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Title: The Cultural Evolution of Love in Literary History

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15 **Abstract:**

Since the late 19th century, cultural historians have noted that the importance of love has increased during the Medieval and Early Modern European period (a phenomenon that was once referred as the emergence of "courtly love"). However, more recent works have shown that a similar increase is also detectable in Chinese, Arabic, Persian, Indian and Japanese cultures. Why such a convergent evolution in very different cultures? Using qualitative and quantitative approaches, we leverage literary history and build a database of ancient literary fictions for 19 geographical areas and 77 historical periods covering 3800 years, from the Middle Bronze age to the Early Modern period. We first confirm that romantic elements have increased in Eurasian literary fictions over the last millennium, and that similar increases also occurred earlier, in Ancient Greece, Rome and Classical India. We then explore the ecological determinants of this increase. Consistent with hypotheses from cultural history and behavioral ecology, we show that a higher level of economic development is strongly associated with a greater incidence of love in narrative fictions (our proxy for the importance of love in a culture). To further test the causal role of economic development, we used a difference-in-difference method that exploits exogenous regional variations in economic development resulting from the adoption of the heavy plough in medieval Europe. Finally, we used probabilistic generative models to reconstruct the latent evolution of love and to assess the respective role of cultural diffusion and economic development.

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Main text

Introduction

5 Love is a central value of modern societies (1): finding 'true love' is one of the main goal of individuals (2), long-term relationships, and marriage in particular, are regarded as improper if both partners do not love each other (3) and love is everywhere in recreational arts, in movies, in books or in children anime (4). The gradual rise in the importance of love has been well documented in European history, and historian Lawrence Stone has described the rise of love as "perhaps the most important change in mentality to have occurred in the Early Modern period, indeed possibly in the last thousand years of Western History" (5)

10 In *Love and the Western World* (6), Denis de Rougemont famously showed that 'romantic love', the idea that love is central in human existence, emerged suddenly in 12th c. France. The *trobadors* in southern France, the *trouvères* in northern France, the *Minnesänger* in Germany, all celebrated a new intensity in love (the so-called *fin 'amor*, 'refined love' in Occitan), distinct from a sexual desire and short-term passion, and based on mutual attraction, emotional attachment, long-term commitment and the reordering of life priorities. In literature, dozens of love stories, from *Tristan and Iseult* to *Floris and Blanche-flour*, suddenly appeared at the turn of the 12th c. and enjoyed a tremendous success all over Western Europe (7).

20 However, more recent scholarship has shown that the emergence of romantic love is far from being a Western phenomenon. Historians of literature have described similar increase in the importance of love in the Arab world (8), in India (9), in Persia (10), in China (11) and in Japan (12). As historian of medieval Persian literature Julie Meisami writes: 'A number of important and mutually illuminating parallels exist between the appearance of romance, at nearly the same period, in the courtly literature of both East and West' (10).

25 What can explain the rise of love in history? How can we account for such a cultural convergence between Eurasian regions? Forty years ago, medieval historian Georges Duby hypothesized that economic development is key in explaining the rise of love in Western Europe (13). As he put it, the famous orchard of *The Romance of the Rose* 'would never have bloomed' without several centuries of 'forest clearing, draining and field opening'. In line with this idea, more recent data show that the flourishing of romantic literature during the Central Medieval period (1000 – 1300) corresponds to an unprecedented increase in population (19), urbanization (20), and GDP per capita (21, 22). But are economic development and romantic love also associated outside Western Europe? Is the relationship between economic development and romantic love really causal? Is it possible to rule out cultural diffusion?

30 Causal theories are notoriously difficult to test in history (14,15), due to both measurement and identification issues. In principle, it would be possible to measure romantic attachment in history using highly diverse materials, such as private letters, funerary monuments, public speeches (16–18). In many cases, however, it is not possible to build long homogeneous series of such documents. For instance, private letters and philosophical treatises on love are only available when sources are abundant and literacy is high. By contrast, literary fictions are ubiquitous in Eurasian history and have been studied extensively by historians of literature (although using literary works has also some limitations, see discussion below). Moreover, the content of romance novels (19–21), epic poems (22), and tragedies (23) have been shown to reflect human's interest for love, social relationships and social status. More generally, individual preferences in fictions have been shown to be correlated with individual personality traits (24–26).

40 Using literary fictions to measure the importance of love is difficult though, because different cultures, and different periods within the same cultural tradition, may use very different words to talk about love. Also, while individuals are very open about their feelings in some cultures, people do not talk openly about love

and attachment in other cultures (27). We overcome this issue by focusing on the plot and the narration. Romantic stories share similar plot devices (love at first sight, tragic separations, faithful love, suicide for love) that tap onto well-known psychological elements of love: idealization of the partner, emotional attachment, long-term commitment, reordering of life priorities (28–30). In other words, they are superstimuli artificially designed to trigger the human evolved interest in pair-bonding (31,32). For instance, the ancient Greek novels of the Early Roman Empire (1st-3rd century CE) such as *Leucippe and Clitophon*, *The Ephesian Tale* and *The Aethiopica* are characteristically romantic: 'A young couple in love, of extraordinary beauty, are plunged by hostile fate into various adventures and dangers, until, in the end, for the most part after a rather long separation, they are united in a stable, faithful love for a life that is henceforth unchangingly happy' (33,34). At the other end of Eurasia, the Chinese *caizi-jiaren* or scholar-beauty stories such as *The Story of the Western Wing* are also characteristically romantic: 'A *caizi-jiaren* romance is a romantic story about an idealized couple. Attracted by each other's physical and literary talent, the protagonists fall in love with each other at first sight. They manage to overcome all obstacles and marry each other at the end' (35).

The example of Greek novels and scholar-beauty stories demonstrates that narrative plots can function as a particularly convenient tool for studying the evolution of love in history. Many others examples of romantic works can be found in the world literature, from *Layla and Majnun* in Arabic to *Khosrow and Shirin* in Persian, from *Nala and Damayanti* in Sanskrit to *The Love Suicides at Sonezaki* in Japanese.

The second major difficulty in testing causal theories in history is the need to neutralize the role of different confounding factors (15). We overcome this difficulty in two ways. First, we exploit an exogenous source of variation in economic development that created as-good-as random differences in economic development. This technique shows that economic development had a causal impact on romantic love in medieval European history. Second, we model the evolution of love in history, and compare the explanatory power of economic development and cultural diffusion. This method shows that while Eurasian societies were in contact with each other, cultural diffusion played a minor role in explaining the concomitant rise of love.

Results

Study 1: Assessing the rise of love qualitatively

Since the early 19th c. there has been a strong academic interest in love in literary works, and the academic literature on the topic is immense. To leverage this academic literature, we first created the *Ancient Literary Fictions Values Survey*, a systematic survey of the academic literature on romantic fictions in literary history, supplemented with feedback from more than 40 experts from all cultural areas (see *Methods*). Literary traditions were selected a priori based on the amount of data available in literary history and matched with 19 geographical areas for which quantitative data in economic development is available (Figure 1). All together, these geographical areas account for 70% to 80% of the human population during the studied period (36).

Following the behavioral literature, we use stories that feature narrative elements associated with pair-bonding such as the idealization of the partner (e.g. love at first sight), emotional attachment (e.g. tragic separations), long-term commitment (vows of eternal fidelity), reordering of life priorities (i.e. suicide for love) (28,29). Following the literary tradition, we call these stories High in Romantic Love (HRL) to contrast them with stories where love is either absent or not associated with pair-bonding (e.g. sexual relationships, short-term passion), hence not romantic. We then use both a categorical method (i.e. presence or absence of HRL stories for each period, according to experts) and a comparative method (i.e. increase or decrease in the relative level of Romantic Love across periods, according to experts).

Using Western Europe's level of economic development at the time of the emergence of HRL stories, we dichotomized our sample into countries low in economic development (per capital GDP < \$700 or urbanization rate < 2%) and countries high in economic development. Our survey reveals that fictions are more likely to be present in countries high in economic development (Table S1) and that within each cultural area, an increase in economic development is associated with an increase in the relative importance of HRL stories (Table S2). For instance, fictions are much more romantic during the Hellenistic and Early Roman periods (300 BCE - 200 CE) than during the Archaic Greek period, during the Central Medieval German period (1000 - 1300) than during the Early Medieval German period (500 - 1000), during the Song, Yuan and Ming dynasties (960 - 1644) than during the Tang Dynasty (618 - 907), during the Edo period (1603 - 1868) in Japan than during the Kamakura and Muromachi periods (1185 - 1568). Conversely, when economic development decreases, fictions are less likely to be romantic. For instance, fictions are less romantic in the Late Roman period (284 - 476) than in the Early Roman period (27 BC - 284), both in Latin and Greek literatures.

To limit potential confounds, we compared stories within the same literary genre (i.e. tragedy, comedy and epic). Our analyses reveal that economic development is associated with an increase in the relative importance of love in literary genres both within and across literary traditions (Table S3). In Molière, Shakespeare and Lope de Vega's famous comedies, for instance, the feminine characters are much more active: they fall in love, communicate their feelings and take decision, making the plots much more symmetric and romantic. In the same way and in contrast with their antique models, most early modern tragedies incorporate a romantic love story between two of the main characters, even when romantic love is not at the center of the plot. Thus, despite its generic constraints (e.g., unity of time, genre and action, focus on political events and calamities), the tragic genre eventually gave rise to very romantic stories. Similar observations can be made about Hellenistic, Roman and Early Modern epics, compared to their Archaic models (*The Iliad*, *The Odyssey*) (37). Again, in case of economic regressions, the converse phenomenon is observable: medieval plays, both in Greek (the Byzantine *Christos paschon*) and Latin (the French 'elegiac comedies', Hrotsvitha's comedies), are less romantic than their antique models (38).

Another potential confound is that a literary period may appear more romantic simply because it produced more fictions, which would mechanically increase the number of love stories, and the intensity of the most romantic ones. One way to circumvent this problem is to compare how the same story line (e.g. the *Trojan War*, the *Aeneid*, the *Alexander Romance*, the *Song of Roland*) is reworked in different periods. This allows comparing periods for which the number of narrative fictions is limited (e.g. Hellenistic world, Central Medieval Wales). Such cultural 'transmission chains' (39) have been shown to reveal cognitive biases in music (40), urban legends (41), or medical systems (42).

We leverage the large literature on literary transmissions in literary history (27,37,43,44). The study of literary transmission chains shows that the same story line becomes more romantic when economic development increases (Table S4). For instance, when the French medieval writer Benoit de Sainte-Maure wrote *The Romance of Troy* (c. 1155), he inserted in the old narrative a new love story of his invention. In the same way, in their rewritings of Sophocles' tragedy *Oedipus Rex*, Corneille and Dryden (17th c.) added a love story as a subplot: between Theseus and Dirce in Corneille's case, and between Adrastus and Eurydice (Oedipus' daughter) in Dryden's (45). The same pattern occurred many times: in Ovid's rewriting of the Greek mythology, in Molière rewriting of Plautus, in Boiardo's epics *Orlando Innmoroto*, a rewriting of the *Song of Roland*, in Early Modern English rewriting of Irish Celtic legends, in *Joruri Monogatari*, a romantic rewriting of the famous military epic *The Tale of Heike* and in Wang Shifu's play *The Story of the Western Wing*, a rewriting of the Tang tale, *The Biography of Yingying*. (This phenomenon is not limited to the pre-modern literature: Hollywood's renderings of the *Iliad* (e.g. *Troy* starring Brad Pitt) give much greater room to the love stories than the Ancient Greek original.) Strikingly, similar rewritings in the other direction, from a more economically developed society to a less economically developed one, display a decrease in romantic love. This is the case for the transmission of the story of *Tristan and Iseult* from

Western Europe to Iceland and Russia (Figure 2) (46), the story of *Ywain* from France to Wales (47) and the *Romance of Troy* from France to Byzantium (48).

Study 2: Assessing the rise of love quantitatively

While the *Ancient Literary Fictions Values Survey* closely reflects the state of the scientific literature in history of literature, it suffers from several limitations. First, each period is given equal weight in the analysis, although not all periods resulted in the same level of literary production (narrative fiction is very rare for some periods) and were not subject to the same level of academic scrutiny. Second, the qualitative approach considerably limits the power of statistical tools. To overcome these limitations, we created the *Ancient Literary Fictions Database*, a corpus of Wikipedia pages, summarizing, commenting and referencing the history of literature publications for 2995 ancient narratives works (predictions, methods and analyses were preregistered at <https://osf.io/ud35x>).

We computed the occurrence of words associated with love in Wikipedia entries using two measures of the intensity of love: 'General Love', based on the frequency of the word 'love', and 'Strong Love', a more conservative measure, based on the presence or absence of n-gram associated with high level of pair-bonding (e.g. 'fall in love,' 'love each other,' 'star cross'). The association between love and economic development is visible, confirming the qualitative observations of historians. There is a first increase during the Greco-Roman Antiquity, a decline at the end of the Antiquity, except in India and the Arab world which are striving during the early Medieval period, and a second increase starting in the Central Medieval period and continuing in the Early Modern period (see Figure 3).

In line with our hypothesis, we find a strong correlation between economic development and the occurrence of words referring to love (t-test between Density at time t and region of production of works with vs. without words referring to romantic love; $t(2917) = 13.03$, two-sided p-value = 9.10^{-38} , Cohen's $d=0.55$, c.i. [0.47-0.64]) (see Figure 4 and S2). We performed a regression analysis (generalized linear model, or GLM) with the romantic content of each work as the predicted variable, and one of five different proxies of economic development as a regressor. Those five proxies were: GDP per capita, urbanization rate, population density, energy capture, and size of the largest city. In each of these five models, we added two control regressors: the number of words in the summary (to control for the amount of information available for each work), and the year in which the work was created.

Weights for all five regressors of interest were significant at $p < 0.05$ after Bonferroni-Holm correction in all four types of analyses (two-sided tests; see Fig. 5, Fig. S2 and Tables S5-8): all five proxies of affluence positively predicted the romantic content of the contemporary works in the dataset. The only exception was the weight of energy capture with the general love index in the automatic and manual datasets). The odds for a book to be romantic increases by 16.3% (for GDP per capita) to 45.6% (for Density) when one proxy increases by one standard deviation. Importantly, we replicated the same analyses with more restricted datasets controlling for the region and the genre ('Non-Western works only', 'Plays only', see Fig. 5), as well as with all the transmission chains identified in our sample (see Fig. S7).

We also tested alternative theories to economic development. According to the political development hypothesis (or the "courtly hypothesis"), notably put forward by Norbert Elias (49,50), romantic love is a natural product of societies where the State becomes more powerful and individuals must repress violence and coercion. In such societies, individuals are more likely to value relationships based on mutual consent and mutual attraction. To test this hypothesis, two extra regressors were added to the main model: state population and state size (pre-registered). These regressors had no significant impact on the romantic content of the produced works (both two-sided p-values $> .168$; p-values obtained by a bootstrap procedure see Fig. S4 and Table S11).

Another approach points toward the role of religion, notably in medieval Europe, the Persian, Arabic and Indian worlds (6,8–10). We tested the association with World religions (Christianity, Islam, Buddhism, Hinduism). We found that two affluence proxies (Density and Urbanization rate) were still positively and significantly associated with romantic productions after adding this control regressor (Density: two-sided $p < .001$, $\beta = 0.39$, 95% c.i. [0.27-0.52]; Urbanization rate: two-sided $p < .001$, two-sided, $\beta = 0.25$, 95% c.i. [0.15-0.34]; p-values obtained by a bootstrap procedure; Figure S7). Regression results also showed that works produced in a country with a World religion were less likely have to romantic content (two-sided $p < .001$, two-sided, $\beta = -1.24$, 95% c.i. [-1.84 - -0.70]; p-value obtained by a bootstrap procedure). This result is in line with the Ancient Literary Fictions Values Survey (Study 1). Most Greek love stories (e.g. Callirhoe, Leucippe and Clitophon, *The Ephesian Tale*) appeared before Christianity became the official religion of the Roman Empire. In fact, the first love stories appeared during the 1st century (with Chariton's *Callirhoe*) and companionate marriage started to increase during the late Roman Republic (1st c. BCE), that is before the rise of Christianity (17,50). In the same way, in medieval Europe, most of the romantic stories (*Tristan and Iseult*, *Floris and Blancheflour*, *Chretien of Troy's stories*, etc.) appeared during the 12th and 13th centuries, that is seven centuries after Christianity became the official religion in Western Europe.

Study 3. The causal impact of economic development on love

Although Studies 1 and 2 demonstrate an association between economic development and human preferences, they do not show that economic development *caused* the change in human preferences. An alternative explanation for this relationship is that an unobserved characteristic influenced both economic development and romantic love (omitted factors bias), or that romantic love caused economic development (reverse causality). To properly assess the causal role of prosperity, Study 3 relies on a natural experiment, a standard method in econometrics. This method seeks to approximate the experimental method by focusing only on exogenous variations in regional development, i.e. variations that were caused by a factor that does not have any direct impact on human preferences except through its impact on economic development.

Since the work of Marc Bloch (51) and Lynn White (52), it has been argued that the invention and widespread adoption of the heavy plough facilitated the exploitation of soils, stimulating agricultural productivity and food production, disproportionately in regions with a high concentration of clay soils (Fig. 6). In a recent paper, Andersen et al. (53) tested this idea in a difference-in-difference set-up by exploiting regional variations in the presence of fertile clay soils. Their estimation suggests that the heavy plough accounts for almost than 15% of the increase in urbanization in the Central Middle Age in Europe. Importantly, this finding provides an exogenous income shock among European countries: countries with a high prevalence of clay soils benefitted from the heavy plough much more than the other countries.

Following Andersen et al. (53), we use a difference-in-difference type strategy to test the impact of the introduction of the heavy plow on population density in Medieval European countries. Our instrument exploits two sources of variation: time variation arising from the adoption of the heavy plow (i.e. prevalence of clay soil) on the one hand, and cross-sectional variation arising from differences in regional suitability for adopting the heavy plow on the other hand. Since the breakthrough of the heavy plow was around AD 1000 (27), our instrument is equal to 0 in centuries before 1000, and to the proportion of land suitable for the heavy plow times time elapsed since 1000 after 1000.

Therefore, our identification strategy exploits changes in economic development, as measured by population density, in the post-adoption period relative to the pre-adoption period between countries that were able to benefit from the heavy plough and countries that were not. It relies on the assumption that differences in soil composition have no direct impact on the evolution of love except through their impact on economic development. Since country fixed effects work as included instruments, we exploit only changes in economic development in the post-adoption period relative to the pre-adoption period, which

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neutralizes possible spurious correlation between soil suitability to the heavy plough and time-invariant country-specific psychological and cultural traits. Hence, differential changes in economic development resulting from differential suitability to the heavy plough can be interpreted as exogenous.

5 The first stage estimated equation is:

$$Density_{it} = \beta PlowFraction_i \times T_t^{post} + \theta_i + \theta_t + \epsilon_{it} \quad (1)$$

10 In the equation, t denotes time, i denotes country, $Density_{it}$ is population density (the proxy for economic development that was the most impacted by the heavy plough), and $PlowFraction_i \times T_t^{post}$ measures the interaction between the share of heavy-plow-suitable area in country i (see Table S19) and time elapsed since 1000. The variable $PlowFraction_i$ is equal to the fraction of land in country i with both a clay soil and a suitability index for growing barley $SI \geq 55$. The remaining variables include country fixed effects θ_i and century fixed effects θ_t . The error term is denoted ϵ_{it} .

15 The first-stage estimates show that coefficients for the instrument are positive and highly significant ($t(39)=7.10$, two-sided $p < 0.001$, $\beta = 17.35$, 95% c.i. = [12.37 – 22.24], standardized effect size = 0.30, see Table S23), suggesting that the more suitable the land to benefitting from the heavy plough and the further in time from 1000, the denser the population, even after neutralizing the country invariant characteristics and the century common trends. First-stage F-statistic (Cragg-Donald F-stat) is high (42.9) so the instrument is not weak and produces consistent estimates.

20 The second-stage estimates are reported in column (5) of Table 1. The estimates of the impact of population density on the incidence of love in fiction are positive but did not reach conventional levels of statistical significance ($z=1.79$, two-sided $p = .073$, $b = 0.03$, 95% c.i. = [-0.002 - 0.054], standardized effect size = 1.24). These magnitudes are substantially larger than the magnitudes of the OLS estimates. This is not surprising, because the measurement error in the population density estimates are expected to bias the OLS estimates downward. Overall, the IV results confirm the positive relationship between population density and the rise of love in human preferences. The effect size is 1.24 standard deviations, which means that a one standard deviation increase in population density caused a 1.24 standard deviation increase in the incidence of love in narrative fictions. These results also suggest that the OLS estimates may be a lower bound estimate of the strength of the impact of economic development on romantic love.

25 Study 4. Cultural diffusion versus economic development

35 Overall, studies 1-3 suggest that economic development is an important factor in the endogenous emergence of romantic love. This conclusion contrasts with a widespread hypothesis in literary studies according to which the rise of romantic literature often results from cultural diffusion from other societies. For instance, medieval courtly love has notably been seen as a consequence of the contact with the Arabic courtly culture or the rediscovery of the Roman and Greek literature. In the same way, it has been hypothesized that the love story between Tristan and Iseult has its origins in an unknown Irish or Welsh tale or in the Persian story of *Vis o Rāmin* (54,55). However, our results suggest that the romantic plot of *Tristan and Iseult* is more likely the product of economic development. Like archaic Celtic fictions the original Tristan story was probably not romantic, and was infused with romantic elements around the 12th c. to respond to the growing demand for romantic stories in most affluent parts of Western Europe (56).

45 Our results also strike at the heart of the notion of ‘national cultures’, that is long-term cultural identities faithfully transmitted generation after generation. In our study, national literary cultures vary significantly across periods, and oscillate between romantic and non-romantic values. Greek, the lengthiest literary culture of our sample, started as non-romantic during the Archaic period, became more romantic during the

Classical and Roman periods, then switched back to lower levels of love during the early medieval period and finally developed a new romantic culture during the central Middle Age and the early modern period. To take a very different example, the Russian culture quickly developed a highly romantic literary tradition during its economic take-off in the 18th c., despite a long tradition of non-romantic works. This suggests that the transmission of earlier works (i.e. tales, epics) is less important in explaining the 18th c. level of love than the ecology of 18th c. Russia (i.e. higher economic development).

While Studies 1-3 identified economic development as a key environmental factor influencing the evolution of cultural love, Study 4 takes a wider perspective and interrogates how other factors such as cultural diffusion from other societies and inheritance from previous generations ('national cultures') shaped romantic love. Specifically, Study 4 aims at testing the respective role of the economic development, the social diffusion (of norms, values and preferences) and the transmission from previous generations in explaining the cultural evolution of romantic love. To use a standard contrast in evolutionary human sciences, we compared the explanatory power of *evoked* culture (here, economic development) and *transmitted* culture (here, the level of love in adjacent societies and in the previous generation) (57,58). To do so, we use a latent probabilistic model (Figure 5a) (59) which describes the evolution of a latent cultural trait (here, romantic love) in a set of interconnected regions. The cultural trait is modelled as a stochastic dynamical process $T_r(t)$ (r is the index of the region and t is time). It evolves in each region based on the time-dependent value of an ecological factor $E_r(t)$, here economic development (evoked component), the level of love in neighboring regions (horizontally transmitted component) as well as in previous generation (vertically transmitted component):

$$\frac{dT_r}{dt} = \lambda E_r(t) + \xi \sum_s G_{rs} T_s(t) - \rho T_r(t) + \gamma + \eta(t) \quad (2)$$

G is the matrix of between-region connectivity (see Figure 7a and Fig. S9), and $\eta_r(t)$ is a white noise process. The second term in the right hand side of Equation 2 represents the diffusion of the cultural trait which is proportional to the cultural connectivity between regions, thus creating spatial correlation in the cultural trait. The main parameters of the model include λ (degree of influence of the ecological factor on cultural trait), ξ (degree of diffusion), ρ (degree of lability) and γ (default tendency of the cultural trait). The ecological factor is a composite measure that averages three z-scored proxies for economic development: Population Density, Urbanization rate and per capita GDP (data for other proxies were too limited geographically). The outcome variable is the romantic content of each literary work in the database, which is determined by the value of the romantic trait $T_r(t)$ at the date and location of production. The model parameters θ are fitted using Expectation-Maximization (EM) to maximally predict the degree of love in each produced work, based on the value of the cultural trait in the region and time it is produced. The EM algorithm also allows to reconstruct the trajectory of the cultural trait in each region $p(\mathbf{T}|\theta, \mathbf{E}, \mathbf{A})$.

Compared to the values given in Study 2, this trajectory of romantic love (Figure 3B) is a considerable improvement because it is adjusted to the number of works produced in each data point, and it is constrained by the dynamics of trait evolution given by equation (2). Estimated trajectories are in line with qualitative assessment in cultural history revealed by Study 1, with notable increases during the Roman period in Greece (34), the Abbasid Caliphate in the Arabic countries (8), the Heian period in Japan (12), the central medieval (6,7) and early modern periods in France and England (60). In each case, this corresponds to periods of high economic development. By contrast, the level of romantic love appears to be lower in the least developed European areas (Wales, Ireland, Norway, Russia and to some extent Byzantium). Finally, in line with the growing concern for love reported by cultural historians (61) the convergence of Eurasian societies can be observed at the end of the time frame. France, England, Japan, India and China: all experience an increase in romantic love.

Our analyses show that both economic development and transmitted culture contribute significantly to the model (Figure 7C; bootstrapping test on parameters λ and ξ , two-sided $p < 0.001$; p-values obtained by a bootstrap procedure; see Table S25). We further tested the relative influence of the economic development and cultural diffusion by comparing the full model to reduced models: 1) without economic development (*cultural diffusion only*: i.e. enforcing $\lambda = 0$); 2) without transmitted culture (*economic development only*: enforcing $\xi = 0$); 3) without either economic development or cultural diffusion (*control model*: $\lambda = \xi = 0$). This comparison showed that the contribution of economic development is much larger than that of cultural diffusion: unlike removing evoked component, removing cultural diffusion as a drive to the evolution of love has little influence on how well the model accounted for which works in the corpus were romantic (Figure 7D; see also SI for further results). Introducing a constant term in the connectivity matrix G representing global cultural diffusion through e.g. the Silk Roads did not impact the results (Figure S9). In conclusion, a latent model approach showed that economic development has a much stronger influence than horizontal transmission on the evolution of romantic love.

Discussion

In *Love and Marriage in the Middle Ages* (12), Duby put forward the idea that the flourishing of romantic love is the product of economic development. In this article, we put this conjecture to the test. Combining literary history, cultural evolution, causal methods and model-based analysis, we demonstrate that the economic development in ancient societies contributed to the increase in the importance of romantic love. This result is in line with classical works in anthropology demonstrating a difference between horticulturalist and pastoralist societies where love is culturally marginal, and societies with intensive agriculture where love can have a more importance place (62,63).

One important question remained to be asked: Why such a rise in romantic preferences in response to economic development? One possibility is that economic development liberates people from the constraints of family ties, allowing people to find their own mates, often choosing them because of love rather than the economic and strategic considerations that come into play when marriages are arranged. Economic development and freedom in marriage would thus increase the cultural importance of love. However, it must be noted that what we are measuring here are not actual behaviors (i.e., marriage for love), but people's preferences for love. In fact, up until the 18th c, arranged marriage remained the norm in most Eurasian societies, including Europe (3). Thus, the freedom to marry for love and the preference for love do not always go together. For instance, as historian of Chinese literature Patrick Hanan notes, social control over romantic relationships was more important during the Ming dynasty (1368-1644) than during the Tang dynasty (618-907), and yet love stories from the Ming period are more romantic than those from the Tang period, not less (64).

Another way to explain the development of love comes from human behavioral ecology. Compared to other mammals, humans display a longer period of dependency which is made possible by a very high level of parental investment and the participation of both parents in providing resources to the children (65). In human behavioral ecology, love is thus seen as an emotional device facilitating the establishment and the maintenance of 'pair-bonding' that is necessary to provide the massive investment required to rear children (28). In line with this idea, parental investment and romantic investment have been shown to vary hand in hand in contemporary populations: across societies, when parental investment is high, romantic investment and emotional attachment is also higher (66,67). We reviewed the literature in cultural history. When the data are available (Greece, Rome, Europe, China, Japan), a higher importance of love in literary narratives is always associated with more positive attitudes toward children in the society (50) (see Table S25).

Why thus the increase in love? Human parental investment is very plastic, and varies according to the level of resources. When people's resources increase, parents tend to invest more resources, more time, and more attention in their children (68). This is consistent with the observation that, in history, attitudes toward

children tend to be more positive when economic development is higher (69,70) (see Table S26). In light of this literature, it is thus possible that the growing importance of romantic love in Eurasian literature results from a phenotypic change in both parental investment and romantic investment in response to better living conditions (71).

This finding directly speaks to the role of religion in shaping marriage norms. A common view in social history is that the progressive condemnation of polygamy and the sacralization of marriage was due to the activity of the medieval Church (13,72). However, our results suggest that this shift toward committed monogamy and sexual fidelity corresponded to the preference of the population. In fact, during the European medieval period, many stories like *Erec and Enide* celebrate fidelity and self-control. Medieval authors even made a parallel with the monastic life and noted that lovers, just as monks and nuns, need to discipline their sexual appetites and their selfishness in order to be faithful to their lovers and respect them. More generally, the conception of love in the medieval literature is that it is spiritual rather than physical, that is long-term rather than short-term: "For the troubairitz and troubadours, the idea of sexual desire as an appetite was utterly inadequate for describing all the things that lovers felt for each other" (73). These observations suggest that the new conception of marriage that emerged in medieval Europe was in line with people's preferences and may not have been imposed by the Church (74,75). In fact, it is possible that people's preferences have caused religious doctrine to evolve. For instance, in Antiquity, very romantic novels (i.e. *Daphnis and Chloe*), celebrating monogamy, chastity before marriage and eternal fidelity, appeared just before the rise of Christianity (see Table S1). In this perspective, technological change and economic development would have first changed individual preferences, which in turn would have changed the content of religious norms (76,77).

Beyond the case of love and marriage, our results suggest that adaptive responses to ecological changes can provide a new way to study historical changes in human societies (77,78). Recent works in behavioral sciences have indeed demonstrated that higher level of resources are associated with a cluster of preferences, which includes a higher attention given to romantic love and parental care, but also a higher attention to health, a higher level of trust, a higher preferences for exploration and a lower level of impulsivity and materialism (79,80). In line with this idea, sociologists have observed a shift from "survival values" to "self-expression values" in Western and non-Western societies alike in response to economic development during the 20th and 21st centuries (77). In more ancient history, this behavioral framework could explain the clusters of cultural changes observed in times of economic development, such as the concomitant rise of romantic love, parental care, charitable religions and ascetic movements observed in medieval Europe at the turn of the 12th c. (6,13) or in the Mediterranean in the late Republic and early Roman Empire (17,50). This could also explain why, across very distant societies in Eurasia (China, Japan, Western Europe), historians observe similar cultural evolutions in association with economic development (puritanical morality, romantic love, parental care) (76,81). Future works should test more systematically whether these clusters fit with the predictions of behavioral sciences, and evolve in line with economic development. Such an interaction between behavioral sciences, economic history and cultural history could thus opens new way to explain cultural changes in the *longue durée*.

Limitations regarding the methodology

The present work assumes that literary works reflect the preferences of the people who read them. Is this a valid assumption? Here is what Georges Duby wrote on medieval love stories:

The poets who wrote on the Tristan theme sought to please: their patron, first, and their public, second. They thus all made great efforts to present, through the character of Iseult, an image of womanhood that fit with the fantasies of the courtiers. There is no doubt that they were able to strike a chord: if they had not, what would be left of their work? There was every chance that those verses that, each time he went to present the work, the interpreter drew from his memory—those

words flying from mouth to mouth—would be lost. The fact that we are still able to read them now means that they were indeed found pleasing, and that the story they tell enthralled the hearers. (82)

5 Duby's formulation ("those words flying from mouth to mouth") is very close to modern understandings of cultural transmission, in which cultural items are transmitted only if they fit with people's psychology (83,84). In this perspective, the story of Tristan and Iseult was transmitted and enjoyed enormous success in the 12th and 13th centuries because it fit with people's preferences for romantic stories. If it had not matched people's preferences, it would have disappeared quickly (which it did eventually, when a new generation of fictions more in line with the new norm of monogamy eventually appeared in the 14th and 10 15th centuries). This was also Duby's hypothesis: 'That is why the telling of this adventure allows us to reconstruct, with less uncertainty than by other means, an image that is very difficult to perceive: that of womanhood and love toward 1170-1180, at the forefront of social sophistication, in the Anglo-Norman courts.'(82) Cultural artefacts thus present the remnants of people's past psychologies. In other words, they can function as *cognitive fossils* of extinct mentalities and preferences.

15 To validate further this assumption, we systematically compared the attitudes regarding romantic love expressed in literary works according to literary historians with the attitudes regarding romantic according to cultural historians. Importantly, cultural historians use a larger variety of sources to study romantic love: letters, philosophical books, laws and so on. We thus searched academic works devoted to the 20 cultural importance of romantic love in cultural history. While the literature on romantic love in cultural history is large, many works do not properly distinguish between specific historical periods. For instance, one can find academic work on 'romantic love in Ancient Greece' that, in fact, merge historical periods as different as Archaic Greece and Roman Greece. Moreover, such works usually focus on the period that produced the most documents (the Classical period in the case of Greece) and neglect the less developed 25 periods.

We found 26 historical periods for which romantic love had been the object of a specific academic study. This led to 13 cases of comparison. In all cases, the academic publications in literary history and the 30 academic publications in cultural history were in agreement (see Table S24). In Rome, for instance, a range of cues indeed suggests that love became a more important value between the late Republic and the early Empire: tomb inscriptions celebrating conjugal happiness, letters from exile lamenting the absence of the loved spouse (from Cicero, Ovid, Pliny), debates in the Senate revealing the emotional bounds between spouses in aristocratic circles, philosophical treatises emphasizing the role of love in marriage (Plutarch's *Conjugal Precepts*, Musonius Rufus), biographies of exemplary women, etc. (17) In China, 35 the cultural importance of romantic love also increased between the Tang and the Song, although scholarship is more limited. This increase is notably visible through women's private poetry, literary biographies of courtesans, as well as through funerary texts concerning women who start celebrating not only their fidelity, but also their emotional commitment to their lover (through voluntary seclusion, illness, even suicide) (85). The full details and the academic references used for these comparisons are 40 available in a sister project, the *Ancient World Values Survey*.

In the same way, we systematically compared the attitudes toward love in literary works of a given society with the consensus in cultural history regarding the attitudes toward children in the same society (See Table S25). This later comparison provides another way to test the external validity of literary 45 works. From a behavioral perspective, attitudes toward romantic love and children should have the same dynamics (i.e. attitudes toward children should be more positive in societies where attitudes toward romantic love are more positive) (28,66,86). Thus, the presence of romantic stories should be associated with culture-specific cues of the importance of childhood.

50 We searched academic works devoted to the cultural importance of romantic love in history. Again, while the literature on the history of childhood in cultural history is large, many works do not properly

distinguish between specific historical periods. In the end, we identified 10 cases of comparison. Of these 10 cases of comparison, the academic publications in literary history on romantic love and the academic publications on the attitudes toward children in cultural history were in agreement (see Table S25). In Rome, for instance, while there are very few inscriptions, no funerary monuments and almost no art dedicated to children during the Republic, children start being represented during the Augustan period and the frequency of children representation culminate under the Antonines, in the 2nd c. CE (18,87,88). Similarly, in China, the corpus of writings commemorating a child's death began to grow steadily, from about 800 CE onward at the time where the first romantic stories start to be written (89). This up-ward trend goes on during the Ming and culminates during the Qing dynasties. The full details and the academic references used for these comparisons are available in the *Ancient World Values Survey*.

One final issue is that unlike in modern societies (24,25), people's preferences may not be adequately reflected in fictional literature because of artistic norms or social pressure. A common view in literary history is that some literary traditions' focus on certain topics (e.g., politics and war for tragedy), or their stylistic requirements (e.g., unity of place, time and action for classical plays), hinder the flourishing of love stories. For instance, Phyllis Gaffney explains this problem in her study of old French narratives:

Genres shape content (...). If the generic convention requires heroic combat, young protagonists displaying brute strength in battle will be celebrated; if, on the other hand, the conventions require a protagonist to fall in love, then young characters have to be taken to a plausible stage of maturity (emotional, cognitive and psychological as well as biological) appropriate for romantic entanglements. (90)

One problem with this view is the assumption that generic constraints are exogenous—in other words, that they are imposed on authors and their audience by some external force, rather than chosen by them. However, it is probably the other way around, that is writers choose the genre that best fits their purpose: if they want 'romantic entanglements', they turn to romances, and adopt some of their conventions, while if they want 'heroic combats', they turn to epics, and their conventions. In 12th-century France, for instance, when love and marriage came to be much more culturally valued (something historians know from other kind of documents), a new generation of writers such as Chrétien de Troyes gave up on *chansons de geste* and turned to new genres (verse romance, prose romance) because the latter were more suited to telling the kind of stories their audience wanted.

Generic constraints are more flexible than is often thought, as shown by the evolution of the tragedy. Originally, tragedy was a highly codified genre (e.g., unity of time, genre and action) with a focus on political events and calamities. However, transposed into early modern Europe, it eventually gave rise to very romantic stories. For instance, in adapting the plot of ancient tragedies (Euripides' *Hippolytus*, Seneca's *Phaedra*) to create his *Phèdre*, Racine added a love story between Hippolytus and Aricie, a character who does not exist in Euripides' *Hippolytus* or Seneca's *Phaedra*. Similarly, in their rewritings of Sophocles' *Oedipus Rex*, Corneille and Dryden added a love story as a subplot: between Theseus and Dircé in Corneille's case, and between Adrastus and Eurydice (Oedipus' daughter) in Dryden's.

To take yet another example, if Sophocles had wanted to put greater emphasis on the love story between Antigone and Haemon in his *Antigone*, he could very well have done so, withing the very genre of tragedy. He could have chosen to focus the audience's attention on the separation of the two lovers, just as Shakespeare did with his *Romeo and Juliet*. On the contrary, he chose to focus his tragedy on moral issues and family relationships (Creon carrying his son's body, Eurydice, Creon's wife, killing herself and cursing him, etc.). Sophocles' focus on moral issues rather than on romantic love is probably not the result of generic constraints specific to the tragedy, but the consequence of his audience's preferences for stories about moral values and family solidarity. As a matter of fact, a few decades later, a new genre of tragedies emerged that was more similar to modern drama. Euripides' *Helen*, for instance, is centered on

the personal, intimate relationship between Helen and Menelaus. In this new genre, romantic feelings came to have a more important role, despite the apparent constraint of classical plays (91–93). In line with this evolution, Euripides' new version of *Antigone* also placed a much greater emphasis on love.

5 More generally, love stories are present in all kinds of literary genres, from novels (*Leucippe and Clitophon*, *Rodanthe and Dosikles*) to drama (*Romeo and Juliet*, *The Story of the Western Wing*) to short stories (*Pyramus and Thisbe*, *The Biography of Yingying*) and long poems (*Tristan and Isold*, *Khosrow and Shirin*). This demonstrates that the demand for romantic stories can flourish in all sorts of literary genres.

10 Another factor that could prevent the use of love stories as a cross-cultural indicator of investment in romantic attachment is social constraints. Again, one common view is that some social norms, such as sexual segregation, female modesty, and condemnation of premarital sex hinder the expression of love stories in literary narratives. However, this does not seem to be the case, as shown by the evolution of ancient comedy during Antiquity. In Greek and Roman comedy, citizen girls could not appear on stage and it was not appropriate for them to express their opinion on marriage (94). One consequence could have been the limitation of love feelings in plays. Yet this social norm did not prevent Roman authors from portraying young female citizens in love. One way to represent women's desire was to tell a story with a woman of lesser status, a slave, a courtesan, or a stranger who was not subject to the same social norms. This artifice allowed writers to let female characters express their feelings, as in Terence's *Heauton Timorumenos* (Act II, Sc. 3) or Plautus' *Cistellaria* (Act I, Sc. 1) (95). Obviously, this made marriage (and the happy ending) impossible if it was not discovered conveniently that the girl was a citizen after all, the kidnapped or lost or exposed daughter of the rich family next door. In the end, despite the constraints of the Roman comedy, a handful of comedies managed to tell typical love stories in which a girl and a boy, both young, beautiful and respectable, meet and fall in love, face and overcome some obstacles to their love, and are finally reunited (95).

20 More generally, it must be noted that most of the stories used in this study were written in societies where females' freedom was severely limited, and contact between young people often impossible (96–98). In *Falling in Love: Stories from Ming China* (99), Patrick Hanan notes that in *Romeo and Juliet*, the two lovers are able to meet, chat and (in some versions) dance with each other. This would have been impossible in Ming China: "A Chinese Romeo was unlikely to be able to see Juliet, let alone to serenade her." Yet despite social norms making it impossible for young lovers to meet and live out their love stories in real life, love stories abound in the literature of the Ming dynasty, demonstrating that social norms do not prevent romantic literature from flourishing. In fact, norms were looser during the Tang dynasty than during the Ming dynasty (11,100,101). Yet Tang love stories were less romantic, not more, than Ming love stories.

40 Limitations regarding the data

45 It must be noted that our work has several limitations regarding the data. First, our study is based on a limited set of works, especially, from the older periods (for which available texts are probably less representative of mentalities than in more recent periods). We dealt with this issue in two ways. First, we controlled for the number of works per period in Studies 2-4. In regressions (Study 2) and in the diffusion model (Study 4), we notably used bootstrapping to assess the significance of each parameter. This technique relies on comparing parameter estimates from control parameter estimates with shuffled versions of the dataset, and thus inherently controls for the inhomogeneity of the dataset. Second, we systematically reviewed the scholarly literature in literary history and cultural history, area by area, and period by period (see *Ancient Literary Fictions Values Survey*). This review shows the same effect of economic development on love, both in literary history and in cultural history. However, future studies should aim at extending the

number of literary works, especially for the early modern period where extant literary works are more important (102).

5 Second, our proxies for economic development have limitations, especially for the most ancient periods for which we only have very coarse indicators such as population density, size of the largest city and energy capture (103,104). As a robustness check, we carried independent analyses on a smaller sample of countries (Roman Empire, Europe, China, Japan, the Arab world) for which data on GDP and urbanization are more recent and of better quality. Also, our qualitative survey (Study 1), which is based on pairwise comparisons between two periods, shows the same result.

10 Third, our study necessarily reflects the preferences of the most affluent parts of the population. As Wace wrote in the *Roman de Rou* (12th century): “Books are made for the powerful people who own the rents and money.”(105) Our study thus reflects the psychological evolution of the elite population. The psychology of the middle and the lower classes of the populations remains beyond the scope of our data. Folk tales and songs, although they are more difficult to date, might offer a way to access to the preferences of non-elite classes (106).

15 Similarly, we do not know exactly who were the elite audience who produced and consumed the literary works studied here. Thus, it is possible that the evolution we observe does not result solely from a change in preference but also from a change in readership. This alternative explanation has been put forward in particular to explain the emergence of ancient Greek romance. A number of scholars suggested that the rise of ancient novels, in which love is central, could be the result of a rise of the female readership in the increasingly educated upper classes of the Roman Empire (107). This alternative explanation is not incompatible with our own results, and it could be the case that economic development is associated with a change in people's preferences and an increase in female readership. However, the scholarly consensus is that although this might be possible in principle, so far “there is little positive evidence in favor of the ‘female readership’ hypothesis” (108). Moreover, the study of more recent periods for which more data are available does not seem to support the idea that the success of romantic works can be explained solely by the rise of a female readership. For instance, males seem to have been well represented among the readers of Rousseau’s bestseller *La Nouvelle Héloïse* (1761) (109). Obviously, more studies are needed to rule out this alternative explanation.

20 Another possibility is that the rise of romantic works results from the rise of a new male readership, more bourgeois and less sophisticated, and thus more likely to turn to the easy pleasures offered by romantic stories (106). This idea arose from the fact that the first historians of Greek novels, at the beginning of the 20th century, considered these works to be of a lower stylistic and intellectual quality than the works of the classical period. They concluded that the audience of Greek novels must naturally be less educated. Perry's "children and the poor in spirit" and "uneducated youth or naivety" are the most frequently cited examples. (106). However, recent years have seen a growing appreciation of the sophistication and wit of Longus, Achilles Tatius, and Heliodorus. As Hunter notes 'the novels anticipated an educated readership deeply familiar with the literary classics' and indeed 'the papyri on which fragments survive suggest expensive, high-status productions' (108).

25 In the same way, comedies were widely appreciated by the elite. Plutarch, for instance, expressed a predilection for Menander's comedies as entertainment that an intellectual can enjoy without shame:

30 What is the reason that really justifies a cultured man going to the theatre, if not the desire to hear Menander? Are there other occasions when we see the theatre filled with scholars when a comic character is staged? Just as painters, when they are tired of seeing, turn to the colours of flowers and meadows, philosophers and students rest from their sustained and constant efforts thanks to Menander, who allows their minds to find, so to speak, a flowery, shaded and breezy meadow (110)

Moreover, the study of more recent periods for which more data are available does not seem to support the idea that the success of romantic works can be explained solely by the rise of a female or bourgeois readership. For instance, the taste for romantic works in late 18th-century France seems to have been shared by all elites, whether bourgeois or aristocratic (111). Obviously, more data are needed to rule out these alternative explanations.

Methods

Inclusion criteria

All literary narrative fictions are included, whatever their genre: epics, romances, novels, comedies, farces, ballads, operas, ballets, etc.

This means that:

1) non-literary works are excluded. A story that is known to us only from reports of mythographers or from iconography with no detailed literary parallels is excluded (see (37) for a similar choice). This is due to the need to have the most homogeneous corpus.

2) non-narrative works, and in particular non-narrative poetic works, are excluded

3) non-fictional literary works are excluded: historiography, biographies, diaries, letters, travelogues, philosophical texts and religious books whose main purpose is doctrinal or historical.

The distinction between fictional and non-fictional is sometimes difficult to operate. Here is what Tim Whitmarsh (112) writes about ancient Greek narratives: 'The definition of 'fictional' is hard to draw with precision, particularly when it comes to the more imaginative end of the historiographical spectrum. Asking how 'historical' Herodotus is, for example, and how 'fictional', only betrays the limitations of those analytical categories'. (p. 15)

This issue is all the more important that the first Greek love stories arise in historical narrative such as Xenophon's *The Education of Cyrus* and Ctesias' *Persica*. The same problem arises for the medieval period. For instance, Monmouth's famous *Historia Regum Britanniae* is presented as work of history. Yet, even during the medieval period, some already considered it as a work of fiction. To limit bias in the analysis, we adopted a conservative approach and excluded all works whose intentions were non-fictional.

Delimitation of the sample: The sample was decided a priori based on the amount of data in literary history and economic history. For literary history, we used Wikipedia's entries, a good proxy of both the production of a literary tradition and the academic production of studies on this tradition (113–115). To be included in the study, a literary tradition had to have more than 10 narrative works with a proper page in Wikipedia. We used cultural traditions to select the most relevant geographical areas for which economic data are available (e.g. England for English literature, Eastern Mediterranean for Ancient Greek literature). We end up with 19 areas:

- **2000 BCE – 500 BCE:** Egypt (from Ancient Egyptian) and Mesopotamia (from Sumerian and Akkadian).

- **500 BCE – 500 CE:** Eastern Mediterranean (from Ancient Greek), Western Mediterranean (from Latin), India (from Sanskrit and Tamil), Central Asia (from Persian), China (from Chinese)

- **500 CE – 1800 CE:** England (from English), France (from French), Germany (from German), Italy (from Italian), Spain (from Spanish), Low Countries (from Dutch), Ireland (from Irish), Wales (from Welsh), Norse world (from Old Norse), Russian (from East Slavic), Japan (from Japanese), Arabic world (from Arabic), India (from Sanskrit and Tamil), Central Asia (from Persian), China (from Chinese)

In order to have comprehensive series, we then completed the series with additional literary traditions when needed (Persian in Early Modern India, Latin in Early Medieval France, etc.). This method is common practice in literary history. For instance, the authors of the *Handbook of Spanish Literature* write: 'As "Spain" did not exist as a political entity in the Middle Ages, we will have to understand the term "medieval Spanish literature" to be merely a useful shorthand for something like "the literature written in the medieval period in that geographical area corresponding, roughly, to the borders of the present-day Spanish state.'" (116). Such a definition means that a survey of Spanish literature will include 'a number of languages and literary traditions we identify today with names like Latin, Occitan, Catalan, Galician-Portuguese, and Aragonese, in addition to the Arabic, Hebrew, and Castilian.' (116).

The starting date of the project is based on the earliest available material, that is Egyptian and Sumerian narratives. The stopping date was set a priori at 1800. After 1800, the amount of literary production would require a different method. Also, after 1800, highly romantic love stories become increasingly frequent, making a comparative study more difficult.

Temporal and spatial level of analysis

The temporal and spatial level of analysis were decided based on the availability of economic data. Before the 19th c., it is impossible to go below the national level for most countries. The only exception is the Roman Empire where some estimates allow for distinguishing between the Western part and the Eastern part of the Empire, which corresponds to our Latin and Greek areas ((117,118).

To limit bias in data analysis, we use standard historical periods whenever possible, deferring to Wikipedia to label each period. In particular, we use the same temporal division for all European countries: Early Medieval period (500 – 1000), Central Medieval period (1000 - 1300), Late Medieval period (1300 – 1500) and Early Modern period (1500 – 1800). These temporal division do not always match the evolution of economic development. However, they allow for limiting the degrees of freedom in the analysis. In the end, the combination of the 19 geographical areas and their standard historical periods leads to 77 cases of observation.

Environmental variables

- Density

By default, we use McEvedy and Jones's *Historical Atlas of World Population* (119). Wherever possible, we updated the database with more modern data: for the Roman Empire (120), ancient Greece (121), Japan (122), China 400 BCE-1100 CE (119) and China 1100-1800 (123,124). For China, there is a problem of continuity in 1100 CE: both sources estimate large population growth during the Song dynasty, but they disagree on the start and end points. We considered having better estimates for recent periods more important, and followed McEvedy and Jones. Note that Deng (125) suggests that the Chinese population was much lower.

Density is computed by dividing the population by the area. However, modern areas are often at odds with the geographical boundaries of ancient societies. For instance, modern Egypt is much larger than the actual area of ancient Egypt. Using the area of modern Egypt to compute the density of ancient Egypt (and thus its development) would lead to a massive underestimation of density in ancient Egypt. To account for this problem, we computed density by dividing the population by the amount of arable land in modern countries, using the list provided by Wikipedia (https://en.wikipedia.org/wiki/Land_use_statistics_by_country).

- Urbanization

Only cities with over 10,000 inhabitants were included in the estimation of the urbanization rate. Urbanization rates were based on the information on urban populations, except when this information was not available, in which case we use estimated urbanization rates.

Western Europe: We used Bosker et al.'s (126) database (which is based on Bairoch's work; see (127)) for the period 800-1800. The period 500-800 was reconstructed using Chandler's database (128). Chandler's data are not as good as Bairoch's, but the margin of error is probably small considering that the urbanization rate of Western

Europe before 800 was so low that all the potential cities are well known (i.e., Rome, Paris, etc.). Bosker et al. do not give any data for Wales and Iceland. However, it is safe to assume that Iceland did not have any city with more than 10,000 residents before 1800, or Wales before 1500 (129,130).

5 Arab world: We used Bosker et al.'s (126) database (which is based on Bairoch's work: see (127)) for the period 800-1800. For 700, we used Chandler's database for the biggest city (i.e. Baghdad) and ased that the ratio between large cities and small cities was similar as in 800 CE to get the total urban population. For Muslim Spain, we also used Bosker's database (see their Excel file at http://www.cgeh.nl/sites/default/files/Bagdad_London.xls).

10 Roman Empire: Wilson's urbanization rate includes all cities of over 5,000 inhabitants (117). To obtain the urban population of cities over 10,000 inhabitants, we computed a new set of urban population estimates including only the cities over 10,000 in Wilson's dataset. For the small cities, usually between 5,000 and 25,000, for which Wilson only gives aggregate numbers (e.g., Italy: 375,000 people in cities with a population of between 5,000 and 25,000), we divided this number in half (so, for instance, $375,000/2 = 187,500$ for Italy).

15 To calculate the urban population before 150 CE, we assumed a constant growth of urban population from 300 BC onward (following 117), using Chandler's data about big cities in 200 BCE with updates from Morris (131). This is consistent with the recent work by Ligt on urbanization during the Republic (132). To calculate the urban population for the period after 150 CE, we extrapolated these estimates, assuming a constant decline from 150 CE to 700 CE (the low point of urbanization in the Mediterranean zone and Europe), although some work suggests that urbanization in the eastern part of the Roman Empire may have declined only from 300 onward (117).

20 Ancient Greece: For the period between 800 BCE and 300 CE, we use Ober's estimate of urbanization rate for 300 BCE to calculate Greece's urban population (121). Ober uses a threshold of 2,000 inhabitants, but provides a breakdown of this urbanization rate by city size, noting that cities with between 500 and 7,000 inhabitants accounted for 35% of the total urban population. We thus consider that the urban population in cities over 10,000 inhabitants must have been around 60% of Ober's urbanization rate.

25 For the period between 300 BCE and 200 CE, we extrapolated from Ober's estimate in 300 BCE and Wilson's estimate for 200 CE. This leads to a slow decline, in line with the decline in living standards proposed by Ober for this period (see Figure 4.3, p. 99).

30 China: Xu et al. (124) give urbanization ratios for cities with over 2,000 inhabitants. However, they suggest that, for inner China, the ratio of small cities (from 2,000 to 10,000) to big cities (more than 10,000) was about 7/12 in 1200 and 3/7 in 1776. We use an average ratio of 50% uniformly (which also corresponds to Rozman's estimate: (used by 133))-

35 Japan: Bassino et al. (134).

40 - Population of the largest city

By default, we used the same sources as for urban population. For the areas where there no detailed urban population data is available (India, Persia, Egypt, Mesopotamia), we used Chandler (128), completed by Morris (135) when possible.

45 - GDP per capita

50 England, France, the Netherlands, Belgium, Germany, Sweden, Portugal, Poland, Spain, Italy, China, India, Japan 1300 – 1800 CE: We used the most comprehensive and up-to-date database on GDP, produced by Broadberry and collaborators (for the most recent up-date, see 134). An estimate of France's GDP per capita estimate was published online during this project (136). Although it is not peer reviewed yet, we decided to use it rather than to rely on extrapolations based on neighboring countries.

55 Arab world: We used the estimate of Pamuk and Shatzmiller (137) for Lower Egypt (760-1450) and Southern Iraq (760-1220). We extrapolate a stable GDP per capita from 1220 to 1850 (Maddison project updated), in line with

Pamuk and Shatzmiller's observation that "real wages in Cairo around 1780s were not any higher than the peak levels attained during the fourteenth century."

5 Greek world (Classical Greece, Roman Greece and Byzantium): We rely on Ober's estimates (121), which are more accurate and more recent than those of Amemiya . Ober demonstrates that Greece's per capita productivity and wages in 300 BCE were on a par with Holland in 1650, at about 3 times subsistence level (i.e., \$1,200) (see Figure 4.3 p. 99). This value is consistent with very high level of urbanization in Greece at the time (24%, that is higher than any European country up to the 19th century). After the beginning of this study, we discovered that Milanovic (139) inferred a similar value (i.e. \$1,333) from Ober (121).

10 After the maximum period of prosperity (4th c. BCE), we relied on Ober again: core Greece went from \$1200 in 300 BCE to \$840 in 100 BCE. Economic development is stable during the early Roman period, before declining again from 200 CE: \$640 in 300 CE and \$560 in 400 CE. According to Obert, Greek economic development stayed between \$540 and \$720 until the 19th c. These estimations are in line with Milanovic's estimation for Byzantium in 1000 CE (139) and Foldvari et al.'s reconstruction of the early medieval period (140).

15 Ancient Rome: Goldsmith (141), Temin (142), Maddison (143), Milanovic, Williamson and Lindert (144), Scheidel and Friesen (145), Lo Cascio and Malanima (146) produced various estimates of Roman GDP. They range from a low estimate of around \$720 per person (145) to a high estimate of around \$1,500 (146). We used Scheidel and Frier's low estimate (\$720), which is more widely accepted (see, for instance, its use in Foldvari et al. (140), Milanovic (139) and the Maddison project).

20 Roman Italy is a special case here, as it was much more developed than the rest of the Empire (Egypt included) during the Augustan period (1st c. CE) (143). For the period 300 BCE – 0, we build on the work of Phillip Kay in his recent book *Rome's Economic Revolution* (2014). Kay concludes that the real per capita GDP of the Roman economy grew by 72% from 150 to 50 BC (147). This would mean that Roman Italy grew from a rather low level in 300 BC (\$550, Maddison 2007) to a very high level around 0 (\$1200). This is compatible with recent estimate or Roman urbanization during the same period (132). This very high estimate has been contested by the Maddison project on the ground that Italy's affluence does not reflect a high level of economic development, but rather its domination over the Mediterranean. In any case, given the relatively low level of romantic love in Roman tragedies and Roman novels, this probably plays against our main hypothesis (see Study 2, section Results 'Hypotheses 3 and 4').

25 For the period 0 – 1200 CE, we used the estimates produced by Foldvari et al. (140) and Milanovic (139) based Scheidel and Friesen's estimate, with an upward correction for Roman Italy.

30 Early European Middle Ages (500-1300): We used Foldvari et al.'s revision (140) of Milanovic (139) for England, Italy, and Spain. For Spain in 1300, there is disagreement between the estimates of Foldvari and Broadberry et al. (134). We chose the latter and extrapolated Spain's GDP per capita from 700 CE (Foldvari's value) and 1300 (Broadberry et al.'s value). For the Netherlands, Germany, and Belgium, we used England's value in 400 CE because of their similar position at the margins of the Roman Empire and extrapolate up to 1300. For France, we used Spain's value in 400, again based on their similar position in the Roman Empire. The result is compatible with Pamuk and Shatzmiller's comparison with the Arab world "Our calculations as well as the high rates of urbanization and manufacturing output suggest that around the year 1000 and possibly until a later date sometime in the eleventh century, real wages and incomes in the more prosperous regions of the Middle East were comparable if not higher than those in the more prosperous regions of Europe. After that date, however, the divergence between the Middle East and parts of Europe began to emerge." (137)

35 Ireland and Wales: Maddison provides an estimate for Ireland in 1500. We assumed that Ireland and Wales had similar levels of economic development at this time, that is 66% of England's per capita GDP according to Maddison). We used England as a benchmark and used this ratio (66%) to estimate Wales and Ireland's per capita GDP before 1500 (e.g. per capita GDP of Wales' in 1000 is 66% of per capita GDP of England in 1000). These results are consistent with independent works (129,130,148). We then extrapolate, assuming a continuous growth from 600 onward (as in the rest of Western Europe), starting with a GDP of \$400 (following Maddison's assumption that this the GDP per capita in a non-urbanized country).

Iceland: During the studied period, Iceland's rate of urbanization is 0, density remains very low, and population does not seem to have increased except in the very beginning of the colonization of Iceland. Given the low level of development of Norway (for which Maddison gives an estimate in 1500), we assumed that Iceland's GDP always remained close to subsistence level (\$400).

- Energy capture

We use Morris's estimates of energy capture whenever possible: for China, ancient Greece, the Roman Empire, the Arab world, and modern Europe (131).

- State size

Ancient Egypt, China, India, Roman Empire, Arab empires: For the largest states, we relied on Taagapera (149,150).

European states (500-1500): For European states, we relied on the EURATLAS database. State sizes were obtained using QGIS.

For all other areas, state sizes were estimated using the sizes of modern countries and modern provinces as a benchmark.

- State population

In a few cases (Russia, Prussia, France, Holy Empire, etc.), McEvedy and Jones (119) give an estimate of the state population. In the other cases, state population was obtained from McEvedy and Jones' demographic data. When a state covered only a fraction of a given modern country, we calculate an estimate of the state population based on the fraction of the modern country covered by the state.

- Number of locutors

The number of locutors was obtained from McEvedy and Jones' demographic data, except for India, for which there is no demographic data by linguistic area.

Methodology of Study 1

This study leverages the academic literature in literary history. The *Ancient Literary Fictions Values Survey* reviews the literary production of 77 standard historical periods in 19 geographical areas covering the major literary cultures of Eurasia.

We combine three strategies to find works where love is central. First, we searched Google Scholar for 'romantic love', 'love story', 'love' in association with terms related to the particular literary traditions involved in the study (e.g. 'Latin literature', 'Roman literature' 'literature in Rome'). This allows for finding works devoted to the study of love in a specific tradition (such as Konstan's *Sexual symmetry* on ancient Greek novels). Second, we searched Google Scholar and Amazon for *Companions, Handbooks* and General History books devoted to the specific literary traditions involved in the study (e.g. *Cambridge Companion to Greek Tragedy*). Within each book, we then systematically searched for 'romantic love', 'love story' and 'love. Finally, we contacted over 70 academics in cultural history and history of literature and we organized two workshops at the Ecole Normale Supérieure in Paris with academics in cultural history and history of literature.

In each case, when we found a story or a literary tradition that could be considered as high in romantic love, we looked up to the more specialized scholarship devoted to this particular story. Such a method certainly has drawbacks. In particular, it is possible that some romantic stories have been overlooked. However, the probability of false negatives (i.e. concluding that love stories are absent while they are present in reality) is very limited. The negative results correspond to poorer periods for which there is a limited number of literary works (e.g. Early Medieval Ireland, Archaic Greece, Central Medieval Russia). These works have therefore been particularly well studied and well documented. It is therefore unlikely that a romantic story will remain undetected.

We then test four hypotheses regarding the level of love in literary works, from the least stringent to the most stringent. All predictions were preregistered.

We encourage readers to download the *Ancient Literary Fictions Values Survey* and check by themselves the content of the survey. In any case, almost all the narrative works cited in Tables S1-4 are summarized and commented on Wikipedia, making it easy for fact-checking.

Categorical method (absence/presence of HRL stories): We started with Konstan's work on sexually symmetric stories as a benchmark for stories high in romantic love. A story is considered as HRL (i.e. High on Romantic Love) when it features narrative elements associated with pair-bonding:

- 1) idealization of the partner (e.g. love at first sight),
- 2) emotional attachment (e.g. tragic separations),
- 3) long-term commitment (e.g. vows of eternal fidelity),
- 4) reordering of life priorities (e.g. suicide),

and when these elements are displayed by both the male and the female characters (i.e. the story is symmetric, see Konstan 2014). Such a definition clearly includes the Ancient Greek novels, the Chinese *caizi-jiaren* stories, the Chivalric romances (e.g. *Tristan and Iseult*) as well as typical love stories such as *Layla and Majnun* in Arabic and *Shirin and Koshrow* in Persian.

We hypothesize that within the same literary tradition, stories High in Romantic Love should be more frequent in economically more developed periods. Because we used a binary category (absence or presence of HRL stories), we needed to decide on a threshold of economic development above which HRL stories should be more frequent. We used Western Europe as a benchmark because it is the best studied area in both literary history and economic history. With this method, and choosing 1100 CE for the emergence of romantic love stories in Western Europe, we get the following thresholds for 'High Economic Development':

- 1) \$700 in per capita GDP (134),
- 2) 3% in urbanization (126)
- 3) 20,000 kcal/cap/day energy capture (131)

Methodology of Study 2:

Using Wikipedia: In recent years, Wikipedia has become an essential scientific instrument in the study of cultural evolution and economics. Its size allows researchers to track the trajectories of millions of people in history (151,152) and the circulation of hundreds of thousands of artworks (153). In the study of literature, Wikipedia is by far the largest and the most documented database of academic studies of narrative fictions. Wikipedia provides information about hundreds of narratives that are either no longer extant, have not been translated into English, or have not been digitized, but that have been studied by specialized historians of literature.

Another advantage of using Wikipedia entries is that narrative texts (epic poems, plays, etc.) can differ widely from each other in terms of style or vocabulary, which makes comparison difficult. In this perspective, Wikipedia entries offer a way to compare very different works: all love stories, whether in the form of a tragedy or a short story, whether originally written in English or in some other language, are described with much the same words in Wikipedia entries.

Third, the creation of a database of narratives could have been easily biased by the goal of the study. Since there is no exhaustive database of fictions (except for certain periods, and certain genres, such as Classical French Plays and ancient Greek literature), it is easy to allocate more energy and time to gathering certain kind of narratives (e.g., operas) that are intuitively more likely to contain love stories. From this perspective, Wikipedia makes the inclusion criteria very clear and makes cherry-picking more difficult.

Fourth, Wikipedia diminishes other potential biases in the assembly of the database or in the summary of narratives as, unlike academic or traditional anthologies, Wikipedia summaries are usually written by a large number of contributors, who are more diverse in terms of culture and background. It is worth noting in passing that modern

readers may of course distort the plots of ancient fictions or project their modern views on love in these fictions. However, this should work against us, as this distortion should decrease the variability of narrative fictions. If we still find statistical differences, this means that they are probably pretty robust.

5 Finally, compared to the actual text, summaries have the advantage of having been already “coded” by human readers. For instance, it is well known that in ancient literature emotions are less frequently described, and that characters talk less openly about their feelings. As a consequence, love stories might be hard to detect using lexicographic techniques. By contrast, their presence in a summary is unambiguous.

10 *The database:* We included all narrative fictions—such as novels, romances, epic poems, epyllia, mimes, operas, ballets, masques, novellas, eclogues—as long as a summary of the content was available on Wikipedia. We thus excluded texts for which we only have the title (even if the title provides some idea of the content of the text).

15 If an article in Wikipedia covered several works, we created several items (e.g. *Epics of Gilgamesh*). If a work exists in several versions (e.g. *Tristan and Isolde*), we created an item for each version for which we had a summary. If an article is about a collection of stories, we created an item for each story to the extent that there was a summary for this story (e.g. *The Decameron*, *The Metamorphoses*). If the article does not include a summary, but point toward another article where the summary is, the summary was included (but only if this article refers to the specific work, and not to another work covering the same topic). This was the case for instance for well-

20 known stories of Antiquity such as the ones told in Ovid’s *Metamorphoses*.

Some decisions had to be taken regarding the boundaries of narrative texts in certain cases, such as short story collections (e.g., the *Decameron*) or inserted stories (*Histoire de Troilus et de Zellandine in Percefores* and *Cupid and Psyche in The Golden Ass*). We considered that a narrative was an independent story when its story line was unrelated to the rest of the work. Thus if the stories were connected, even loosely, to the same plot, they were considered to be part of the same story. The only exception is when it is explicitly said that the story was also independently transmitted. This was the case for instance of the : " Among the principal works and stories in the *Mahabharata* are the Bhagavad Gita, the story of Damayanti, an abbreviated version of the Ramayana, and the Rishyasringa, often considered as works in their own right.")

25 Wikipedia is organized by lists. We manually surveyed all lists related to the “History of Literature” in Wikipedia. This includes century-based lists such “Books by century,” “Writers by century,” and language-based lists such as “Old English Literature.”

35 In the case of some well-known stories (e.g., *Cinderella*), the summary is not included in the page for the work or the author, but on an independent page that usually presents several versions. When the entry of the author or the work links to this kind of “narrative page,” the summary on the latter was also included in our survey (as long as the narrative page gave a summary for each version).

40 In most cases, entries for a work have a summary or plot section. When there was no such section (for instance, because the work is described on the author’s page), we manually entered the summary into the database. When the same story was told by different authors, we only included versions for which we had an independent summary, or for which we had information about the similarities and differences with other versions. Summaries were recorded from September 2015 to December 2016.

45 When the date was approximate, we applied the following rules:

10th century = 950
Early 10th century = 910
50 Late 10th century = 990
First half of 10th century = 925
Second half of the 10th century = 975

55 When there were several conflicting dates, we tried to choose the most consensual. If not possible, we average the date. If there is not date for the work, but only a date for the author, we assumed that the work was created in the middle of the life of the author.

Genre (e.g. comedy/tragedy) was assigned when given in Wikipedia. In order to use information contained in the rest of the page, we also gathered the URL of the work (if the work had no entry, we used the URL for the author's page).

We thus had two datasets: a manually built dataset (N=2925) and an automatically built dataset (N=2484). The second is smaller than the first due to the fact that, in many cases, multiple works from the same author are summarized on the same page, which prevents an URL from matching for each of the works.

We recorded the country, the author and the date of creation of each narrative. When there was no country of creation (because the author was anonymous or its location unknown), we used the language of the work as an indication of the country. When there was no date for the work, but there were dates for the author, we assumed that the work was created in the middle of the author's life. In the absence of dates for either the work or the author, we put the date of the oldest known source of the narrative. When there were several conflicting dates, we chose the most consensual (based on citations in Wikipedia). If not possible, we averaged the dates.

Quantifying romantic love

We recorded the number of words in each summary, as well as in each entry. For the coding of romantic love, a preliminary survey suggested that the word "love" is relatively unambiguous in Wikipedia summaries, and that it is by far the most used word to describe a love story (compared to "amorous," "infatuated," etc.). Thus, we counted all occurrences of the word "love" in the summaries, and computed the frequency of its occurrence in each summary. Obviously, "love" is also used to sometimes describe non-romantic feelings (although this is much rarer in a summary than in a real text). We thus use more specifically romantic n-gram such as "in love," "star-crossed," "love story," "lovesick," "lovestruck," and "star-crossed."

We built two indexes with different levels of stringency in the criterion for inclusion of each word love pattern:

General Love refers to the count for words "love," "loves" and "loved," which is a moderately conservative measure for romantic content.

Strong love corresponds to the observation of any of the expressions "in love," "star-crossed," "love story," "lovesick," "lovestruck," and "star-crossed." Since this quantification is much more stringent, we reasoned that any work whose summary contains any of it has romantic content, so we used a binary observable (presence vs. absence of any of the pattern) rather than the phrase count, as used for "General Love."

Data availability statement

The data, as well as the *The Ancient Literary Fictions Values Survey* and the *Ancient World Values Survey (Romantic Love and Attitudes toward Children)*, are available on OSF (<https://osf.io/ud35x>).

Code availability statement

The code that supports the findings of this study is available on OSF (<https://osf.io/ud35x>). A detailed description of the model for Study 4 as well as matlab code to fit and run such models can be found on https://github.com/ahyafil/Evoked_Transmitted_Culture.

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Author contributions statement: N.B. conceived the project, supervised the creation of the *Ancient Literary Fictions Database* and wrote the *Ancient Literary Fictions Values Survey*. L.S. and A.H. designed the analyses for Study 1. L.S. designed the analyses for Study 2. E.H. designed the difference-in-difference for Study 3. A.H. designed the latent probabilistic generative models for Study 4. All authors wrote the paper.;

Competing interests statement: Authors declare no competing interests.

Tables:

	Dependent variable: Incidence of love in summaries of narrative fictions				
	(1)	(2)	(3)	(4)	(5)
	OLS	Random Effects	Fixed Effects	Country and Century Fixed Effects	2SLS
Explanatory variable: Population density					
Coefficient	0.016	0.017	0.020	0.019	0.026
Standard error	(0.004)	(0.005)	(0.007)	(0.013)	(0.014)
95% confidence interval	[0.007 ; 0.025]	[0.008 ; 0.026]	[0.007 ; 0.034]	[-0.007 ; 0.044]	[-0.002 ; 0.054]
P-value	0.001	0.000	0.005	0.149	0.073
Effect Size (σ)	0.790	0.808	0.967	0.896	1.237
<i>Additional control variables</i>					

Number of fictions	YES	YES	YES	YES	YES
Number of words in fictions' abstracts	YES	YES	YES	YES	YES
Country FE	NO	NO	YES	YES	YES
Century FE	NO	NO	NO	YES	YES
R-squared	0.260	0.260	0.252	0.490	0.486
Cragg-Donald F-stat	-	-	-	-	42.921
Mean dep. var.	0.261				
Observations	54				
Notes: All regressions include the number of fictions and the total number of words in fictions' summaries as control variables. In column (5), population density is instrumented by the fraction of land that is suitable for the heavy plow multiplied by the number of centuries after plow introduction in 1000 (Andersen 2016).					

Table 1 | The impact of the heavy plough on the importance of romantic love in European narrative fictions. In (1), we estimate an OLS model of love as a function of population density at the country-century level, including the number of novels and the number of words in the novels' abstracts in that country-century as control variables. In (2), we estimate a random effect model and find the same relationship between population density and love. In (3), we add the country fixed effects and find that the coefficient on population density remain positive and significant, and the magnitude of the estimated coefficient actually increases. In (4), we include both country and century fixed effects and find the same effect size, although the precision of the estimation decreases and the coefficient is barely significant. In (5), we use land suitability for the heavy plow*time elapsed since the introduction of the heavy plow as an instrument for population density, and find a significant and slightly larger impact of population density on love.

Figure Legends/Captions (for main text figures)

Figure 1 | Distribution of literary fictions. Size of white circles indicate the total number of literary works per area (The maps were created with Khartis 2.3).

Figure 2 | The cultural chain of the story of Tristan and Iseult. Blue arrows represent cultural transmission (each number refers to one work, see Figure S12 for details)

Figure 3 | Average distribution of the occurrence of words referring to love in Wikipedia entries across works per century. Error bars: standard error of the mean.

Figure 4 | Average distribution of the occurrence of words referring to love in Wikipedia entries by decile of density across region-century pairs (error bars: standard error of the mean).

Figure 5 | Regression weights for GLM analyses predicting romantic content of works from different proxies of economic development at the time and area the work was produced. Left panels indicate results obtained with the complete dataset. Upper left panel: weights when the predicted variable was the Strong Love index (binary variable, assessed from a logistic regression model). Bottom left panel: weights when the predicted variable was the General Love index (count variable, assessed from a Poisson GLM). Right panels indicate results obtained with a restricted dataset: non-western narratives only (top) and plays only (bottom). Bars indicate weights for the corresponding regressor of interest. Error bars represent standard errors for weights obtained from bootstrap procedure. P-values after correction for multiple comparison in top-left panel: $p=8.10^{-4}$, 5.10^{-4} , 5.10^{-4} , 4.10^{-4} and $p=3.10^{-4}$ for GDP per capita, Urbanization rate, Density, Energy capture and Largest City, respectively; bottom left panel: $p=0.0012$, 5.10^{-4} , 5.10^{-4} , 0.0428 and 0.0024 ; top right panel: $p=1$, 0.0020 , 0.20 , 0.008 and 1 ; bottom right panel: $p=0.0232$, 5.10^{-4} , 0.98 , 5.10^{-4} and 0.003 .

Figure 6 | The introduction of the heavy plough in Europe as a positive income shock. The invention of the heavy plough, (a) depicted in a miniature in *Très Riches Heures du Duc de Berry* (picture from the Web Gallery of Art), made it possible to plough deeper into heavy soils, such as clay soils, which are also more fertile. Depending on soil type, the introduction of the heavy plough was thus associated with a positive income shock in some, but not all, European regions. (b) Based on a European soil map and a

map indicating suitability for growing plough-specific crops, economists were able to combine these two indices to produce a map of heavy plough-suitable land, represented in red (Figure 9 in (27)).

Figure 7 | Quantitative assessment of the role of economic development versus and transmitted culture in the evolution of love. a. Ecological Factors and Transmission Culture model. Cultural trait $T_r(t)$, here the importance of love, evolves in each region based on ecological factors $E_r(t)$, (here, economic development) and the diffusion of cultural traits from other regions. Cultural diffusion between regions depends on their level of connectivity (scaling as the inverse of the distance between regions, bottom graph). The content of artifacts (how much love is present in each work) depends on the level of love at the time and region it is produced. b. Inferred trajectory of love in 10 regions from 800BC to 1800AD. Full line and area represent the mean and standard deviation of the posterior probability of $T_r(t)$, respectively. c. Estimated parameter values. Blue symbols: strong love metric; green: general love metric. ▼/▲: manual/automatic datasets. Error bars: bootstrapping standard errors. d. Difference in Cross-Validated Log-Likelihood between reduced and full model.

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Supplementary Information:

Supplementary text

Figures S1-S18

Tables S1-S24

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