	3,763,640
14	Raleigh–Durham, NC	2,775	15.7	1,554,250
15	Washington, DC	2,491	19.4	3,369,256
16	Cincinnati, OH	2,481	14.6	1,776,679
17	Atlanta, GA	2,162	19.0	2,529,174
18	Austin, TX	2,089	9.2	1,492,160
19	Wilmington, DL	2,046	15.5	70,644
20	Indianapolis, IN	1,596	16.0	1,982,531
21	Hartford, CT	1,540	9.7	1,240,483
22	Rochester, NY	1,414	15.4	816,263
23	Phoenix, AZ	1,378	13.0	2,707,525
24	Cleveland, OH	1,346	11.2	1,385,879
25	Boulder, CO	1,319	14.4	2,806,543
26	Salt Lake City, UT	1,293	10.8	1,638,476
27	Ann Arbor, MI	1,289	14.1	620,199
28	Pittsburgh, PA	1,283	14.0	1,399,419
29	Albany, NY	1,184	13.0	749,001
30	St. Louis, MO	1,138	17.4	1,422,096
31	Baltimore, MD	1,089	20.7	2,861,888

5. Results and Discussion

The primary objective of this paper is to measure the effect of gender diversity, as measured by the share of women inventors (WI) on the innovation productivity of a given innovation hotspot, as measured by its total number of patent filings (PCT), while controlling for the possible moderating effect of the total population of a hotspot's area (POP).

5.1 Numerical Results

All the analysis was performed with the open statistical software package *jamovi* (Jamovi n.d.). Table 3 introduces the descriptive statistics of the variables. Patents from top US innovation hotspots list, on average, 14.7% of women

inventors with the range extending from 9.2% to 20.7%. For comparisons purposes, the US Patent and Trademark Office (USPTO) estimated the number of patents with at least one woman inventor for the same time period at 20% - for the entire US not just hotspots.

Table 3. Descriptive statistics of the variables

Statistics	PCT	WI (%)	POP
Minimum	1,089	9.2	70,644
Maximum	34,324	20.7	15,539,937
Mean	5,067	14.7	3,004,007
Standard deviation	6,803	3.0	3,419,395
Shapiro-Wilk W	0.607	0.972	0.752
Shapiro-Wilk p	<0.001	0.570	<0.001

The Shapiro-Wilk test indicates that there is no significant departure from normality for WI ($p > 0.05$). PCT and POP on the other hand fail the normality test with 95% confidence that the corresponding data do not fit the normal distribution. The box plots in Figure 1 indicate that the distributions of PCT and POP have 5 and 2 outliers respectively while WI has none.
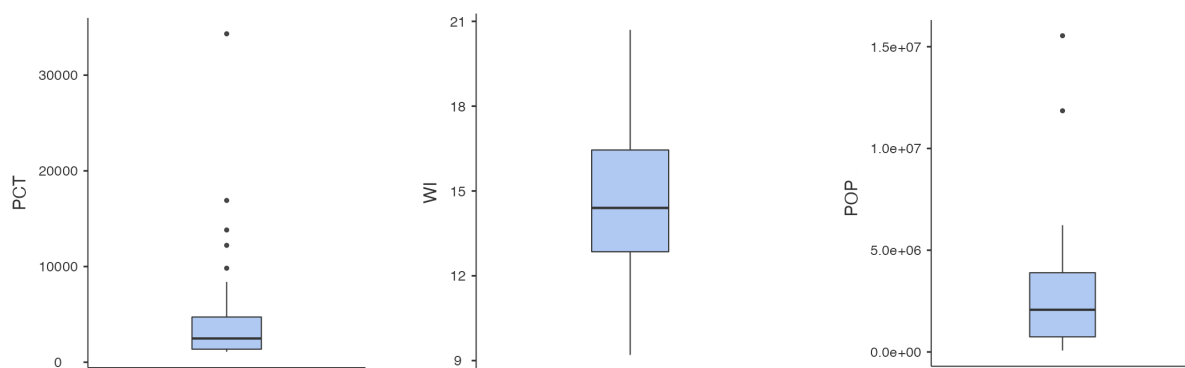

Figure 1. Boxplots of PCT, WI and POP

An outlier in one distribution may not be an outlier in a multivariate one. Computing the Mahalanobis distance can help identify such multivariate outliers. In the present case, the hotspots of San Jose–San Francisco, New York and Los Angeles emerged as potential outliers. Additional testing revealed that removing these outliers was not significantly affecting the outcomes of the analysis and the decision was taken to keep the potential outliers in the mix.

The correlation matrix in Table 4 reveals that there is a statistically significant correlation between the population in a hotspot area and the total patent productivity of the hotspot, a somewhat intuitive outcome. On the other hand, there is a weak positive correlation between the % of women inventors and the total patent productivity of a hotspot. This correlation however does not appear to be statistically significant.

Table 4. Correlation Matrix

		PCT	**WI**
WI	Pearson's r	0.134	
	p-value	0.472	
POP	Pearson's r	0.447*	0.346
	p-value	0.012	0.057

Note. * p < .05, ** p < .01, *** p < .001

The value of statistically insignificant results in socio-econometric studies has led to numerous debates and discussions (Lakens et al. 2018; Mehler et al. 2019). It is the authors firm belief that non-significant results are just as important as significant ones and should be duly reported to avoid contributing to underreporting bias. In fact, the absence of statistical significance does not necessarily imply the absence of the effect in a question. It may also indicate that the data are inconclusive either way or that the dataset employed is underpowered to confirm the effect observed.

5.2 Graphical Results

Flexplots have emerged as formula-based visual aids for statistical procedures such as correlation. Instead of the traditional approach where one simply needs to determine whether the p-value is below the 0.05 threshold, they provide a rich visual tapestry that allows for a more nuanced interpretation of the results obtained. Flexplots leverage the capacity of the human visual processing system to interpret vast amounts of data in a split second and help mitigate human biases (Fife 2021).

The most common form of flexplots is the scatterplot of bivariate relationships. The flexplots in Figure 2 describe the relationship between PCT and POP and PCT and WI respectively. They place pairs of the variables at hand on 2D graphs, fit the *Loess line* (to highlight the deviation from linearity) and shade the confidence band around it.
The graphical interpretation reveals the patterns which were not evident from the correlation coefficients in Table 4. For instance, the PCT filings are practically directly proportional to the population among the hotspots of less than 8 million. Two remaining instances may repeatedly raise the issue of possible outliers, however, as it has been discussed in the previous section and the omission of the outliers from the analysis does not materially change the outcome of the whole study.

Similarly, although PCT-WI relationship was failed to be captured by correlation analysis due to lack of linearity, the corresponding flexplot reveals the presence of the effect in question and leave an open question for further investigation.
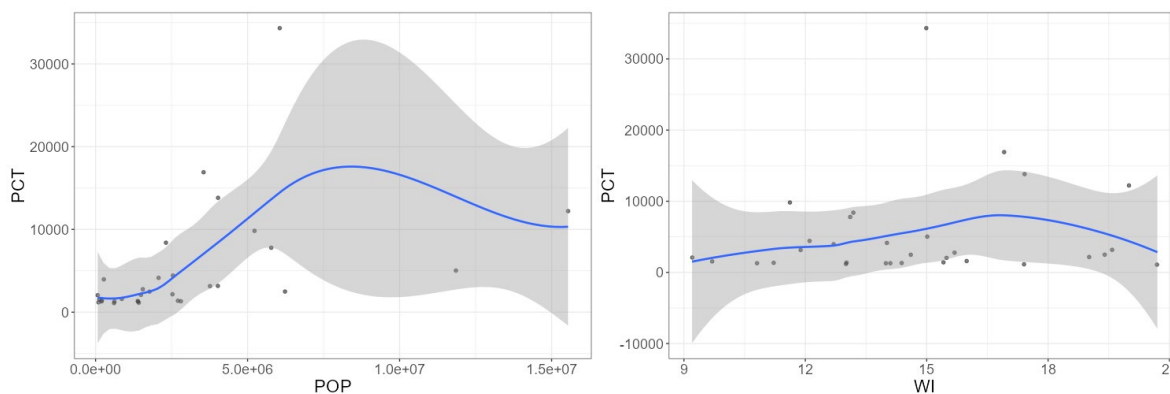

Figure 2. PCT vs POP and PCT vs WI

5.3 Proposed Improvements

The ambiguity of the non-significant result obtained maybe ameliorated by performing an equivalence test (Lakens et al., 2018). The test *cannot* verify that there is no effect, but it can reveal whether such an effect, if it exists, is likely to be of negligible practical significance. In this context, two one-sided tests (TOST) are performed to further investigate the weak correlation between WI and PCT.

To decide whether the effect can be neglected or not one sets the equivalence bounds based on the smallest effect size of interest (SESOI). Then, if the effect of the given sample is smaller than SESOI it is considered as equivalent to zero. The smallest effect size is obtained from the power analysis of the sample, which includes 31 observations in this case. Table 5 presents the correlation coefficients and their significance from the TOST analysis.

Table 5. TOST Correlation

			r	p
PCT	**WI**	Pearson's r	0.134	0.472
		TOST Upper	0.134	0.178
		TOST Lower	0.134	0.009

Apart from the Pearson's correlation already calculated in Table 4, it includes two tests across the upper and lower equivalence bounds. As a result of the first one, the correlation of WI-PCT is significantly higher than the lower band (*p=0.009*), whereas the correlation from the second test is not significantly lower than the upper bound (*p=0.178*). It means that one cannot reject the PCT-WI correlation at least at one of the extremes (Lakens et al. 2018).

This outcome motivates further study of the issue with the proposed improvements targeting the increase of the size of the sample to empower its interpretive power.

6. Conclusion

Innovative businesses thrive by anticipating market trends and needs and responding in fashion with improved products or brand-new ones that meet and exceed customer expectations. Creating business growth through innovation is considered the most important business challenge today. In fact, in modern manufacturing intangible assets like inventions, designs and specialist knowledge are worth nearly twice as much as tangible assets such as raw materials (WIPO 2018).

Putting together an innovation team is the most challenging job for an organization, but one that is often conducted in an ad hoc manner. Individual innovator profiling is still a puzzling issue in innovation, but gender diversity is certainly a desirable team characteristic. Yet women inventors are strongly under-represented in almost every country around the world.

Recent research has focused on the challenges facing women in the IP system (Cutura 2019) and the policy interventions needed to close the gender gap (Brant et al. 2019). The consensus in the literature is that the underrepresentation of women in the IP system is due to reasons such as the lack of access to financial and knowledge resources; the lack of understanding of the value of IP rights; the limited exposure to female inventor role models; and the broad discriminatory socio-cultural norms and expectations. Further, the limited availability of gender-sensitive data in innovation, limits the ability of policy makers to develop and implement data-driven initiatives. In addition, the limited availability of sex-disaggregated data and other gender-sensitive indicators hampers the ability of policy makers and IP practitioners to better understand the breadth and depth of the IP gender gap.

The exploratory study in this paper is an attempt to help in this direction. The results demonstrate that adding a gender perspective to the innovation milieu is directly related to innovation performance as measured by patent applications. The quite modest effect observed requires further study with an expanded dataset.

There are two caveats in interpreting the results of this paper. First, the analysis concentrated on the innovation hotspots of the US, and the outcomes might be varied in different countries and cultures. Second, the use of patent filings as a proxy of innovation performance does not capture innovative activities that lead to journal publications and not necessarily patents (Shah, 2019).

Acknowledgements

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